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FUSION ENERGY ADVISORY COMMITTEE

Advice and Recommendations to the Department of Energy

In Partial Response to the Charge Letter of September 24, 1991: Part C

April 1992

U.S. Department of Energy
Office of Energy Research
Washington, DC 20585

FUSION ENERGY ADVISORY COMMITTEE
Advice And Recommendations To The U.S. Department Of Energy.

In Partial Response To The Charge Letter Of September 24, 1991: Part C

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FEAC/92-II

April 21, 1992

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Preface

This document is a compilation of the written records that relate to the Fusion Energy Advisory Committee's deliberations with regard to the Letter of Charge received from the Director of Energy Research, dated September 24, 1991.

During its third meeting, held in March 1992, FEAC provided a detailed response to that part of the charge that pertained to the period between the cessation of experiments on TFTR and the start-up of experiments on ITER. In particular, it responded to the paragraph:

> "By March 1992, I would like your views on how to fill the gap between the completion of TFTR work and the planned start of ITER operation. In addressing this issue, please include consideration of international collaboration, both here and abroad."

In order to respond to this charge in a timely manner, FEAC established a working group, designated "Panel #2", which reviewed the proposed ITER program in detail and prepared background material, included in this report as Appendix II, to help FEAC in its deliberations.

SEPTEMBER 24, 1991

CHARGE TO FUSION ENERGY ADVISORY COMMITTEE

Introduction

A year ago, the Fusion Policy Advisory Committee (FPAC) reported its findings and recommendations on fusion energy programs of the Department of Energy (DOE). The Secretary of Energy adopted FPAC's recommendations subject to existing budget constraints. This translated to terminating work on alternative confinement concepts and pursuing only the tokamak concept within the magnetic fusion energy program, as a precursor to a Burning Plasma Experiment (BPX) that would be integrated into a larger international fusion energy program. Fusion energy was highlighted in the National Energy Strategy, which mentioned both the International Thermonuclear Experimental Reactor (ITER) and BPX as major elements of the program. The Secretary travelled to Europe earlier this year to conduct personal discussions with the Italian government on their potential interest in a bilateral agreement on BPX.

Since that time, a number of events have led to a reexamination of the strategy being used to pursue an energy-oriented fusion program. The estimated cost of BPX has increased and foreign interest in substantial participation has not materialized. Last week, the Secretary of Energy Advisory Board Task Force on Energy Research Priorities was asked to review the relative priority of the BPX proposal among the programs of the Office of Energy Research and to recommend on the appropriate tasking to the Fusion Energy Advisory Committee (FEAC). The Task Force recommended that the DOE not proceed with BPX, but rather focus on ITER as the key next step after the Tokamak Fusion Test Reactor (TFTR) and the Joint European Torus in developing the physics of burning plasmas, along the lines currently being proposed by the European Community. The Task Force also recommended that the U.S. fusion energy program continue to grow modestly (even in an ER budget that is declining in constant dollars) and suggested that a more diverse program that included a less costly follow-on device to TFTR in the U.S. would be more effective in the long run.

Charge

I would like to explore seriously the programmatic implications of this recommendation under two budget scenarios -- a constant dollar budget for magnetic fusion through FY 1996 and a budget at 5 percent real growth per year through FY 1996. I am therefore charging the FEAC to advise me on the following questions.

1. Identify how available funds now used for BPX, as well as a modest increase (described above) could be used to strengthen the existing base program for magnetic fusion research.

2. Within the above envelope of funding, identify what follow-on experimental devices for the U.S. fusion program might be planned for use after the completion of experiments at TFTR and before the planned start of ITER operation. For such devices, indicate how they would fit into the international fusion program.

3. What should be the U.S. position on the appropriate scope, timing, and mission of ITER if BPX does not go forward?

Although you will need some months to complete the work envisioned in this charge, I would like to have your initial thoughts on the above three topics in a letter report from your meeting of September 24-25, 1991.

Then, by January 1992, I would like to have your recommendations on the appropriate scope and mission of ITER and any suggestions you can make to lower its cost or accelerate its schedule. At the same time, I would like your recommendations on the relative importance to the U.S. of the various ITER technology tasks, on the role and level of U.S. industrial involvement in the ITER engineering design activity, and on the balance between ITER project-specific R&D and the base program.

By March 1992, I would like your views on how to fill the gap in the U.S. magnetic fusion program between the completion of TFTR work and the planned start of ITER operation. In addressing this issue, please include consideration of international collaboration, both here and abroad.

By May 1992, I would like to have your recommendations on a U.S. concept improvement program, including relative priorities and taking into account ongoing and planned work abroad.

William Happer

William Happer
Director
Office of Energy Research

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April 1, 1992

Dr. William Happer, Director
Office of Energy Research (ER-1)
U.S. Department of Energy
Washington D.C. 20585

Dear Will:

In your September 24, 1991 Charge to the Fusion Energy Advisory Committee, you asked for advice by March 1992 on the issue: "How to fill the gap in the U.S. magnetic fusion program between the completion of TFTR work and the planned start of ITER operation". You added, "In addressing this issue, please include consideration of international collaboration, both here and abroad". As background to this request, you stated in your Charge letter that the Task Force of the Secretary of Energy Advisory Board chaired by Professor Townes had recommended that "The DOE not proceed with the Burning Plasma Experiment (BPX)" but "Recommended that the U.S. fusion program continue to grow modestly (even in an ER budget that is declining in constant dollars)". The Charge letter also stated that the Task Force "Suggested that a more diverse program that included a less costly follow-on device to TFTR in the U.S. would be more effective in the long run".

This letter is our response to your request for advice by March. To prepare our response, we established FEAC Panel II, co-chaired by Drs. David Baldwin and John Sheffield, to provide the full FEAC with information to help us formulate our advice. FEAC received and discussed the Panel II report and used it in formulating its recommendations. Both FEAC and our Panel II were greatly aided by a National Fusion Task Force (NTF), which was chartered by the Princeton Plasma Physics Laboratory (PPPL) to coordinate the activities within the magnetic fusion program, including the work of advocacy groups, to develop options for a new tokamak initiative. The FEAC Panel II and the NTF did extensive work and we greatly appreciate their efforts.

The plan for magnetic fusion energy (MFE) development recommended to DOE by the Fusion Policy Advisory Committee (FPAC) discussed two classes of important tokamak issues that could potentially be addressed in a new facility: "advanced-tokamak physics" and "steady-state". Advanced tokamak physics issues fall into three areas, all of which require confirmation in long-pulse operation:

1. Stable plasma operation at high beta (e.g., in the "second-stability" regime) with enhanced confinement, which will permit a smaller, more attractive power station;

2. Stable operation with a high fraction of self-sustained plasma current ("bootstrap" current), which will permit low recirculating power in a power station; and

3. Successful disruption control, which would improve the availability of a reactor.

Successful resolution of these advanced tokamak issues have been shown in reactor studies both here and abroad to lead to an attractive tokamak power reactor.

The common thread to all these issues is control of the current profile, which must be demonstrated for a time longer than the greatest natural relaxation time scale. Consequently, research on these advanced physics issues fits naturally with studies of "steady-state" issues such as:

1. Plasma power and particle handling, and helium transport and exhaust at reactor conditions;

2. Efficient techniques and technologies to drive the plasma current and to control the plasma current profile.

FEAC and our Panel II agree with the National Fusion Task Force that the investigation of power and particle handling requires pulse lengths at least as long as 1000 seconds, and extending ultimately to steady state. Therefore, the design of a new tokamak experiment should not preclude steady-state operation.

An important conclusion of FEAC is that a long pulse advanced tokamak machine with ultimate steady-state capability can be built for about $500 million in as-spent dollars by making use of the TFTR test cell and existing equipment at the PPPL site. We refer to this machine as the SSAT. The SSAT will offer the world fusion program a unique combination of advanced-tokamak physics capability and at least 1000 second pulse lengths in reactor-relevant plasma configurations. This conclusion is reached on the basis of preconceptual design work and is also the conclusion of the National Fusion Task Force.

Given this basic conclusion, FEAC strongly recommends that the design and construction of an SSAT tokamak, capable of addressing advanced tokamak physics and steady-state issues, be initiated now and have a target date for first operation of 1999. In our own deliberations, in our guidance to FEAC Panel II, and in the guidance to the National Task Force, the budget scenario given in your letter of 5 percent real growth per year through at least FY 1996 has been assumed. Considering other program needs and consistent with the SEAB Task Force recommendations, FEAC recommends a constraint on Total Project Cost (TPC) for the SSAT of about $500M in as-spent dollars (or about $400M in constant FY 1992 dollars.)

A U.S. SSAT machine will complement the international program in an important way. There is today no facility in either the U.S. or the world fusion program that is capable of developing, in an integrated way, advanced tokamak physics in steady-state. Yet this is one key to developing a more attractive tokamak reactor.

Supplementary to this recommendation, FEAC recommends that the DOE and PPPL, working with the national MFE community, (which includes national laboratories, universities, and industries), develop a plan for the management of the design, construction, and operation of the SSAT as a national facility. This plan should include the early establishment of a National Steering Committee to provide the SSAT project with guidance on issues related to mission, machine concept, cost and schedule. We request that the recommended management structure and, if possible, the selection of the final design option for the SSAT, be presented to us at the next FEAC meeting scheduled for May 20-21, 1992 at UCLA.

Turning now to another issue in your charge, FEAC identified two priority activities of the tokamak confinement program for the period up to about 1995. These are full D-T operation in TFTR beginning in mid-1993 and a strong DIII-D program both in support of ITER and tokamak physics improvements. Our committee has not yet dealt with the relative priorities among other elements in the magnetic confinement experimental program.

In reflecting on the sum of our advice to you at this point, the Committee has come to recognize that our responses to your Sept. 24, 1991 Charge letter will not constitute a complete assessment of the long-term strategy of the U.S. fusion program. As such, the FEAC recommends that further work be undertaken to develop the MFE and IFE program and strategy in greater detail. Examples of important issues are: the priority and phasing among all the elements of the program; the time and procedures to obtain a U.S. fusion power development site; the budget implications relating to these issues; and the effects of the conclusions on the goals in the National Energy Strategy. Following this, the Department should estimate the number of scientists, engineers, technical and non-technical staff that are required each year to carry out the fusion program between 1992 and 2005.

Finally, either in preparation for this more complete long term strategy assessment or as part of it, FEAC recommends that the U.S. program develop a plan for fusion nuclear technology development. A key element here is the need for a fusion-power-capable U.S. site which will serve as a candidate site for ITER and for other fusion nuclear technology facilities. This recommendation is consistent with our earlier recommendations in February, 1992, namely:

1. that the U.S. begin the necessary preparations leading to the earliest possible site selection and commitment to construction of ITER;

2. that the materials development program be enhanced to develop materials for testing in ITER and for DEMO construction with special emphasis on long-life, low-activation materials.

3. that a study be undertaken to investigate what additional complementary activities might be needed to acquire part of the fusion nuclear technology data so as to make more realistic the 2025 goal for operation of a fusion power demonstration reactor.

We trust that you will find our advice here and earlier to be helpful on questions so crucial to the development of fusion power. The FEAC is unanimous and strong in our recommendations to you. And we can report that we are on track to provide you with the advice you requested by May.

Sincerely,

Bob Conn

Robert W. Conn
Chairman, for the
Fusion Energy Advisory
Committee

Appendix I

A letter from the Chairman of FEAC to Panel #2 clarifying the tasks to be undertaken by the panel, dated November 18, 1991.

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November 18, 1991

Dr. David Baldwin, LLNL and
Dr. John Sheffield, ORNL

Dear Dave and John:

Thank you for agreeing to co-chair the FEAC Panel 2 on post-TFTR Initiatives. The work of this panel will be most important to the full FEAC in arriving at its response to Dr. Happer's charge:

> "...if BPX does not go forward...By March 1992, I would like your views on how to fill the gap in the U.S. magnetic fusion program between the completion of TFTR work and the planned start of ITER operation. In addressing this issue, please include consideration of international collaboration, both here and abroad."

There are four intertwined areas of justifiable need within the program today, occurring on somewhat different time scales. There is the need for a premier facility for the U.S. program operating during the "gap" period addressed in Dr. Happer's charge. This bootstrap-current fraction and operation in the second-stability regime) and the important physics issues surrounding very-long-pulse or steady-state operation. If ITER is operational ~2005 as planned, this facility's operation, which could start ~1999, would overlap with that of the ITER. There is also the need to make more productive use of existing facilities whose operations have been sorely limited as the fusion program tried to initiate the BPX under trying budgetary circumstances. Similarly, there is the need to upgrade existing facilities and initiate modest-size, special-purpose ones in order to strengthen the program infrastructure. Finally, there is the need to prepare for ITER construction and operation, activities which will continue to place priority demands on program resources throughout the EDA R&D period.

Although the charge could be interpreted as addressing only the first need, the request can be properly addressed only in the context of the other program needs. I therefore ask your panel to examine the balance and thrust of the MFE program through the 1990's, using the SEAB Task Force recommendation of ~5%/year real growth for the next five years. In so doing, it will be useful to address such questions as the following:

> Assuming that ITER proceeds to construction, what should the US fusion program contain in the year 2000 and how should it evolve through the decade 2000 - 2010? Does that vision have resiliency against the possibility that ITER is not constructed? If not, how could its resiliency be enhanced?

Even with the assumed increases, it appears that the US fusion budget will lag behind the European and Japanese programs. How can the US make the most effective use of these larger programs and, at the same time, continue to influence and impact the world program?

What is the preferred timing of the needed program elements during this decade in order to leave us in a strong position at the end of the decade? This is an issue of balancing short and long term demands.

I look forward to working with you as you wrestle with these important questions.

Sincerely,

RWConn/ce

Robert W. Conn
Chair, FEAC

RWC:bw

Appendix II

The Report to FEAC of Panel #2,
dated March 1992.

Post-TFTR Initiatives for the MFE Program

A Report to the Fusion Energy Advisory Committee

March 1992

by
FEAC Panel 2

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This report was prepared by a panel established by, and reporting to, the Fusion Energy Advisory Committee (FEAC). The report of this panel should not be construed as representing the views, official advice or recommendations of FEAC.

Post-TFTR Initiatives for the MFE Program

A report to the
Fusion Energy Advisory Committee
by FEAC Panel 2

Introduction

In his September 24, 1991 charge to FEAC, Dr. William Happer requested

> ". . . if BPX does not go forward . . . . By March 1992, I would like your views on how to fill the gap in the U.S. magnetic fusion program between the completion of TFTR work and the planned start of ITER operation. In addressing this issue, please include consideration of international collaboration, both here and abroad."

FEAC Panel 2 was created to assist FEAC in responding to this request, and the original charge was later elaborated by the FEAC chairman, Dr. Robert Conn. The full texts of both charges are reproduced in Appendix A.

In responding to the charges, the Panel held three two-day meetings over a six-week period in Princeton, Austin and Livermore, hearing presentations from a broad spectrum of the fusion community regarding program needs. In addition, the Panel was assisted by the New Initiative Task Force, formed to coordinate fusion community design efforts in this area. In general, the Panel was impressed by the vitality of the interest and effort brought to bear by the community on the development of a new initiative.

Background

In its 1990 plan for fusion energy development, the Secretary of Energy's Fusion Policy Advisory Committee (FPAC) discussed five key elements of the fusion program, following TFTR D-T operation, that would be needed in addition to the base program to prepare for a demonstration reactor (DEMO) targeted for operation about the year 2025. They were

- (i) a burning-plasma experiment;
- (ii) an engineering test reactor;
- (iii) a low-activation materials test facility;
- (iv) a steady-state experiment; and
- (v) experiments focussed on concept improvements.

In the FPAC plan, element (i) was to be the Burning Plasma Experiment (BPX), which had been proposed as a US initiative. Element (ii) was to be the

International Thermonuclear Experimental Reactor (ITER) constructed and operated as a fully international collaboration. Elements (iii)-(v) were to be addressed either nationally or as part of international collaboration. With the demise of BPX, the full burden of burning-plasma physics exploration will be transferred to the first phase of ITER operation, which must continue to be a central element of the U.S. fusion program.

In its September 1991 recommendation to cancel BPX for reasons of budgetary constraints, the Secretary of Energy Advisory Board Task Force on Priorities in Funding in Energy Research (SEAB-TF) also called for a new confinement facility of the "$500M class", to address steady-state and advanced-tokamak physics issues and to be constructed following completion of the TFTR D-T operation. The recommendation recognized that this mission required a less costly facility than did the burning-plasma mission of BPX; and it essentially underscored the necessity to move forward with fusion development, despite the loss of BPX. The facility recommended would be much like item (iv) in the FPAC plan, with strong elements of tokamak improvements from item (v).

A Tokamak Physics Experiment (TPX) with the steady-state/advanced-tokamak (SS/AT) mission[1] is important for optimization of a tokamak demonstration fusion power reactor (DEMO). The key feature of such a device will be the *integrated* demonstration of controlled steady-state/high-duty-factor operation of a tokamak plasma in the advanced operating regimes most attractive for a DEMO. In addition to having value for a DEMO, the physics and technology experience gained in TPX could also be transferable to ITER, viz., the advanced operating modes and the power and particle handling techniques. This would permit optimization of ITER operation, especially in its blanket-testing second phase where high availability will be of the greatest importance.

"Advanced-tokamak" features generally fall into three areas, all of which require confirmation in steady-state. The first is operation at high beta (e.g., in the "second-stability" regime) with enhanced confinement, which would permit a smaller DEMO (or reactor) unit size. The second is stable operation with a high fraction of self-sustained plasma current ("bootstrap"

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[1] This document uses "SS/AT" to identify the mission and "TPX" to identify a generic facility addressing the mission.

current), which would permit low recirculating power in a steady-state DEMO. The third is successful disruption control, which would maximize the availability of a DEMO. The "advanced tokamak" mission, therefore, fits very well with studies of "steady-state" physics and technology, i.e., the investigation of power and particle handling strategies and technologies in steady state, and the study of efficient current-drive and current-profile control techniques. These features of an advanced tokamak are identified in the ARIES reactor studies as those leading to a very attractive reactor.

Proposed Machines Addressing the SS/AT Mission

Since the SEAB-TF recommendation, several advocacy groups drawn from the fusion community and working under the auspices of the New Initiative Task Force have been developing preconceptual designs of tokamaks addressing the SS/AT mission within a cost constraint consistent with the SEAB-TF recommendation, taken as about $400M FY92$. Three different variations of the mission have emerged from this design activity. The first approach focuses only on the SS/AT mission and employs either superconducting or resistive magnets. The superconducting design currently bears the name SSAT; the two resistive versions, SSAT-D and SSAT-W. The second and third approaches are resistive designs that in a first phase address the advanced tokamak mission, in either long pulse or steady state, and in later phases are capable (at additional cost) of D-T upgrades to address either a nuclear testing or a burning-plasma physics mission. Respectively, these last two bear the names Steady Burn Experiment (SBX) and Burning Plasma Experiment-Advanced Tokamak (BPX-AT). Appendix B contains the executive summaries of white papers prepared by the SSAT, the SBX and the BPX-AT advocacy groups.

All three missions have technical and programmatic merit. The Panel considers the SS/AT mission to have high priority because it fulfills a key need specified by the FPAC plan. Both the superconducting and resistive SS/AT designs are able to address this mission within the specified cost envelope. The added nuclear missions of SBX and BPX-AT are important; however, these missions are also incorporated in the present ITER plans. In addition, even with phased implementation, both the SBX and BPX-AT designs rise above the cost target, and sacrifice some of their SS/AT scope, in order to have substantial nuclear capability in a later phase.

On the basis of this preconceptual work, which has been monitored and reviewed by the New Initiative Task Force, the Panel concludes that a viable device addressing the SS/AT mission can be built for about $400M FY'92, taking into account credits associated with the TFTR site. The superconducting design looks especially attractive in meeting the mission while advancing superconducting technology. However, there are also some potential advantages of steady-state resistive designs, which should continue to be evaluated. It is critical that the TPX come into operation in 1999-2000, both to maintain the vitality of the U.S. fusion program and to maximize the contribution of the facility to ITER. Consequently, the Panel considers of paramount importance an early commitment to the design and construction of a machine optimized to meet the SS/AT mission. In order to be of greatest value to the fusion program, it must be designed, constructed and operated as a national facility.

The combination of the cost constraint and long-term value of the machine will require trade-offs between the machine's day-one and ultimate capabilities. The Panel is sensitive to the importance of designing a machine that will continue its scientific value through the decade beyond 2000. These trade-offs should be evaluated in further design study.

The shielded TFTR test cell would permit extensive operation in deuterium for any of the designs. Because of the high availability required of the D-T second phase of SBX, it would require location at a fully nuclear-capable site.

TPX addressing the SS/AT mission would complement the international program in a natural way. There is no facility in either the U.S. or the world fusion programs today capable of conducting the integrated development of advanced tokamak physics in steady-state, needed for the development of a more attractive DEMO. Additionally, the Japanese and European programs plan to contain stellarators, also in the $500M class, that will investigate advanced versions of this leading non-tokamak concept, possibly resulting in a stellarator candidate for a DEMO. Taken together, the TPX and these stellarators can be viewed as addressing broadly elements (iv) and (v) of the FPAC plan. Comparisons of TPX performance on the SSAT issues with similar-size stellarators will provide important data, valuable both for comparing these near cousins as competitive reactor candidates and for advancing their common physics understanding.

The Panel believes that a lower level of design effort should also continue to be applied to the two resistive concepts having nuclear second-phase missions. Because of their enlarged missions, these two concepts do not fit within the cost constraint. However, they do provide provocative concepts for future consideration, depending on whether ITER proceeds to construction, the degree of nuclear testing planned if it does, etc.

Priorities in the post-TFTR Program

A key issue for optimizing the post-TFTR confinement program is to prioritize the use of existing facilities and their upgrades. In developing priorities for the next decade, it is important to structure a fusion program in the early 2000's with strengths in both its physics and technology areas and in its laboratory, university and industrial institutions.

As the program moves forward towards its energy objective, facilities of increasing scale, and consequently cost, will be essential. A collaborative style of research involving shared, national facilities will become increasingly important. An appropriate balance between larger and smaller experiments must be found. This will necessitate difficult choices, given limited resources.

The Panel heard presentations on the possibility of addressing parts of the SS/AT mission with existing facilities: TFTR, DIII-D, PBX-M, Alcator C-Mod and ATF. Important information could be gained in this way prior to TPX and ITER operation, in short-to-moderate pulse length in the tokamaks and in steady state in the stellarator. However, such initiatives all fall short of the full, integrated SS/AT mission.

The Panel felt that it had insufficient time and improper composition to set priorities among the toroidal program as a whole. However, in its view, it is important to assure a timely implementation of the TFTR D-T program and a strong DIII-D program in support of ITER, TPX and tokamak physics development. In addition, the Panel recognizes attractive opportunities among the other programs to strengthen the basis for TPX and ITER.

Establishing priorities among all the programs in the toroidal confinement area -- upgrades of the operating tokamaks, ATF operation, U.S. participation in foreign programs, and modest-sized new initiatives -- will require two types of information:

- A detailed compilation of the key technical issues for TPX and ITER and the timescale required for their resolution, coupled with the potential and uniqueness of each facility to produce the needed results; and

- A policy position on the role of alternate concepts and concept improvement in the confinement program to be worked out through the FEAC process, following a report by FEAC Panel 3 in May.

The Panel believes that a specially constituted technical panel should then be chartered to recommend on priorities for the medium-term confinement program (to ~1998). As part of this planning, the total balance in the base program should be reexamined by FEAC in the same context, considering the evolution of the laboratories and universities and the involvement of U.S. industry. In addition, in collaboration with DOE, the FEAC should establish an orderly plan for the conduct of a national program involving fewer, larger facilities as the necessity for larger scale compels phasing-out some of the existing ones.

Embarking on the Nuclear Phase of Fusion Development

The Panel further believes that the U.S. MFE program should develop and implement a strategic plan for the nuclear phase of fusion development. A program based on TPX in combination with U.S. blanket-testing in ITER will provide the U.S. with strong technological expertise in both non-nuclear and nuclear areas. However, in the nuclear area, ITER alone is not enough. Key additional issues are the long lead times required for the development of long-life and low-activation materials, including their testing in a 14-MeV neutron spectrum, and the desirability of other nuclear testing activities in parallel with ITER. Some of these have been suggested as natural candidates for international collaboration. Important also will be the selection of a U.S. nuclear-capable site. The site chosen as the U.S. candidate site for ITER construction could serve as a suitable site for other nuclear facilities, as well as a site ultimately for the U.S. DEMO. On these matters, the Panel supports the statement of the FEAC letter of February 14, 1992.

Resiliency of the U.S. Program to ITER's Future

ITER is foreseen to be such a major element of the U.S. program that it is difficult to be completely resilient against the very negative scenario in which the ITER, or a similar international substitute, did not proceed to construction. Nonetheless, were this to be the case, the SS/AT issues being addressed by TPX would still have great program significance. However, nuclear-capable tokamaks would also then be required, i.e., facilities for addressing the burning-plasma and nuclear-testing issues, as well as for the 14-MeV testing of materials. For these issues, facilities like the BPX-AT and the SBX should then be constructed, using international collaboration where possible. (The earlier recommendation for continued study of the SBX and BPX-AT options was made, in part, as a hedge against this eventuality.)

This fall-back strategy, wherein the elements of the required data would be obtained in a sequence of specialized smaller facilities, would miss the important element of integration that was to have been filled by ITER. Integration would then have to await the DEMO step. For this reason, a loss of ITER would be a serious setback for the fusion timetable.

Conclusion

The Panel finds that the steady-state/advanced-tokamak mission is a critical element in the U.S. fusion strategy as established by FPAC. An attractive SS/AT device can be constructed for about the $400M FY'92 guideline proposed by the SEAB-TF. The design and construction of such a facility should proceed on a schedule to enter operation in 1999-00. Adequate funding for peak construction years should become available following the D-T operation of TFTR. In all its phases, the new device should be managed as a national facility.

Appendix A: Charges to FEAC Panel 2

CHARGE TO FUSION ENERGY ADVISORY COMMITTEE

Introduction

A year ago, the Fusion Policy Advisory Committee (FPAC) reported its findings and recommendations on fusion energy programs of the Department of Energy (DOE). The Secretary of Energy adopted FPAC's recommendations subject to existing budget constraints. This translated to terminating work on alternative confinement concepts and pursuing only the tokomak concept within the magnetic fusion energy program, as a precursor to a Burning Plasma Experiment (BPX) that would be integrated into a larger international fusion energy program. Fusion energy was highlighted in the National Energy Strategy, which mentioned both the International Thermonuclear Experimental Reactor (ITER) and BPX as major elements of the program. The Secretary travelled to Europe earlier this year to conduct personal discussions with the Italian government on their potential interest in a bilateral agreement on BPX.

Since that time, a number of events have led to a reexamination of the strategy being used to pursue an energy-oriented fusion program. The estimated cost of BPX has increased and foreign interest in substantial participation has not materialized. Last week, the SEAB Task Force on Energy Research Priorities was asked to review the relative priority of the BPX proposal among the programs of the Office of Energy Research and to recommend on the appropriate tasking to the Fusion Energy Advisory Committee. The Task Force recommended that the DOE not proceed with BPX, but rather focus on ITER as the key next step after the Tokomak Fusion Test Reactor (TFTR) and the Joint European Torus in developing the physics of burning plasmas, along the lines currently being proposed by the European Community. The Task Force also recommended that the U.S. fusion energy program continue to grow modestly (even in an ER budget that is declining in constant dollars) and suggested that a more diverse program that included a less costly follow-on device to TFTR in the United States would be more effective in the long run.

Charge

I would like to explore seriously the programmatic implications of this recommendation under two budget scenarios -- a constant dollar budget for magnetic fusion through FY 1996 and a budget at 5 percent real growth per year through FY 1996. I am therefore charging the FEAC to advise me on the following questions.

1. Identify how available funds now used for BPX, as well as a modest increase (described above) could be used to strengthen the existing base program for magnetic fusion research.

2. Within the above envelope of funding, identify what follow-on experimental devices for the U.S. fusion program might be planned for use after the completion of experiments at TFTR and before the planned start of ITER operation. For such devices, indicate how they would fit into the international fusion program.

3. What should be the U.S. position on the appropriate scope, timing, and mission of ITER if BPX does not go forward?

Although you will need some months to complete the work envisioned in this charge, I would like to have your initial thoughts on the above three topics in a letter report from your meeting of September 24-25, 1991.

Then, by January 1992, I would like to have your recommendations on the appropriate scope and mission of ITER and any suggestions you can make to lower its cost or accelerate its schedule. At the same time, I would like your recommendations on the relative importance to the United States of the various ITER technology tasks, on the role and level of U.S. industrial involvement in the ITER engineering design activity, and on the balance between ITER project-specific R&D and the base program.

By March 1992, I would like your views on how to fill the gap in the U.S. magnetic fusion program between the completion of TFTR work and the planned start of ITER operation. In addressing this issue, please include consideration of international collaboration, both here and abroad.

By May 1992, I would like to have your recommendations on a U.S. concept improvement program, including relative priorities and taking into account ongoing and planned work abroad.

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November 18, 1991

Dr. David Baldwin, LLNL and
Dr. John Sheffield, ORNL

Dear Dave and John:

Thank you for agreeing to co-chair the FEAC Panel 2 on post-TFTR Initiatives. The work of this panel will be most important to the full FEAC in arriving at its response to Dr. Happer's charge:

> "...if BPX does not go forward...By March 1992, I would like your views on how to fill the gap in the U.S. magnetic fusion program between the completion of TFTR work and the planned start of ITER operation. In addressing this issue, please include consideration of international collaboration, both here and abroad."

There are four intertwined areas of justifiable need within the program today, occurring on somewhat different time scales. There is the need for a premier facility for the U.S. program operating during the "gap" period addressed in Dr. Happer's charge. This facility would likely address physics issues of advanced-tokamak concepts (e.g., high bootstrap-current fraction and operation in the second-stability regime) and the important physics issues surrounding very-long-pulse or steady-state operation. If ITER is operational ~2005 as planned, this facility's operation, which could start ~1999, would overlap with that of the ITER. There is also the need to make more productive use of existing facilities whose operations have been sorely limited as the fusion program tried to initiate the BPX under trying budgetary circumstances. Similarly, there is the need to upgrade existing facilities and initiate modest-size, special-purpose ones in order to strengthen the program infrastructure. Finally, there is the need to prepare for ITER construction and operation, activities which will continue to place priority demands on program resources throughout the EDA R&D period.

Although the charge could be interpreted as addressing only the first need, the request can be properly addressed only in the context of the other program needs. I therefore ask your panel to examine the balance and thrust of the MFE program through the 1990's, using the SEAB Task Force recommendation of ~ 5%/year real growth for the next five years. In so doing, it will be useful to address such questions as the following:

> Assuming that ITER proceeds to construction, what should the US fusion program contain in the year 2000 and how should it evolve through the decade 2000 - 2010? Does that vision have resiliency against the possibility that ITER is not constructed? If not, how could its resiliency be enhanced?

Even with the assumed increases, it appears that the US fusion budget will lag behind the European and Japanese programs. How can the US make the most effective use of these larger programs and, at the same time, continue to influence and impact the world program?

What is the preferred timing of the needed program elements during this decade in order to leave us in a strong position at the end of the decade? This is an issue of balancing short and long term demands.

I look forward to working with you as you wrestle with these important questions.

Sincerely,

RW Conn/cc

Robert W. Conn
Chair, FEAC

RWC:bw

Appendix B: Executive summaries of white papers prepared by the New Initiative advocacy groups

STEADY STATE ADVANCED TOKAMAK (SSAT)

THE MISSION AND THE MACHINE

Keith Thomassen
Rob Goldston
Bill Nevins
Hutch Neilson
Tom Shannon
Bruce Montgomery

MARCH 1992

Steady State Advanced Tokamak (SSAT)

Executive Summary

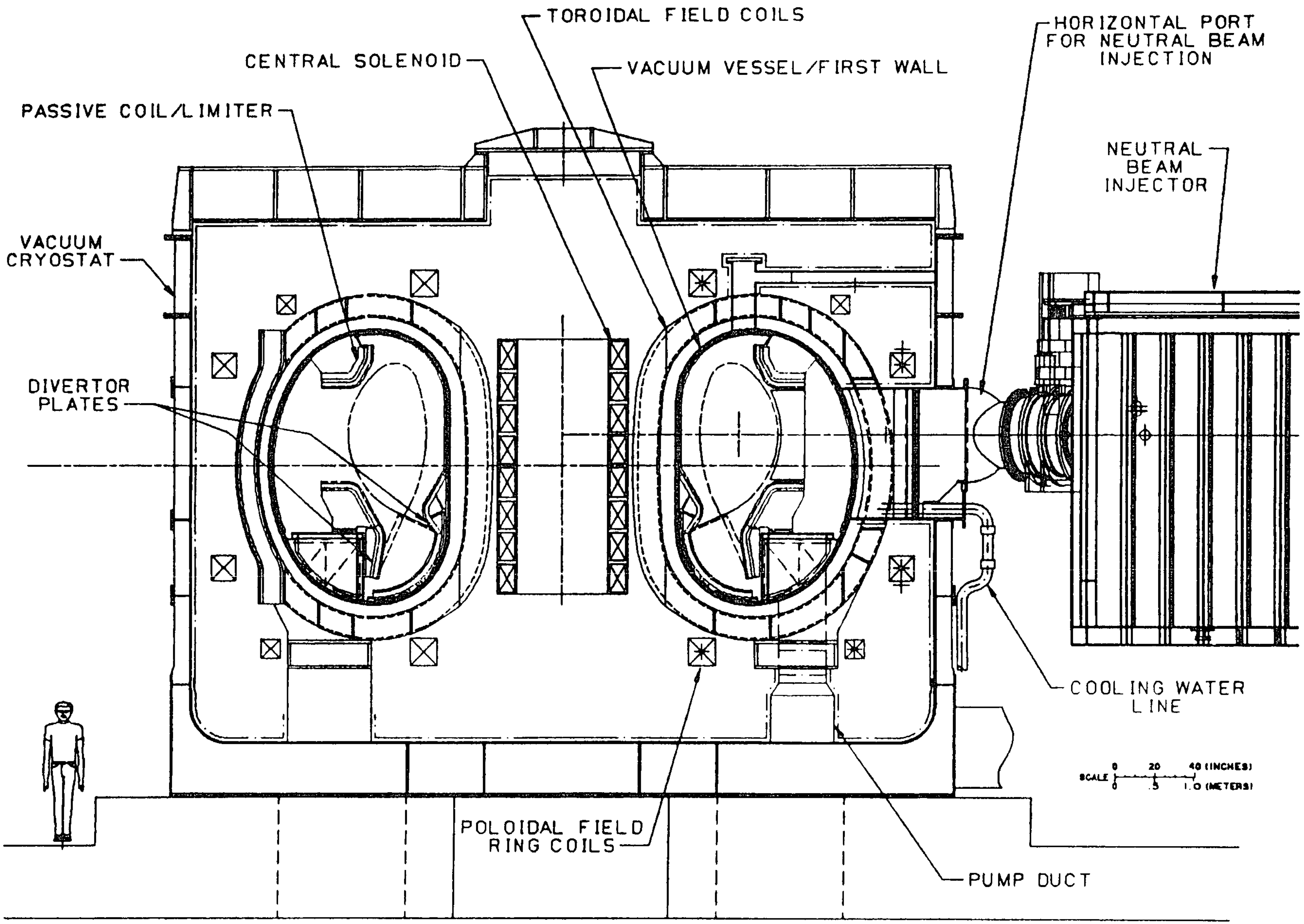
Extending the tokamak concept to the steady state regime is an important step for the magnetic fusion energy program. The required transition, away from inductive current drive, will also provide exciting opportunities for advances in tokamak physics and technology. Recognizing this, the Fusion Policy Advisory Committee and the U.S. National Energy Strategy identified the development of steady state tokamak physics and technology, and improvements in the tokamak concept as vital elements in the magnetic fusion energy development plan and called for the construction of a steady state tokamak facility to support them. Advances in physics that produce better confinement, higher pressure limits, and a largely internally-driven steady state current will help point the way to a more attractive (smaller and simpler) demonstration reactor (DEMO) than the present data base would predict.

To meet these challenges, we propose a new "Steady State Advanced Tokamak" (SSAT) facility that would develop and demonstrate optimized steady state tokamak operating modes. The SSAT tokamak would be the first to use a fully superconducting magnet set. Reference parameters for the design are shown in Table 1.

TABLE 1. SSAT MACHINE AND PLASMA PARAMETERS

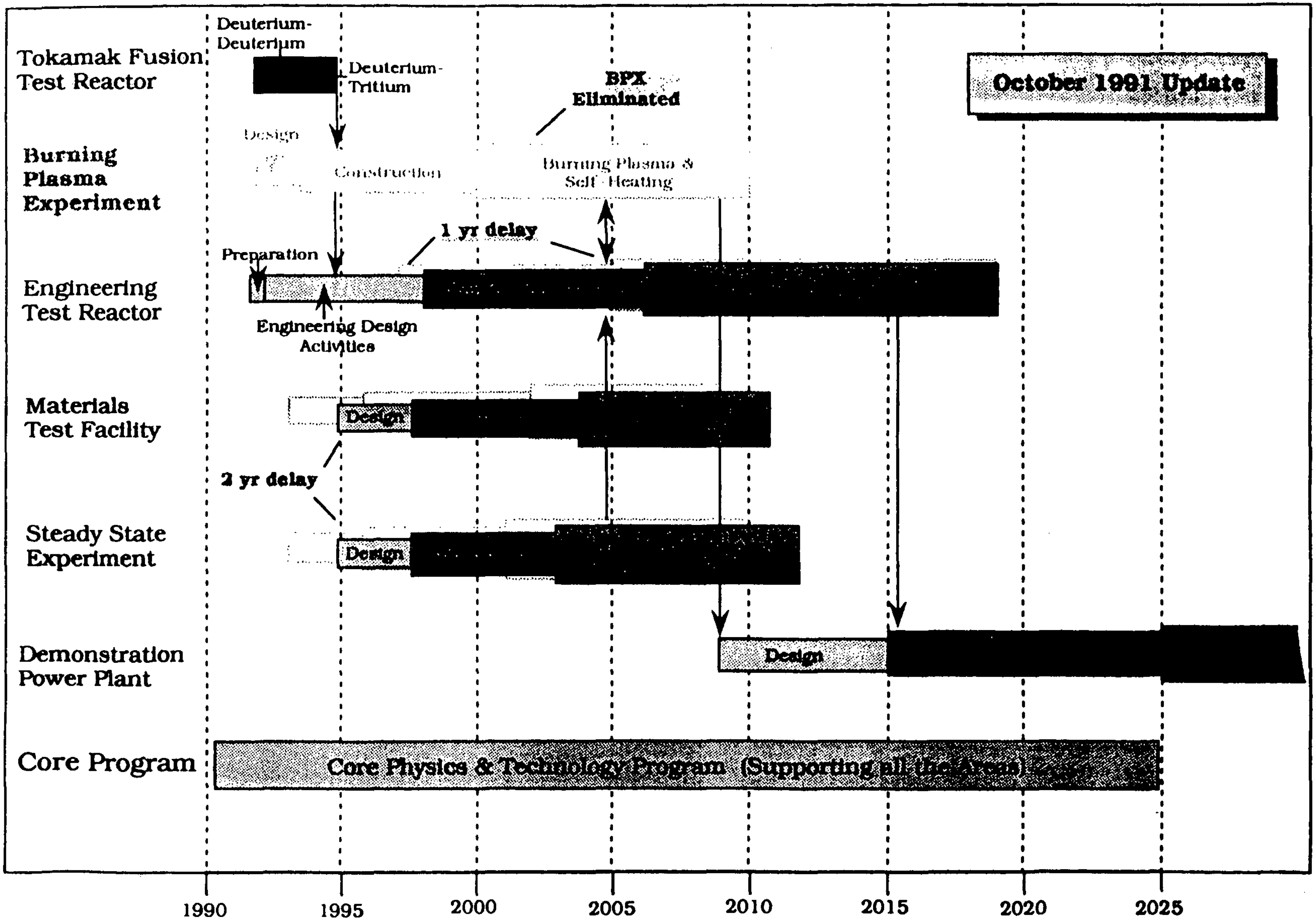
Major radius	R (m)	2.25
Minor radius	a (m)	0.5
Aspect ratio	A	4.5
Magnetic Field	B (T)	3.35
Current	I (MA)	≤ 1.7
Elongation	κ_x	2.0
Triangularity	δ	≤ 0.5
Power	P (MW)	≈ 35

It has a major radius of 2.25 m, a toroidal magnetic field of 3.4 T, an aspect ratio (the ratio of major to minor radius) of 4.5, an elongated shaped cross section, and a spacious poloidal divertor. It would use deuterium fuel and be remotely maintainable. At the same time, it would use low-activation materials, e.g. a titanium vacuum vessel, to permit hands-on access to the fullest extent possible. An elevation view of the SSAT is shown on the next page.



ELEVATION CROSS SECTION OF SUPERCONDUCTING SSAT

NATIONAL ENERGY STRATEGY
Magnetic Fusion Energy Development Strategy



Note: Elements are drawn from recommendations of the Fusion Policy Advisory Committee, U.S. Department of Energy (September 1990). Schedule estimates are subject to uncertainty and will depend upon technical readiness, availability of funding, and international agreements.

Its cost is estimated to be $429M (FY92 dollars) if existing hardware were used where appropriate. Fabrication of tokamak components could begin in in FY 1995, with operations starting in FY 2000. Costs for this design are given in Table 2.

TABLE 2. SSAT COST BREAKDOWN ($M)

Tokamak Systems	159.0
Heating/Current Drive	48.6
Fueling/Pumping	14.8
Magnet and Heating Power	47.0
Remote Maintenance	41.4
I&C/Data Acquisition	10.8
Diagnostics	22.8
Facilities	44.0
Preparation for Operations	27.4
TOTAL	$428.8 M

For this investment the U.S. program would have a national facility with capability for this purpose unmatched in the world by existing machines or their upgrades. Other machines can and will investigate, for short pulse lengths, physics phenomena to provide a good data base for SSAT when operations begin. However, the SSAT would be truly unique in its combination of physics capability and machine technology. Under present schedules it would not affect initial design choices for ITER, but it could have a significant influence on the later operation and upgrades to ITER.

The SSAT Mission

As the name suggests, SSAT has the dual mission of steady state and advanced tokamak operation. Not only are these are both critical tasks for magnetic fusion development, they are also naturally addressed in a single facility because their objectives are complementary.

The steady state aspect of the mission has as its goal the demonstration of integrated steady-state operating modes near "standard" tokamak limits of current (safety factor q) and pressure (normalized beta, $\beta_N \approx 3.5\%$, the first stability Troyon limit). These limits are those generally used in reactor design studies. Operations of this type are crucial to establishing the viability of the tokamak for reactor applications, since very long pulse lengths and high duty factors are needed for commercial power stations and for tokamak-based nuclear testing facilities. To achieve such operating modes will require reliable operation of steady state magnets and actively-cooled in-vessel components. It will also demand reliable plasma operation, avoiding the major current disruptions that often terminate discharges in present machines. The key technical issues for this element are non-inductive current drive, power and particle handling, and disruption control. A satisfactory demonstration of reliable steady state operation will require that these all be resolved in an integrated manner.

Pulsed tokamaks, even those with tens of seconds' pulse length, have relied on their built-in transformers to drive the toroidal current inductively. Steady state tokamak currents must be driven by suitably configured auxiliary plasma heating systems (neutral beams and waves of various frequencies) and by the plasma's own pressure-gradient-driven "bootstrap" current. Experimental confirmation of current drive theory has been obtained for neutral beams and lower hybrid waves. Planned current drive experiments with fast ion cyclotron waves in DIII–D and JET will determine the outlook for this very promising frequency range. The theoretically-predicted bootstrap current has been observed on several tokamaks, and has constituted as much as 70% of the total current.

The ARIES studies have shown the importance of the bootstrap current for reactor economics because it reduces the recirculating power requirements associated with auxiliary current drive systems. The SSAT would use non-inductive current drive in all of its operating modes, capitalizing on the expected developments over the next few years. A mix of neutral beams, supplemented by a lesser amount of lower hybrid or fast wave power, would be used initially for heating and current drive. Development of actively cooled, remotely maintainable wave launching structures would be required. As the SSAT experimental program progresses, it would further benefit from other technological advances, such as negative-ion neutral beams and high-power microwave sources.

Power and particle handling in tokamaks involves a complex set of physics and technology issues associated with the poloidal divertors used in advanced tokamaks. Such divertors provide conditions for enhanced (High) confinement modes ("H–modes"), but such benefits are not without penalty. They also concentrate particles and heat on small surface strips around the torus, limiting the power handling capability of the machine. Substantial progress is being made in understanding the boundary plasma physics that determines the power flux and other divertor conditions. Pumped divertor experiments planned for JET and DIII–D will provide important data in the next few years.

A key feature of the SSAT design is the ample volume and flexibility in the divertor region to test a variety of configurations and operational techniques for optimally controlling the heat and particle fluxes. High-performance, actively-cooled, and remotely maintainable target designs would be developed to handle the steady state power exhaust. Instead of the transient techniques used to control particle recycling in present experiments, an active pumping system coupled to the divertor would be used for particle control in SSAT.

Disruptions, in which the thermal and magnetic stored energy in the plasma is suddenly dumped to the plasma walls and vacuum vessel, are a problem for tokamaks that must be avoided. These more readily occur near plasma operating limits where performance is best. Feedback-controlled ac coils, non-axisymmetric dc coils, and local current-profile control using electron cyclotron waves are techniques that may prove successful against disruptions. Research planned for JET and for DIII–D should lead to further progress in the near term. In SSAT, disruption avoidance will be approached first through careful control of boundary conditions and current profiles. Other techniques will be considered, depending on the results of upcoming experiments.

In SSAT we would approach the steady state issues in an integrated fashion, obtaining plasma conditions that are simultaneously compatible with efficient current drive, effective divertor performance, high plasma purity, and H–mode confinement. Current drive systems must not only sustain the total current, but must control the current profile. This requires localized power deposition as well as good confinement in the tokamak to localize the current-carrying electrons. A key issue for plasmas with high bootstrap current fraction is MHD stability, especially when operated near the beta limit. A driven "seed" current near the axis is expected to be necessary for stability. An objective for SSAT will be to optimally control the seed current profile in high-beta, bootstrap-dominated plasmas, with good confinement and for many current relaxation times.

The goal of the advanced tokamak aspect of the SSAT mission is the *optimization* of steady-state plasmas to provide a data base for extrapolation to an attractive reactor. The following, achieved transiently in present machines or for short times, are sought in the steady state in SSAT: 1)energy confinement times equal to the best H–mode enhancements; 2)beta values significantly above the Troyon limit; 3)stable configurations with very high bootstrap fractions. We seek this good performance at high aspect ratio, where data is scarce but studies suggest there are certain advantages to this configuration.

Encouraging examples of enhanced-confinement modes, documented experimentally, are distinguished by particular profile characteristics: peaked density profiles in one case (TFTR's "Supershots"), and high edge bootstrap current densities in another (DIII–D's "VH–Mode"). Operation in the theoretically-predicted "second MHD stability regime" is a possible route to higher confinement, beta limits, and bootstrap fraction. Experiments showing evidence of second stability accompanied by reduced transport are promising. Crucial tools for exploring concept improvements such as these are current profile control and particle recycling control. Techniques that have been successful to date are of a transient nature, so the SSAT would develop more refined techniques, applicable in steady state, for controlled optimization of the tokamak.

To address the advanced tokamak mission element, we have defined specific operational scenarios that reflect the desired tokamak improvements, but otherwise use standard physics formulas for confinement, bootstrap current, current drive efficiency, profile shapes, and operating limits. Such formulas have been compiled and used in the ITER conceptual design study and have gained wide acceptance in the international fusion community. The "advanced" scenarios and their attributes are:

- High bootstrap current fraction (>67%) modes
- Current profile control modes for second-regime access.
- Advanced confinement modes using fueling/current/particle control.

Although the objective in these scenarios is improved physics, the SSAT is designed to achieve them using standard physics rules. This allows individual advances to be developed independently and explored without requiring success in all aspects at the outset. It is these scenarios that determine the characteristics and major parameters of the tokamak.

Current-carrying electrons must be well confined to provide localized current profile control, and the collisionality must be low over most of the plasma cross section to gain reactor-relevant data in advanced regimes. To satisfy these two conditions simultaneously under standard physics rules requires a tokamak of sufficient size. Moreover, as the tokamak size decreases, the power handling surface area decreases while the heating power must increase to maintain plasma parameters. The SSAT would be large enough to accommodate advanced plasma scenarios within achievable power handling criteria.

Access to advanced regimes requires special plasma geometries, including the poloidal divertor. Plasmas in SSAT would be elongated and shaped in their cross section for performance and stability in an optimum way. Also, ARIES and other reactor studies have found potentially attractive design points at aspect ratios of 4 or greater, where the bootstrap current helps to substantially reduce auxiliary current drive requirements and divertor loading. The SSAT would be designed to help meet the critical need for tokamak data at high aspect ratio.

Deuterium fuel in the tokamak plasma gives better plasma performance and deuterium neutral beams have higher power using the same hardware. Deuterium also provides more relevant conditions for divertor erosion studies, so while such operation imposes requirements for remote maintenance and local shielding, equivalent performance in hydrogen would require more power and a larger tokamak. We chose therefore to use deuterium, but limit through operations the annual DD (and incidental DT) neutron production to 6×10^{21} neutrons. For greater productivity in the early phases, radiation dose levels will be minimized by using hydrogen, reducing the annual production, and by an optimum choice of materials and shielding in the tokamak.

Uniqueness and the Need for SSAT

Running a tokamak for very long pulses at high duty factor, or in full steady state, is an important achievement for demonstrating its viability as a fusion reactor. Such operation has not yet been attempted, but Tore Supra, a large circular cross-section tokamak with superconducting TF coils, is potentially capable of 10-minute pulses. It will need superconducting coils in at least part of its poloidal system, and it lacks a poloidal divertor, a crucial feature for tokamak reactors. Also, full deuterium operation in Tore Supra is constrained by a DD neutron budget of only $1.2\text{x}10^{20}$ per year, with no provision for remote maintenance. While that facility will clearly make important contributions in current drive and disruption control, SSAT would be unique in comparison. The TRIAM–1M tokamak is also superconducting, and also has copper poloidal coils. It is small in size (80 cm major radius), but has achieved pulses longer than one hour with lower hybrid current drive, at very low density and currents. It could not address the issues for which SSAT is proposed.

There are a number of experiments that together will make substantial progress on particular steady state and advanced tokamak issues, but for relatively modest pulse lengths and low duty factor. The DIII–D experiment has as its main thrust the development of high beta, current-driven operating scenarios. Current drive experiments have begun and will be augmented through upgrades. Power handling issues have been studied extensively in the DIII–D open divertor configuration, but to accommodate the spacious divertors of SSAT the plasma size would have to be reduced. Additional hardware is being implemented to study particle control issues and advanced divertor concepts. The VH–mode of advanced confinement was pioneered in DIII–D, which also has a reasonable capability to explore our advanced scenarios. Obviously DIII–D will provide important short pulse data that will be valuable for optimizing the operation of the SSAT.

JET and JT–60U are both large tokamaks with poloidal divertors and current drive programs. A divertor upgrade is planned for JET. It has operated at low field for pulse lengths of about one minute, but its program is now strongly focussed on preparations for short-pulse, high-performance DT experiments. JT–60U will study disruption control, particle control, a range of aspect ratios between 3 and 4, and advanced tokamak regimes. They plan to study current drive combined with bootstrap current at high densities. However, these experiments will be limited to short pulse, except for very low-field studies, and deuterium operation will likely be limited.

Thus SSAT would be a unique facility for developing integrated steady state tokamak operating modes, combining an elongated shaped cross section, a spacious poloidal divertor, active pumping, non-inductive current drive, and substantial deuterium capability in a size necessary for confining the fast electrons that carry much of the steady current. The steady state and advanced tokamak missions are readily combined in a single facility, because the hardware requirements for the two elements are highly complementary. Poloidal divertors, for example, are important elements both in steady-state power and particle handling, and in providing conditions for enhanced confinement. Current profile controls needed to obtain advanced regimes and suppress disruptions complement the more basic capabilities needed for steady state current drive. Tokamak physics improvements must ultimately be demonstrated under conditions compatible with reliable steady state operation.

The SSAT would make important contributions in optimizing operating modes in ITER, particularly in the later stages when high availability will become a requirement. Certainly, the SSAT could test disruption control techniques and divertor concepts that might allow greater power handling in ITER should enhanced confinement modes be found there. The advanced tokamak mission elements would prototype physics improvements, develop *optimized* steady state scenarios, and make important contributions to the data base in advanced regimes. These contributions should help point the way to a more attractive, possibly smaller DEMO than the present data base would project.

Technology Benefits of SSAT

To carry out the SSAT mission advanced technologies would be used. In fact, an important aspect of SSAT is the integration of new physics and technology. For example, superconducting magnets are the natural design choice to provide the long-pulse, high-duty-factor operation called for in the SSAT mission, and indeed it could be the first tokamak with a fully integrated superconducting magnet set. To house such magnets the machine would be built inside of an evacuated cryostat, a configuration quite different from the copper machines of today, but very much like the configuration of ITER. The impact of the configuration on a remotely maintained machine is one the program must address, and the experiences from SSAT would be valuable.

Magnets for SSAT would use ITER-type conductors, and could be built patterned after ITER magnet designs. The R&D program for ITER, with its emphasis on reliability, and experience gained in previous magnet R&D projects and fusion confinement devices, all improve the reliability of this technology, perhaps above that of steady state copper coils. These magnets could give valuable experience to US manufacturers in preparation for ITER. In sum, the design, manufacture, and operation of a superconducting magnet set in a relevant tokamak configuration and operating environment, including full inductive start-up, eddy currents due to fast-changing control fields, plasma disruptions, and a DD neutron radiation field, would be quite valuable to the program.

Remote maintenance would be required in SSAT, although activation levels can be increased gradually in the first few years to allow hands-on access while testing remote maintenance operations. In this sense, the SSAT provides an excellent environment in which to develop tokamak remote maintenance approaches. A key objective in this area is to demonstrate the remote replacement of actively-cooled divertor and first wall components for the first time in a tokamak.

Power and particle handling in SSAT would require a high-performance poloidal divertor to handle high heat fluxes, exhaust particles, and support optimum plasma conditions in steady state. It would provide a platform for developing actively-cooled target structures designed to handle high heat loads and also be remotely maintainable. Divertor optimization objectives would include the testing of different geometries, materials, and operational procedures. The operational techniques developed on SSAT can be of great benefit to ITER operation.

Heating and current drive in SSAT would require development of actively cooled, remotely maintainable launching structures. Although initial power source needs can be met by upgrading existing systems, the mission would benefit greatly from the application of more advanced systems in the future, such as negative-ion neutral beams and high-power microwave sources.

Plasma diagnostics and controls would evolve beyond those used in pulsed experiments. Steady state sensor techniques would be needed to replace the time-integrated magnetic signals currently used to control the equilibrium in tokamaks. Real-time data displays would be incorporated, offering interesting possibilities for online decision-making and operator interaction. Automated learning techniques can be valuable for adjusting conditions in real time, both to optimize performance and to avoid disruptions and other failure modes. And, the controls, data storage, and data analysis centers could be distributed around the country at remote experimental sites.

Conclusion

The SSAT would move tokamak and fusion development into a new era. It would incorporate the main features of presently envisioned tokamak reactors, except for the DT nuclear fuel cycle and a burning plasma. It would test high-duty-factor plasma operation, non-inductive current drive, power and particle handling, and disruption control in an integrated manner. It would seek to significantly improve the physics of tokamaks by exploring advanced regimes with the potential for better confinement, higher pressure limits, and an internally-driven steady state current. It would advance reactor technologies including superconducting magnets, high-heat-flux divertors, steady state launch structures, and remote maintenance. In summary, the SSAT would be used for important and exciting experiments to advance fusion in the U.S. and the world.

SBX (Steady Burn Experiment)

Report for

FEAC-Panel 2 and New Initiative Task Force

Prepared by:

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Emanuel A. Chaniotakis

for the SBX Design Group

February 20, 1992

1. Summary

1.1 Objectives

The objectives of the SBX (Steady Burn Experiment) are:

- **Provide an early demonstration of continuous fusion power generation.** The device will provide continuous fusion power of 30 to 60 MW with power multiplication factor Q = 1-2 and a peak neutron wall loading of 0.5 to 1.3 MW/m^2. The fluence goal is >0.1 MW-yr./m^2. The availability goal is >10 percent.

- **Demonstrate steady state operation and resolve burning plasma issues that can have substantial impact on reactor operation.** All low-Q ($Q \leq 2$) alpha-particle physics issues which would have been studied on BPX can be addressed in SBX. However, SBX offers the advantages relative to BPX of steady-state operation in both conventional and advanced tokamak regimes. The long pulse or steady-state feature will be especially useful in exploring the issue of helium transport and exhaust. Should the helium confinement time prove too long, a significant part of the "physics phase" of SBX operation would be devoted to developing methods of enhancing the helium transport and reducing the effective confinement time to acceptable levels. The SBX could also be used to investigate various advanced physics issues such as steady state current drive, profile control, and bootstrap current. (By raising $q_0 > 1$, SBX could demonstrate the potential of the second-stability regime to simultaneously optimize τ_E/I, β/I, and I_{BS}/I.)

- **Test key fusion power generation technologies.** These technologies include:
  - Divertor configuration and plasma facing components (PFC's)
  - Non-inductive systems for sustaining current in a reactor environment

- Blanket technology and high grade heat production
- Continuous helium removal and tritium processing systems
- Remote assembly and maintenance technology
- Instrumentation and control
- Safety, waste management, and decommissioning technologies

- **Fulfill these goals in a compact, low cost (under $1 billion) device that can be built in a relatively short time and will provide the necessary operational flexibility.**

1.2 Programmatic Relevance

Relation to Pilot Plant and Small Fusion Development Plant (SFDP) and Other Previous Work

The SBX concept builds directly upon the pilot plant (Dean, Baker, Cohn, et al.) and the SFDP--Small Fusion Development Plant (Sheffield) concepts. Key objectives of these concepts were to provide operational experience with continuous fusion-power production at the earliest possible time and at minimum cost and to perform initial tests of key fusion power generation technologies at a low cost. The larger driven test reactor concepts--TETR (Conn and co-workers) and TORFA (Jassby and co-workers) and the compact high field demountable magnet concept of Bogart also provide a base for the SBX design.

Relation to ITER

The SBX concept has been developed to improve prospects for achieving the maximum performance for ITER. The first and most definite goal of ITER is to obtain information on long pulse (>1000 sec), ignited (Q >20) plasmas. During this physics-oriented phase of ITER operation, SBX would be providing a variety of information on steady state fusion power production and performing the first tests of various fusion power generation technologies. This information would facilitate the nuclear testing phase programs of ITER. For example, data from SBX could be used to qualify the driver blanket that could be used for ITER's nuclear testing phase. Moreover, given the significant possibility of a slip in the ITER schedule, it is likely that the SBX information on burning plasma physics (such as TAE modes, other alpha-particle instabilities, alpha confinement, and helium ash buildup) could provide important information for the physics phase of ITER.

A key issue in maximizing the overall performance of ITER is the development of divertor/first wall components that would allow DEMO relevant neutron wall loadings (~3 MW/m^2). Operation with these high fluxes is also very important for obtaining endurance information on fluence-limited technologies. Operation of SBX at $Q = 1\text{-}2$ with a neutron wall loading around 1 MW/m^2 will provide thermal wall loadings (~0.75 MW/m^2) that are equal to those required for 3 MW/m^2 neutron wall loadings in ITER or DEMO. SBX can thus be used as an integrated test bed for obtaining this high thermal loading performance capability in ITER. The attainment of ~3 MW/m^2 wall loading, 3000 MW thermal power capability in ITER would play an important role in demonstrating the potential cost competitiveness of fusion. A 3000 MW thermal power capability in a $5-$10 billion ITER device would be a much more convincing argument for the economic feasibility of fusion energy than the 1000 MW power output constrained by divertor performance limits. In our view, any new initiative should be capable of divertor operation at DEMO-relevant area-averaged thermal power densities.

Relation to DEMO

SBX can provide important information for DEMO that is complementary to information from ITER. In analogy to the need for many tokamaks worldwide to study plasma confinement issues, it will be necessary to have more than one tokamak device to study fusion power generation issues such as blanket operation at power reactor temperatures. The development of fission power reactors involved testing of power generation technology in a number of engineering test reactors.

High thermal wall loading components could be more thoroughly explored in a small more flexible device such as SBX than in a large device of the ITER class. Blanket and other fusion power generation system tests that complement those of ITER can be carried out. SBX can be used to down-select blanket concepts while ITER is operating in its physics mode. Full sector testing of the selected blanket concept could be carried out in ITER within a few years of the end of the physics exploration phase. Assuming success in addressing the divertor issues, high fluence tests could be performed in ITER at a neutron wall loading of ~3 MW/m^2 and thermal wall loading of 0.75 MW/m^2. In this way, endurance and possibly lifetime tests could be obtained in ITER in a relatively short time.

Role in U. S. Program

In the event ITER is substantially delayed or cancelled, SBX could provide the single vehicle for advancing the U. S. fusion program from plasma physics research into fusion energy research. The SBX may well be the only type of device that could provide a major forward step into the next frontier of burning plasmas for under $1 billion. (The BPX design studies indicate that the cost of a device that will ensure reactor level high Q operation (Q >20) for short pulses (~10 sec) would be in excess of ~$2 billion on the same costing basis used for SBX. To ensure high Q operation for long pulses (>60 sec), a suitable device would be even more expensive; the major radius would be 3.5 to 4.0 meters even if high field copper magnets are employed.) The construction of a high Q type of device is thus unlikely to proceed without international collaboration. On the other hand, an SBX type device at the ~$1 billion level could well be built by the U. S. alone or with a relatively minor level of participation from other countries. Moreover, the experience of building and operating an SBX will uniquely enable U.S. industry to gain the experience necessary to undertake the DEMO.

1.3 Reference Copper Magnet SBX Design Features

The reference SBX device is a compact device which uses water-cooled copper plate magnets. The use of copper magnets which employ inorganic insulators eliminates the need for neutron shielding of the magnet. Elimination of the shielding is a key factor in reducing machine size. An Alcator C-MOD jointed design is used in the reference design to facilitate maintainability and the use of internal coils. Other types of water-cooled copper plate magnet configurations will also be considered to fully explore the range of options.

The major radius of the reference design is 2 m. The aspect ratio is 4. The toroidal magnetic field on axis would be operated at levels up to 6 T (corresponding to 3.75 MA plasma current) with much of the operation being carried out at 4 T (corresponding to a 2.5 MA current).

At a toroidal field level of 4 T, the resistive power requirement of the toroidal field magnet is approximately 140 MW. At 6 T the power level is approximately

300 MW. These power levels can be provided at a number of possible machine sites. Operating power costs for 200 MW power levels at 10 percent availability are on the order of $10 to $20 million per year.

The OH transformer in the reference SBX design provides approximately 22 V-s, of which 12 V-s are available for driving current during the burn phase in 4 T, 2.5 MA operation. This OH drive (which is sufficient to drive ~100 second pulses by itself) can provide an important augment to neutral beam and bootstrap-driven currents.

SBX is designed with large ports (~2 m x 1.8 m) and extended outboard magnet legs to facilitate blanket testing. Approximately 18 m^2 is available for blanket test modules. A perspective view of the reference SBX design is shown in Figure 1.3.1.

Fusion power levels of the reference SBX design are between 30 and 60 MW. Neutral beam-driven operation which provides substantial power from two-component effects provides total Q values between 1 and 2. For $Q = 1$ and an absorbed neutral beam power of 30 MW, an average neutron wall loadings of 0.42 MW/m^2 and peak wall loadings of 0.65 MW/m^2 can be obtained. At $Q = 2$, a peak wall loading of 1.3 MW/m^2 can be obtained.

Both positive and negative ion neutral beam systems have been considered. While negative ion systems offer significantly improved performance, 120 keV positive ion beams may be able to provide wall loading (~0.4 MW/m^2 peak) and current drive requirements (steady state current drive with neutral beams and bootstrap current). Substantial cost savings are possible with positive ion neutral beams by upgrading equipment which exists at PPPL. The upgraded beams could provide pulse lengths of ~1000 seconds.

1.4 Possible Use of Superconducting Magnets

We have also considered whether the SBX mission might also be met with a superconducting magnet with sufficient shielding to limit the refrigeration load from the neutron heating. The potential main advantage of the superconducting option is the use of established ITER-relevant technology. However, the machine size and cost for a performance level that is comparable to the reference copper magnet SBX would increase.

We have made some very preliminary studies based on the SSAT design. The 2.25 meter major radius, 5 Tesla field, SSAT superconducting option was modified to allow room for 45 cm of tungsten shielding on the inboard side. This thickness of shield would provide an attenuation of at least 500 in the neutron power, reducing the magnet heat load to about 30 kW. A refrigerator comparable to that used with the MFTF-B could be used to remove an average heat load of 10 kW, allowing a 30 percent duty cycle. The helium vaporized during a 1000 second pulse could be stored at 4^0 Kelvin in a 3 meter diameter cold sphere until it could be recooled. True steady state performance capability would require more shielding and/or a larger refrigerator.

To accommodate 45 cm of shielding in the SSAT design at constant major radius, it is necessary to displace the inner leg of the TF coil to a smaller radius, placing the conductor in a larger peak field and reducing the space available for the central solenoid. Only half the volt seconds needed for inductive ramp-up are available, requiring that the current drive strategy allow for a hybrid ramp-up. The TF peak field would be increased from 9 Tesla, in the SSAT 5 Tesla design, to

11 Tesla. This is still well within the capabilities of the Nb_3Sn conductors, but would require use of a somewhat more expensive conductor.

At this time it is not possible to provide a meaningful assessment of the benefit/cost tradeoffs of the possibility of using superconducting magnets in SBX. We plan to keep it as an option. We intend to expand on this preliminary investigation and more fully explore the range of possibilities for compact superconducting magnet SBX devices.

1.5 Siting Issues

The tritium requirements (~130 grams per day throughput) and related radiation for the reference SBX design essentially preclude siting at the Forrestal site at Princeton. A nuclear-qualified site is required. Possible locations include Oak Ridge and other major DOE and DOD sites. The SBX would provide a forcing function for the U. S. Fusion Program to locate and develop a fusion energy development site. Such a site could be used for other key devices required for the realization of fusion energy, such as the intense point neutron source needed for materials development. Naturally, a fully nuclear-qualified site would be a very important negotiating point for U.S. future deliberations on the siting of ITER.

1.6 Reference Design Cost

The costing for the New Initiative design studies has been developed for device location at the Forrestal site at Princeton. As discussed in the previous section, the reference SBX design cannot be located there. However, costing for location at Princeton provides a useful frame of reference. For DD operation at Princeton, the cost would be ~$450 million, comparable to the SSAT cost. For DT operation at Princeton, the cost of the reference design would be on the order of

$570 million (excluding decommissioning costs). These cost estimates assume use of upgraded positive ion beams with 1000 second capability. The cost for DT operation includes costs for an adequately shielded building for the SBX level of DT operation and for tritium systems and nuclear hardened diagnostics.

The cost of location at a suitable nuclear-qualified site, such as Oak Ridge, would be moderately increased relative to that estimated for location at the Forrestal site. There could be additional costs for roads, buildings other than the already costed shielded test cell, and some costs for power handling equipment. Assuming use of upgraded positive ion beams (if they could be made available), the cost at Oak Ridge would be around $750 million. If 40 MW of negative ion beams were used instead, the estimated cost for operation at Oak Ridge would be ~$880 million.

With additional costs for nuclear-related issues, such as decommissioning, the estimated cost for an SBX using negative ion beams at Oak Ridge approaches ~$1 billion. For fluence goals beyond the nominal goal of 0.1 MW-yr/m^2, the cost would be further increased reflecting increased reliability requirements.

There is a possible option for phased operation of SBX located at a new fusion energy development site such as Oak Ridge. A first phase of hydrogen and limited deuterium operating could be carried out without tritium, remote handling, and nuclear- hardened diagnostics costs. The goals of this first phase would be steady state operation and advanced physics (similar to other new initiative proposals such as SSAT). In this stage, upgraded positive ion beams would be used. The cost for this phase could be in the $500 million range.

Section 2 provides a breakdown of the cost estimate.

1.7 Conclusions

The SBX can provide an exciting step that takes the U. S. Fusion Program into the physics of burning plasmas and into the technology of continuous power production. It would complement ITER and make important contributions toward maximizing ITER performance. The SBX would study a range of steady state and advanced physics issues that are directly relevant to the Demonstration Reactor.

Because of its tritium burning characteristics, SBX cannot be located at the Forrestal site at Princeton. Location at a suitable nuclear-qualified site, such as Oak Ridge or other DOE and DOD sites, would be required. Placing SBX at such a site would serve to initiate the realization of a fusion energy development site. This site should eventually include other key facilities such as a fusion neutron source.

Because of its high performance compact magnet design and use of neutral-beam driven two-component plasma operation, the SBX would have a high performance to cost ratio. The SBX cost would be under $1 billion. Phased operation of SBX might be employed to meet New Initiative Task Force goals for non-DT steady state and advanced physics operation for a cost in the $500 million range.

With its capability for continuous fusion-power production, the SBX would move the U. S. Fusion Program into a new frontier and strongly support ITER and DEMO.

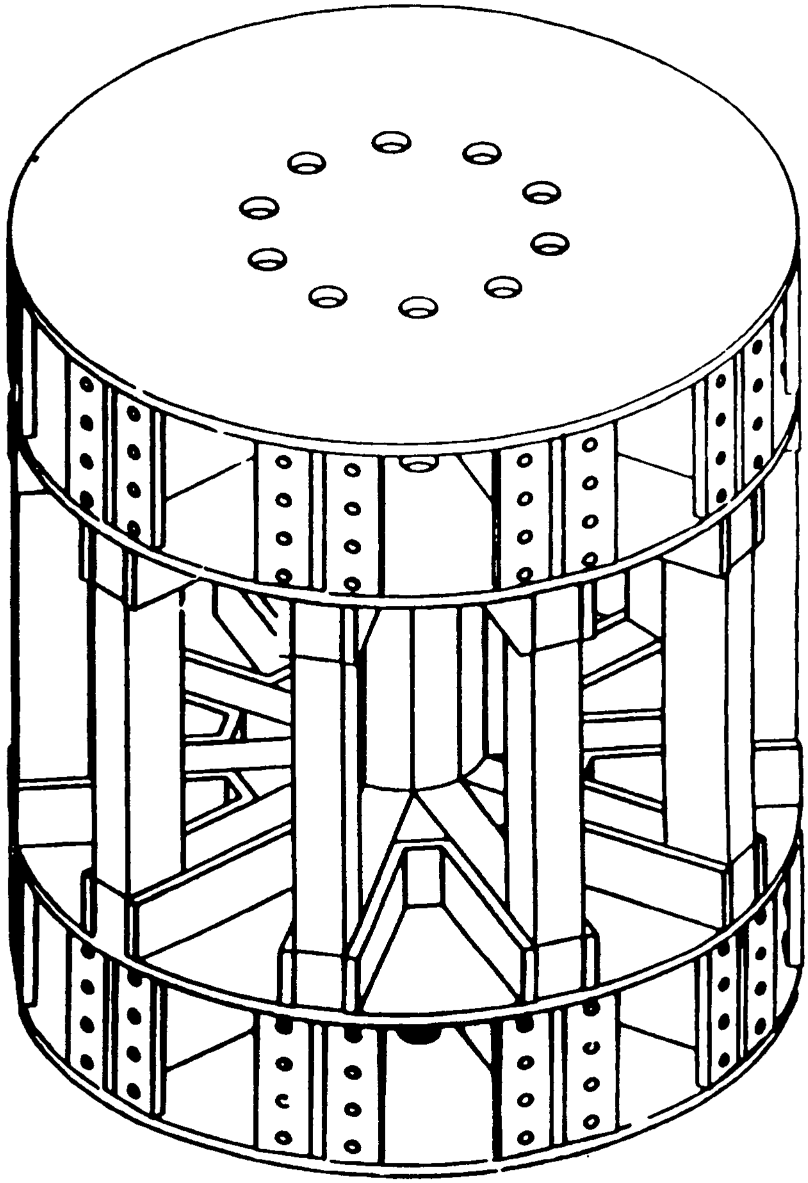

Figure 1.3.1 Perspective View of Reference SBX Design

BPX-AT

- EXECUTIVE SUMMARY -

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March 10, 1992

A. BPX-AT Executive Summary

Introduction

BPX-AT is an advanced tokamak optimized to study the critical physics issue for ITER and DEMO - burning plasma physics, especially alpha heating, in advanced tokamak regimes. BPX-AT is the only device proposed in the New Tokamak Initiative that has the capability of resolving advanced tokamak physics issues at reactor relevant plasma conditions that can be extrapolated directly to DEMO. Furthermore, BPX-AT has the capability of exploiting the progress expected during the next decade of fusion research by installing sufficient engineering capability to study thermal stability, disruption control and ash accumulation in ignited ($Q > 25$) plasmas with an advanced tokamak configuration for ~ 50 energy confinement times. BPX-AT is capable of addressing long pulse issues in lower performance ($I_p = 1.9$ MA) advanced tokamak regimes with full current drive and profile control for pulses lengths of > 400 seconds. BPX-AT makes optimum use of existing facilities at the TFTR site and has a cost of $642M (FY92), less than 1/2 of BPX, with first plasma in the year 2000 and full hardware capability in 2001. The funding profile required for BPX-AT fits within the 5% real growth per year fusion funding plan recommended by the SEAB Task Force on Energy Research Priorities (1991).

Background

During the last decade numerous technical review committees [MFAC Panel 3 (1983), MFAC Panel 14 (1986), ERAB(1986), National Research Council(1989) and FPAC(1990)] have thoroughly reviewed the magnetic fusion program and all concluded that burning plasma issues were the next technical issues to be addressed in fusion research, and that a device should be built to address these issues as the next step in the US magnetic fusion program. The demonstration and study of self-heated plasmas is not just the next frontier but the most important step in over 40 years of fusion physics research. The most recent review of the world fusion program by the FPAC[1] led to a plan described in the United States National Energy Strategy (NES)[2] for the development of fusion as an energy source by the mid-21st century. The NES adopted the goal of operating a fusion demonstration plant (DEMO) by the year 2025, and a commercial plant by about 2040. The main elements of the plan are a strong core physics and technology program, D-T experiments on TFTR, burning plasma experiments on the Burning Plasma Experiment (BPX), long pulse burning experiments and technology development on the International Thermonuclear Experimental Reactor (ITER), a materials test facility and a steady-state experiment leading DEMO. A key element of the FPAC recommendation and NES was a Burning Plasma

Experiment (BPX) costing approximately $1B, which would address the critical D-T physics issues, i.e., self heating of the plasma by alpha particles and would " greatly reduce the risk that ITER could run into difficulties which would compromise its ETR mission" [1].

The Secretary of Energy Advisory Board (SEAB) Task Force on Energy Research Priorities reviewed (1991) the Energy Research priorities under the constraint of capped Energy Research budgets and recommended that "magnetic fusion program funding must increase at a modest rate (e.g., 5 per cent real growth per year)..." and that this was incompatible with the authorization of the BPX proposed at $1.4B (FY91$). SEAB [3] recommended that:

> "Concept exploration should begin to define a new experiment in the $500M class for the purpose of scientific study of tokamak improvements (e.g. , second stability, steady state, bootstrap current) that could suggest new operating modes for ITER and permit the design of more reactor-desirable follow-ons to ITER."

The Fusion Energy Advisory Committee (FEAC) was charged(1991) to determine the appropriate next step in the absence of BPX and the effect of the loss of BPX on the ITER program. Recently, FEAC [4] reaffirmed the preference for the NES plan for fusion and a " national effort focussed on the physics of burning plasmas" but felt that " it does not appear possible to proceed with the construction of BPX without either diminishing its mission or timeliness, or severely affecting important core programs which remain". The BPX-AT with drastically reduced costs provides a substitute for BPX that can carry out a broader mission than BPX without impacting that core program. Without a BPX-like device, the present plan is to have ITER be the "burning plasma experiment" and to address self heated plasmas for the first time in a huge device whose main mission should be as an Engineering Test Reactor. This high risk approach is like attempting to build a 747 before the Wright brothers demonstrated the basic principles of self-sustained flight at Kitty Hawk. This one-step-does-all plan is without precedence in large technology development programs (e.g., aviation, fission, space, computers, etc.), and dramatically increases the probability of total program failure. Presently there are over 10 deuterium tokamaks operating and addressing overlapping physics issues, which provide the ability to develop solutions to problems using small devices and then to implement these solutions quickly and cost-effectively on larger devices. For example, the success of JET is due to the H-mode discovered on ASDEX 4 years after JET construction began. Since over 10 deuterium tokamaks are needed now, it seems overly optimistic to assume that one large deuterium-tritium device will be sufficient to address much more difficult problems. If burning plasma physics problems arise on ITER, there will be no place to test solutions except on ITER. FEAC [5] together with other ITER parties has concluded that the loss of BPX will cause the duration of the physics phase of ITER to increase from 6 to 10 years in order to carry out the burning plasma physics mission, possibly delaying the 2025 startup of DEMO. Even larger delays will occur if ITER has a major misstep. BPX-AT would have the capability to resolve these critical issues prior to and during the operation of ITER whose annual operating cost is estimated to be \$400M and total program cost is likely to be in the 15-20 \$B range.

Since ITER will not test the advanced tokamak features identified by ARIES, a separate device is needed to develop the advanced tokamak features that will be incorporated in the DEMO design. In particular, demonstration of self-heated plasmas in an advanced tokamak regime prior to DEMO design, such as the proposed BPX-AT, is required to provide a solid foundation for DEMO.

BPX-AT Description

This white paper describes an upgrade to the TFTR facility based on the BPX design concept, BPX-AT, that will address advanced tokamak and burning plasma issues concurrently. The engineering and costing of BPX-AT is on solid ground due to the several years of BPX design and review. This \$642M facility is designed to take advantage of the advances likely to be made during the next decade of confinement research costing over \$3B worldwide. Long pulse (~420 s) plasmas with high bootstrap currents and advanced divertors can be studied in the initial configuration ($B_T = 3T$, $I_p = 1.9$ MA) starting in the year 2000 which costs \$462M. Additional power, heating systems, and D–T capability would be added within 1 year so that burning plasma physics, especially alpha heating, can be done in conjunction with advanced tokamak features. BPX-AT is projected to attain $Q \sim 5$ using standard confinement assumptions of $C_\tau = 2$, thereby satisfying the minimum requirement to study self heated plasmas. Several tokamaks (TFTR, PBX-M and DIII-D) have already achieved $C_\tau \sim 3.5$ for short pulses ($<\tau_E$) and $q \sim 4$, if these advanced tokamak confinement enhancements required for DEMO can be realized for longer pulses and $q \sim 3$ during the next 10 years, then BPX-AT will ignite ($Q > 25$) at 7.5T with a pulse length of 45 seconds and a fusion power output of ~ 120MW. This regime allows the study of advanced tokamak features (enhanced confinement, high bootstrap current, and second stability) with self heated plasmas for ~ 50 energy confinement times. The total project cost is \$642M (FY92\$) and the required funding profile fits within the 5 per cent real growth per year fusion funding plan recommended by SEAB.

BPX had a simple, elegant, and mature design and a sound physics design basis. Although BPX-AT is different from BPX due to its smaller size and higher aspect ratio, key elements of the tokamak configuration, structural design criteria, and physics design basis were preserved.

The tokamak (Fig. 1) features self-supporting, BeCu TF coils, wedged in the nose region. The PF solenoid is also constructed with a BeCu alloy and is self-supporting for radial loads. BeCu is a well-characterized material with outstanding strength (σ_y~107ksi) and good electrical conductivity (68% IACS). Minimal additional conductor R&D would be required. Self-supporting designs have the desirable feature that EM loads are reacted internally, avoiding interfaces between systems which are often difficult to quantify and are sensitive to manufacturing tolerances and differential thermal growth. Structural analysis of the TF indicates that the peak stress in the conductor occurs in the nose region and is 68ksi. Stress levels in the TF are within the allowables prescribed in the BPX Structural Design Criteria Document [6]. In fact, the stress levels appear low enough in the outer leg to use OFHC Cu, thereby reducing the conductor material cost and the cost of power supplies.

The TF and external PF coils are adiabatic during a shot with a pre-shot temperature of 80K. At full parameters, joule heating limits the flattop to ~10s. However, at reduced parameters, the rate of joule heating is reduced so pulse lengths can be extended rather dramatically. At 3T, the flattop time can be extended to ~420s which should be ample for the advanced tokamak mission. The time required to cool the coils down to 80K with LN_2 between thermally limited pulses is ~1 hour. Cooldown times would be shorter for pulses which are not thermally limited.

Strategy for BPX-AT

BPX was sized to achieve Q=5 with 100MW of fusion power provided the energy confinement time was at least 1.45 times the confinement time predicted by ITER89-P scaling. Analysis of H-mode data on various tokamaks indicates that a confinement enhancement of 1.85 is the "center of the error bars" on what can be expected based on current physics understanding and operating techniques. The philosophy for sizing BPX was that the device should be capable of meeting the minimum mission objectives even if confinement were substantially less than predicted for H-mode plasmas. This ultra-conservative posture led to a BPX which was a 2.6m tokamak with an aspect ratio of 3.25 and a total project cost of $1.43B (FY91$). In order to reduce the cost, it is necessary to reduce the size of the device.

For BPX-AT, a more optimistic philosophy (consistent with the SSAT philosophy) was adopted.

It was assumed that when BPX-AT is operated, achieving a confinement enhancement of at least 2 over ITER89-P scaling is a reasonable expectation because of improvements in physics understanding and operating technique derived from operating existing tokamaks during the next 8 years. Thus, the tokamak parameters were reduced from an IA product of 38 for BPX (11.8MA, A=3.25) to 25 for BPX-AT (6.25MA, A=4) with an attendant reduction in size from 2.6m to 2.0m. An expanded list of machine parameters is provided in Table 1.

Once the high performance tokamak is available, the advanced tokamak features are "free". For example:

- long pulses (~ 400 seconds) are available at reduced field (3T);
- ICH heating for D-T operation can be used for advanced tokamak current drive;
- high bootstrap current regimes are accessible;
- second stability regimes (q_0~2, q^*/q_0>2.3) are also accessible;
- advanced divertor concepts can be incorporated.

The experimental program of BPX-AT can be phased so that initial (Phase I) experiments are carried out in hydrogen and deuterium at reduced field with modest heating (15MW ICH, 2MW LHCD), thereby reducing front end costs. The first phase of operation reflects the standard startup procedure and will be spent optimizing the tokamak configuration and plasma performance while validating remote maintenance techniques. Phase I objectives are to demonstrate successful long pulse, current driven operation with adequate:

- power handling capability;
- current profile control;
- bulk density, density profile, and particle control;
- diagnostic capability, and
- remote maintenance capability.

The total number of neutrons produced in Phase I will be budgeted to preserve hands-on maintenance capability until Phase I objectives are met. During this 1 year startup period when the machine is being optimized, power and heating system modifications necessary for Phase II can be installed during shutdown periods.

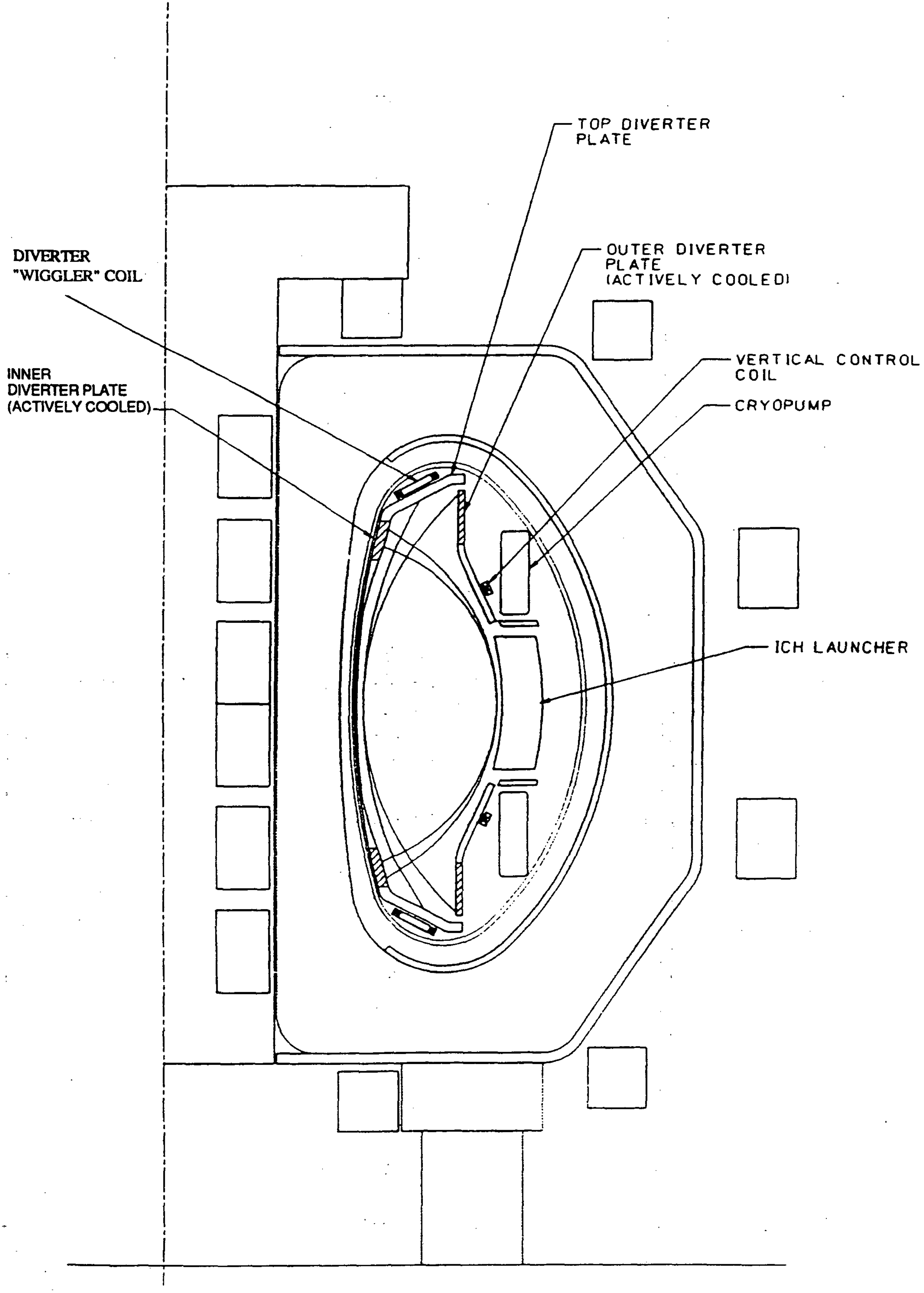


Figure 1 - BPX-AT Elevation View

Table 1 - BPX-AT Parameters

Parameter	Units	BPX-AT	
R	m	2.0	
a	m	0.5	
A		4	
κ_{95}		2	
δ_{95}		0.2-0.3	
B	T	10	
q_{95}		3.3	
I	MA	6.25	
$t_{flattop}$	s	10	
$P_{ICH/FWCD}$	MW	32	to plasma
		40	source power
P_{LHCD}	MW	2	to plasma
C_{τ}		2	
Q		5	

Phase II objectives will be to:

- confirm and further develop advanced tokamak operating features in D-D with the increased heating and field available, including
    - high bootstrap current,
    - second stability,
    - high beta, and
    - enhanced confinement;
- confirm and further develop advanced tokamak operating regimes in D-T;
- study D-T physics, especially alpha-heating in a DEMO relevant advanced tokamak configuration;
- demonstrate the production of fusion power in excess of 100MW.

Operating Scenarios

The work on SSAT has served to focus thinking on the operating scenarios required for an advanced tokamak. These scenarios include exploring:

- first stability beta limits ($\beta_N \sim 3.5$) with $q \sim 3$;
- high bootstrap fraction ($f_{bs} \sim 0.6$) regimes;
- second-stable regimes with very high bootstrap fraction ($f_{bs} \sim 0.9$).

These scenarios come "free" on BPX-AT. The adiabatic coils, which can provide 10T for 10s, also can provide 3T for ~420s. Parameters for these scenarios are listed in Table 2. These operating points are not isolated but actually represent an envelope defined by power handling/heating limitations, q limits, and β limits.

The advantage of BPX-AT over SSAT as an advanced tokamak is that these scenarios can be replayed *at DEMO-relevant $n\tau T$ and in D-T with alpha physics*. One premise for these scenarios is that they be achieved with "standard" H-mode confinement ($C_\tau \sim 2$). If enhanced confinement (C_τ~3.5) is achieved, even more interesting possibilities develop:

- the high beta operating point has *near-ignition ($Q \sim 25$) conditions* ;
- the high bootstrap operating point has $Q \sim 3$ for $f_{bs} \sim 0.6$;
- the second-stable operating point has $Q \sim 1.4$ for $f_{bs} \sim 0.9$.

Parameters for these enhanced confinement scenarios are listed in Table 3. For studying burning plasma physics, at full parameters with "standard" H-mode confinement ($C_\tau \sim 2$), $Q \sim 5$ is expected. If enhanced confinement ($C_\tau \sim 3.5$) is achieved, ignition can be studied at 7.5T for pulse lengths of ~45s. The fusion power may limited by confinement, available heating, or power handling capability. With a hybrid divertor, heat loads of 60MW (300MW of fusion power with an ignited plasma) can be handled for ~5s. Heat loads of less than 30MW can be handled in steady state.

Table 2 - Standard Confinement Scenarios in D-D @ 3T

	High Beta	High Bootstrap	2nd Stable
B	3	3	3
n_{20}	.70	.54	.45
T	7.2	6.3	5.8
C_τ	2	2	2
τ	.16	.11	.08
q_{95}	3.1	4.5	6.3
q_0	1	1	2
I_p	1.9	1.3	.91
β_N	3.5	3.5	3.8
f_{bs}	0.4	0.6	0.9
$t_{flattop}$	420	420	420

Table 3 - Enhanced Confinement Scenarios in D-T @ 7.5T

	High Beta	High Bootstrap	2nd Stable
B	7.5	7.5	7.5
n_{20}	3.0	1.4	1.5
T	9.6	13	10
C_τ	3.5	3.5	3.5
τ	0.9	0.7	0.5
q_{95}	3.1	4.5	6.3
q_0	1	1	2
I_p	4.7	3.3	2.3
β_N	3.5	3.5	3.8
f_{bs}	0.4	0.6	0.9
Q	25	3	1.4
P_{fusion}	120	50	30
$t_{flattop}$	45	45	45

Facilities

BPX-AT is to be located in the TFTR test cell. The length and width of the test cell are more than adequate. The height and crane capacity are adequate for all but the heaviest lifts, e.g., PF coils and TF modules. For these lifts, a gantry crane will be used.

The shielding of the TFTR test cell will be increased to maintain the radiation dose at the PPPL site boundary to < 10mR/year. Three factors contribute to the dose at the site boundary - neutrons, activated air in the test cell, and operational releases of tritium, primarily during maintenance. The thickness of the walls and roof of the test cell will be increased to reduce the dose at the site boundary due to neutrons. Close-in shielding, which is integral to the cryostat , is proposed to reduce the level of air activation in the test cell. Also, it has been proposed that there be no negative pressure in the test cell except in the event of a tritium release, thereby reducing the dose at the site boundary due to activated air. The cryostat-shield connected to the TFTR torus tritium cleanup system will also serve as an effective containment boundary for tritium The design objective is to produce ~3 x 10^{23} D-T neutrons (alphas) per year, about 1/3 of the BPX design requirement. Tritium retention in the divertor and limiters will require HeO GDC after ~50 pulses 30 seconds long, but should not be a problem. A closed cycle tritium reprocessing system similar to the one being developed for TFTR will be used. Accident scenarios are the same as TFTR, i.e., 140mR at the site boundary for a worst case 2.5g HTO stack release and 390mR at the site boundary for a beyond worst case 2.5g HTO ground level release.

Cost and Schedule

A phased mission has been proposed for BPX-AT to minimize front end costs without impeding the experimental program. Phase I capabilities are tailored to match present TFTR site capabilities, especially with respect to TF/PF power supplies (74-1kV units), utility power available for long pulse operation (112MW), and stored energy available from the TFTR MG sets (4.5GJ). For BPX-AT, the TF and PF can be powered from the existing utility line along with 15MW (source power) of ICH/FWCD for fields up to 3T. The pulse length at 3T would be limited by heating of the TF and PF coils to ~420s. Operation at higher fields (up to ~5T) would be possible with the pulse length limited by the stored energy of the MG sets, rather than by heating of the TF and PF coils.

For Phase II, the machine capability would be enhanced by:

- upgrading the power from the utility line from 112MW to 425MW;
- upgrading the TF and PF power systems;
- increasing the capacity of the LN2 refrigeration plant;
- increasing the ICH/FWCD source power from 15MW to 40MW;
- upgrading the divertor to handle the additional power;
- adding the capability to operate with tritium.

The cost for BPX-AT was estimated using cost algorithms developed for the New Initiative and the results are shown in Table 4. The Phase I cost is $462M with $249M of the total in the tokamak systems. The biggest single cost element is the TF system at $123M. Phase II costs an additional $181M, mostly in heating system ($56M) and power system ($49M) upgrades.

The cost of BPX-AT is compared to BPX in Table 4. Substantial cost reductions have been achieved by:

- reducing the major radius from 2.6m to 2.0m ($400M);
- maximizing use of existing TFTR assets;

    - reusing TFTR/FMIT transmitters for ICH/FWCD ($14M),
    - locating the tokamak in TFTR test cell ($85M),
    - reusing TFTR diagnostics where possible ($8M),

- better utilizing the ICH transmitters by using one transmitter per strap instead of two ($30M);
- reducing the diagnostics complement ($40M);
- developing a lower stress TF coil design which permits the use of OHFC copper in the outer leg and saves on TF coil and power system costs ($30M);
- adopting a minimum cost approach to RM, using prototypes for actual maintenance rather than just for development and training ($85M);

Table 4 - A Comparison of BPX and BPX-AT Costs

WBS		BPX (FY92$)	BPX-AT (FY92$)
1	Tokamak Systems	472	249
11	Plasma Facing Components	58	39
12	Vacuum Vessel	48	15
13	TF	218	123
14	PF	110	40
15	Cryostat	14	11
16	Tokamak Support Structure	4	3
17	Tokamak Assembly	20	18
2	Aux Heating & Current Drive	85	84
23	ICH/FWCD	85	74
24	LHCD	0	10
3	Fueling & Vacuum Systems	72	49
31	Fuel Storage & Delivery	4	3
32	Pellet Injection	16	12
33	Rad Monitoring & Tritium Cleanup	20	14
34	Vacuum Pumping Systems	32	20
4	Power Systems	242	59
5	Maintenance Systems	168	41
6	Data Systems	110	56
61	Central I&C	22	12
62	Plasma Diagnostics	89	43
7	Facilities	180	61
71	Buildings, Mods & Site Improvements	166	24
72	Cryogenic Equipment	11	33
73	Water Cooling	2	1
74	Radiation Shielding	1	3
8	Preparations for Operations	67	13
9	Project Support	95	29
	Total	1490	642

- accepting a higher level of risk by;
  - scaling back management, systems engineering, and project physics ($20M),
  - limiting R&D to bare essentials ($60M),
- limiting pre-op staff buildup and training ($50M);
- excluding costs not related to the construction project from the project cost estimate, e.g. Program Physics ($25M).

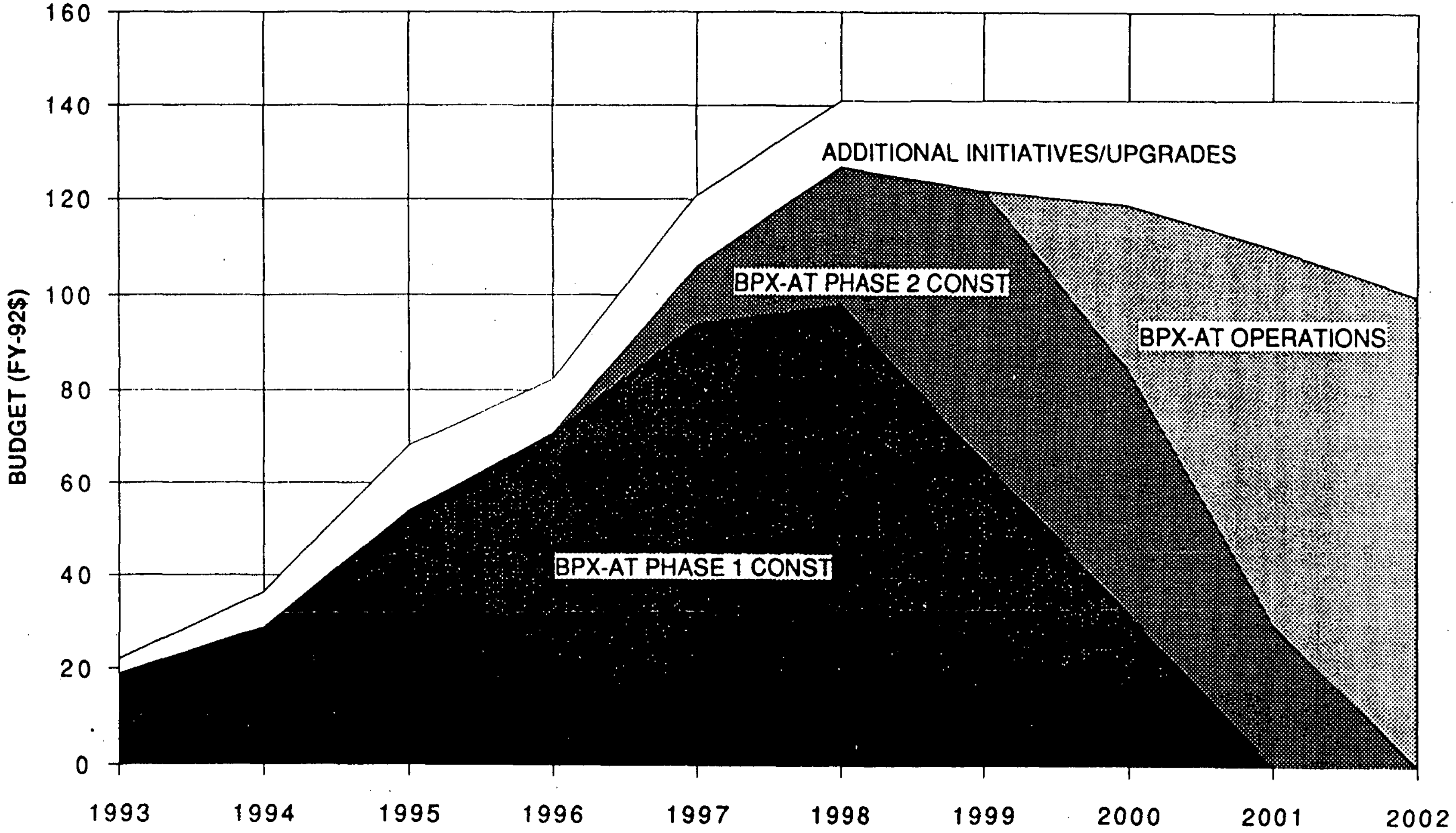
Several features on BPX-AT actually increased costs relative to BPX. These features include 2MW of LHCD ($10M), 32MW of ICH/FWCD delivered to the plasma instead of 20MW ($30M), and a closed-loop LN2 refrigeration plant ($22M). A resource loaded schedule is not available for BPX-AT. However, the BPX-AT schedule should be similar and somewhat shorter than the BPX schedule. For BPX, there were two critical paths – the TF coils and facilities. Since the TFTR test cell is being used, the TF coils are the only critical path. With design-only funding in FY94, a late-2000 first plasma date with full hardware capability 1 year later is reasonable, if funding is available.

The cost profile for BPX-AT is given below:

$M FY'92	FY'93	FY'04	FY'95	FY'96	FY'97	FY'98	FY'99	FY'00	FY'01	FY'02
Phase 1	19	29	54	71	94	98	65	32		
Phase 2					12	29	57	52	30	
Operation								35	80	100

This cost profile allows BPX-AT to be built without impacting the core program as shown in Figure 2. The upper envelope in Figure 2 was determined by assuming the SEAB budget recommendation of 5% real growth per year for the fusion budget and then subtracting the core program, TFTR and ITER design/base budgets. The budgets for 1993 to 1997 are those given by the OFE, budgets for 1997 to 2001 assume constant real budgets for the core program and ITER and the planned shutdown and decommissioning of TFTR. The ITER construction budget is assumed to be a special initiative. In this scenario ~$36M is available for additional initiatives/upgrades from 1993 through 1997 and ~$92M available from 1998 through 2000.

Figure 2 BPX-AT FUNDING PROFILE



BPX-AT-1

Conclusions

BPX-AT will address advanced tokamak and burning plasma issues concurrently. Long pulse (~420s) plasmas with high bootstrap currents and advanced divertors can be studied in the initial configuration starting in 2000 which costs $462M. Additional power, heating systems, and D–T capability would be installed during the next year so that burning plasma physics, especially alpha heating, can be done in conjunction with advanced tokamak features. BPX-AT can attain Q~5 using "standard" confinement assumptions of $C_\tau = 2$. If the advanced tokamak confinement enhancements required for DEMO, i.e. $C_\tau \sim 3.5$, can be realized, then BPX-AT will ignite with B~7.5T and a pulse length of 45 seconds. The total project cost is $642M (FY92$) and the funding profile fits within the fusion funding plan recommended by SEAB. If the BPX-AT device were adopted and built on the proposed schedule, the main features of the NES could be maintained, and burning plasma experience on BPX-AT could shorten the ITER phase by 4 years, saving $1.7B (FY91), while providing a unique combination of burning plasma and advanced tokamak physics that would be needed for DEMO design.

The TFTR D-T experiments in 1993-4 should revive interest and enthusiasm for magnetic fusion in the U.S.. BPX-AT is the ideal vehicle for the next natural step after TFTR/JET, the study of burning plasma issues in a DEMO relevant configuration while providing critical operational support for ITER.

Acknowledgements

The technical work described here is a tribute to the skill and dedication of national CIT/BPX team.

References

[1] Fusion Policy Advisory Committee, Final Report, September, 1991
[2] National Energy Strategy, February, 1991
[3] SEAB Task Force on Energy Research Priorities, Letter Report, November, 1991
[4] Fusion Energy Advisory Committee, Letter Report, October, 1991
[5] Fusion Energy Advisory Committee, Letter Report, February, 1992
[6] BPX Magnet Structural Design Criteria, F-910208-PPL-03, Rev. 0

Appendix III

Minutes of FEAC Meeting of March 18/19, 1992.

MINUTES

Meeting of Fusion Energy Advisory Committee
Princeton Plasma Physics Laboratory
James Forrestal Campus
Princeton, NJ 08543

March 18-19, 1992

Present:

- Dr. Robert W. Conn, Chairman, UCLA
- Dr. David E. Baldwin, LLNL
- Dr. Klaus H. Berkner, LBL
- Dr. Ronald C. Davidson, PPPL
- Dr. Stephen O. Dean, Fusion Power Associates
- Dr. John P. Holdren, UCB
- Dr. Robert L. McCrory, Jr., University of Rochester
- Dr. David O. Overskei, General Atomics
- Dr. Ronald R. Parker, MIT
- Dr. Barrett H. Ripin, NRL
- Dr. Marshall N. Rosenbluth, UCSD
- Dr. John Sheffield, ORNL
- Dr. Harold Weitzner, NYU

Wednesday, March 18, 1992

Welcome and Opening Remarks

Dr. Conn called the meeting to order and welcomed the members to the meeting. He expressed his thanks to the persons who had organized the meeting and made administrative announcements concerning the agenda and meeting rooms.

Up-Date from DOE

Dr. N. Anne Davies presented an up-date of the fusion energy program to the committee. She indicated that the "House" Congressional hearings had been held but not the Senate hearings. During the "House" hearings, the main focus had been on ITER and TPX. However, much interest had been expressed in the opportunities for industrial involvement in the fusion program and for international collaboration.

The 1992 Reprogramming Letter had been sent to Congress on March 16. It included not only fusion but a number of other technologies as well. Dr. Davies stated that the letter was presently awaiting congressional approval. She added that the letter was complex and that it may be approved one item at a time. She considered that the fusion position was fairly clear and that therefore "fusion" may be approved in the early stages of the process.

Dr. Davies reported that the National Energy Strategy had recently been up-dated and re-issued, and that Guidance to the Field for FY94 had been prepared and issued.

Dr. Dean said that the National Energy Strategy contained some misleading statements. In particular, it made it appear that the fusion energy budget had increased by 26%. Dr. Davies agreed but explained that there had been so many budgetary changes, including the matter of "house-keeping" at ORNL for example, that it was now very difficult to make direct comparisons with previous years.

Dr. Davies presented the proposed changes to the budget for FY92. Within the Office of Fusion Energy, $11 million would be re-directed and a further $1 million would be transferred from "Operations" to "Capital Equipment" within each of two specific projects. The changes were summarized as:

Program	Change	Rationale
ATF	+ $0.6 million	Covers coil repairs needed to permit future operation of ATF
BPX/TPX	- $11.0 million	Close out of BPX and start-up of scoping studies and design of TPX
TFTR	+ $3.4 million	Maintains D-T schedule and provides ES&H improvements
DIII-D	+ $3.0 million	Increases usage of facility
PBX-M	+ $2.0 million	Provides HF heating for control of current profile for second stability experiments
TFTR	Internal transfer	Purchase of equipment
PBX-M	Internal transfer	Purchase of equipment

In addition, almost $1 million would be transferred from Energy Research to Energy Management to support regulatory requirements at PPPL. In particular, these funds would be used for hazardous waste management, low-level radioactive waste disposal, radioactive waste management and hazardous waste disposal.

Dr. Davies presented the FY93 Congressional Budget Request for the Fusion Energy Program and provided a summary of disposition of funds by major contractor. Here she compared actual figures for FY91 with those projected for FY92 (before and after reprogramming), which were 17% higher, and with those proposed for FY93. The total FY93 request was 25.5% greater than actual funding for FY91.

Dr. Davies then discussed the guidance that had been provided to the field for FY94 by the Office of Energy Research. She explained that in the past the controller had specified the dollar amounts and that these had not always been consistent with the field task proposals, especially after cost-of-living increases and new initiatives had been taken into account. This year, the Secretary of Energy had made a change and had asked senior personnel, including those at the Deputy Secretary level, to develop the guidance. Following this process, Dr. W. Happer wrote a letter for distribution to all of the DOE Field Offices, which contained the basis for guidance:

- Maintain high energy and nuclear science fundamental research.
- Expand energy, health, and environmental research and focus on the energy, economic, and environmental goals of the NES.
- Improve the excellence and productivity of the nation's scientific infrastructure.
- Develop fusion as an energy option.
- Improve science and mathematics education.
- Increase technology transfer to the private sector

Dr. Davies continued that the letter emphasized the expectation of significantly constrained budgets and that it made it clear that programs would have to identify priorities and alternatives for accomplishing goals in a cost effective manner. Some activities would be eliminated, reduced in scope or stretched-out in time in order to accommodate new important initiatives. Cost sharing with industry, academia, and the international community had received strong endorsement.

Dr. Davies then turned to the guidance for fusion energy for FY94 and beyond. She had been asked to consider three scenarios:

(a) Flat budgets, containing no provision for inflation.
(b) Flat budgets, but with adjustment for cost of living increases.
(c) For FY94 only, real growth of 9% on top of any cost-of-living increase above the budget for FY93, followed by real growth of 5% on top of any cost-of-living increases in each of the subsequent years from FY95 through FY98.

Dr. Davies emphasized that she did not want to raise the committee's expectations concerning the possibility of a real increase of 9% in the fusion budget because it was not at all certain that such an increase would occur; she felt that obtaining even a 5% real increase would be very difficult.

Dr. Davies stated that OFE's main concerns at present involved the phasing-out of BPX, ensuring that TFTR and ITER were both fully funded, bringing industry into the fusion program, and funding the new small machine at approximately $500 million.

Dr. Dean asked if IFE matters were being treated as separate planning issues or if they were being included as part of the base program. Dr. Davies responded that the IFE program was being treated as a special planning issue but that it was contained within the base.

Dr. Davies moved on to the topic of industrial involvement in the fusion program. Drs. Conn, Baldwin and Linford had met with Dr. Happer to provide FEAC's detailed views on this matter prior to Dr. Happer testifying before the Congressional authorization hearings. Dr. Happer had responded positively to FEAC's recommendations. Dr. Davies quoted two specific examples that related to FEAC's letter of February 14 to Dr. Happer:

> "To provide U.S. industry with the knowledge of fusion requirements and to secure the maximum benefit from industrial involvement, the DOE should develop a plan that deliberately includes a broader and more integral industrial participation in the fusion program . . . . "

In response, work had already started on a white paper that would lead to a U.S. strategy for industrial involvement in fusion. The white paper would be writen by Dr. Bennett Miller.

> "The role of industry in the U.S. fusion program should be strengthened in order to prepare industry for the major ITER-construction tasks . . . . "

In response, the U.S. ITER Industry Council had met on March 3, 1992 to provide advice to Dr. Alex Glass, the U.S. ITER Home Team Leader. Agreement had been reached on an industry contracting approach during the EDA phase. Implementation was underway and multiple R&D subcontracts would be issued under the supervision of MIT, ANL, SNL and ORNL. A design consortium was being established that would be supervised by LLNL.

Dr. Weitzner asked when the ITER agreement was likely to be signed. Dr. Davies responded that the U.S. document was still in the State Department collecting the necessary signatures. She continued that a lot of signatures were needed and hence the process was lengthy. However, no real problems had emerged. The EC had indicated that it would have its process completed by the end of April, and the Russians had stated the same thing. It appeared that the Japanese had run into trouble in a number of areas but Dr. Davies was confident that if the other three parties reached agreement, then the Japanese would find a way to move their process along.

Dr. Davies presented the status of the inertial fusion energy program. The reactor studies had been completed and the final report was in preparation. The ILSE physics design had been completed and reviewed. The departmental mission need-statement had been approved and ILSE KD-0 had been completed. The ILSE conceptual design was underway and the engineering design report was scheduled for completion by mid April. She indicated that the Department of Energy would conduct a cost review this spring and decide if the program could be included in the FY94 budget.

Dr. Conn asked for clarification of the role of the design team within the ITER Home Team. In particular, what was the purpose of the Home Design Team and how did it relate to that of the Central Design Team? Dr. Davies responded that the detailed analysis work would be carried out by one or more of the home design teams. She indicated that Dr. Rebut, Director Designate of the EDA, opposed this and wanted a stronger Central design Team. Dr. Conn stated that it was still not clear what the Home Design Teams would do. Dr. Davies responded that their main tasks would involve systems integration.

Dr. McCrory asked what the Secretary of Energy saw as an incentive to industry to participate in the fusion program and to share the costs of that program. Dr. Decker answered that the other projects in which costs were being shared with the Department of Energy had been dealt with on a case-by-case basis and that the incentives had varied. No specific case existed for fusion, since the program has not yet progressed to the necessary stage. There was thus no precedent within the program which might suggest what a suitable incentive might be.

Referring to ITER, Dr. Overskei asked if he was correct in drawing the conclusion that the design activity would be decoupled from the R&D. Dr. Davies indicated that this was indeed the inference that should be drawn but emphasized that appropriate interaction would occur between the design and R&D activities later in the program. Dr. Conn commented that the issues here were not obvious and would take time and effort to clear up.

Dr. Ripin asked how the construction of ITER would be funded. Dr. Davies replied that although there was agreement on the EDA, and the U.S. would seek a site, there was as yet no strategy with respect to the funding of the construction.

Industry Involvement in Fusion

Dr. Bennett Miller informed the committee that he had been asked by the Department of Energy to examine the preferred nature and extent of U.S. industrial involvement in the fusion program, with particular emphasis on implied policy. He stated that, with the exception of General Atomics', no boardroom policies or resolutions existed to indicate that other companies were involved in the fusion program for the "long haul".

Dr. Miller stated that he had been selected for the task since, while he had some knowledge of fusion, he had no vested interest in the program. He also had considerable experience where industrial participation in government programs was involved. He explained that he had left the field of fusion in 1976 and had moved into the renewable energy development program that had been sponsored by the Department of Energy. However, when the government dollars dried up, industry left the program and it collapsed completely. He stated that the problems that fusion was facing in enticing industry into its program were not fusion's at all but were endemic to the government agency concerned.

Dr. Miller cited two instances from his personal experience of difficulties in industry/government relationships. In the early 1980's he had worked for a small company that had operated within a supportive regulatory environment. However, the regulatory climate changed and caused severe problems for the company. It had survived by moving away from government business because it could not solve the industry/government interface problems. That company was now successful. In the mid 1980's, he had worked for another company that had constructed two large power plants. When the demand for gas and oil decreased the company found itself in difficulty. It would have liked to undertake business with the DOE but, even though the DOE had money available, the agency was unable to get it out into industry.

Dr. Miller provided an indication of how he intended tackling his task. He would not establish a committee, nor seek a consensus. Rather he would talk to whomever it made sense to talk to. He wanted to see the fusion program succeed and asked the members of FEAC for their support should he call upon them.

Dr. Baldwin referred to the transient relationships within the renewable energy development program, and stated that it was heavily based in industry with little involvement of the academic institutions and national laboratories. The fusion program is exactly the opposite, with heavy involvement of the institutions and laboratories. The exchange that is needed here is one from the institutions and laboratories to industry. The question that must be solved is how to involve industry in the program without losing strength in the national laboratories.

Review of Charge to FEAC

Dr. Conn drew the committee's attention to the Letter of Charge of September 24, 1991 and reviewed the matters for which a response was required from FEAC immediately following the current meeting. He reminded the committee that two financial scenarios were involved, viz. one involving a constant level of effort, and another in which 5% real growth occurred. Of particular concern to this meeting was the manner in which the "gap" between the completion of the TFTR program and the start up of ITER should be dealt with, bearing in mind that the interim device should fit into the international fusion program.

Dr. Conn referred to the letter that he had written on November 18, 1991 to Dr. Baldwin and Dr. Sheffield, co-chairs of Panel II, in which he had made clear the terms of reference for Panel II. In particular, he drew attention to the following three paragraphs in the letter since these referred to matters that FEAC should take into consideration while arriving at its recommendations:

> "Assuming that ITER proceeds to construction, what should the US fusion program contain in the year 2000 and how should it evolve through the decade 2000 - 2010? Does that vision have resiliency against the possibility that ITER is not constructed? If not, how could its resiliency be enhanced?
>
> Even with the assumed increases, it appears that the US fusion budget will lag behind the European and Japanese programs. How can the US make the most effective use of these larger programs and, at the same time, continue to influence and impact the world program?
>
> What is the preferred timing of the needed program elements during this decade in order to leave us in a strong position at the end of the decade? This is an issue of balancing short and long term demands."

Panel II Report

Dr. Baldwin presented the principal findings of Panel II and made frequent reference to the work of the national New Initiatives Task Force that had been chaired by Dr. Sheffield. He stated that issues of cost constraint had played a major part in the panel's discussions; in particular, how to develop a project that made sense within the available funding envelope. The panel had concluded that a viable device that would address a meaningful SS/AT (steady state, advanced tokamak) mission could be built for about $400 million in FY92 dollars, if credits associated with the TFTR site were taken into account. Typical of the site credits that had been considered were neutral beam power systems.

The panel had considered it critical that the TPX come into operation in 1999-2000, both to maintain the vitality of the U.S. fusion program and to maximize its contribution to ITER, since there is no existing or planned facility anywhere in the world capable of conducting the integrated development of advanced tokamak physics in steady-state. One or other of the Japanese and European stellarators should operate at the same time as TPX to provide a comparison, and to address two aspects of the FPAC plan that calls for a steady-state experiment and experiments focussed on concept improvements.

The panel had been asked to determine priorities for existing facilities in the post-TFTR program. Dr. Baldwin explained that the panel had been reluctant to do this since the question had been asked late in the process after many groups had already been interviewed. To have done this properly would have entailed starting over again and would have prevented a timely conclusion to the panel's work. Nevertheless the panel had recognized that parts of the SS/AT mission could have been addressed on existing facilities but that the combined contributions would still have fallen short of the full, integrated SS/AT mission. The capabilities of the existing machines frequently overlapped each other, and also overlapped the proposed TPX, but TPX was the only steady-state machine. The panel had supported a timely and full implementation of the TFTR D-T program and a continuation of a strong DIII-D program in support of ITER, TPX and tokamak physics development.

Dr. Baldwin continued that the panel believed that a specially constituted technical panel should be chartered to evaluate and recommend priorities for the medium-term confinement program, to approximately 1998. Dr. Conn asked if the panel was recommending a review of all the machines. Dr. Baldwin responded that this was indeed what the panel was recommending since the members considered that most, if not all, of the issues that could be covered by the other machines could be undertaken on a modified DIII-D facility. Dr. Weitzner asked if the panel viewed this as a budget necessity. Dr. Baldwin replied in the affirmative.

Dr. Overskei pointed out that FEAC needed to bear in mind that this charge to the panel was restricted to filling the gap in the confinement systems area only, and did not relate to the U.S. fusion program as a whole.

Dr. Dean pointed out that there were two distinct issues here related respectively to the D-T program and to the advanced physics program. Dr. Conn stated that FEAC should concern itself with what it wanted to recommend to DOE concerning these issues. He indicated that FEAC would discuss this during the meeting, adding that the problem itself was much broader than the issues that the panel had addressed. However, he suggested that, in the interest of expediency, FEAC should confine the present discussion to the matters that the panel had addressed.

Extensive discussion followed on the breadth of the panel's scope. Dr. Berkner indicated that he was concerned that there were too many panels and too few decisions. The need was to get the fusion program back on track. To do this, FEAC should make some decisions. Dr. Rosenbluth pointed out that it was FEAC's role to advise the DOE; he recommended changing one of the panel's priorities to read: "In collaboration with FEAC, the DOE should establish an orderly plan for the conduct of a national program involving fewer, larger facilities as the necessity for larger scale compels phasing-out some of the existing ones."

Dr. Conn raised the question of how much review FEAC was going to do before making recommendations. Dr. Baldwin responded that tackling the issue of fewer, larger facilities would be very difficult and time consuming.

Turning to the nuclear phase of fusion development, Dr. Baldwin stated that the panel had suggested that the site chosen as the U.S candidate for ITER construction could serve as a suitable site for other nuclear facilities, as well as a site ultimately for the U.S. DEMO. With respect to the resiliency of the U.S. program to ITER's future, Dr. Baldwin indicated that the SS/AT issues that were intended to be addressed by TPX would still have great program significance without ITER. However, the loss of ITER would necessitate the construction of new nuclear-capable (D-T) tokamaks for steady burn experiments, and the replacement in some program of the important element of integration that was to have been investigated in ITER.

Dr. Parker stated that since the panel had considered that the steady burn experiment (SBX) would be useful if ITER was constructed, and that the SBX would be essential if ITER was not constructed, why had the panel not included the SBX capability in its recommendations for TPX? Dr. Baldwin replied that cost constraints had been responsible for the omission. Dr. Parker pressed the issue, asking if the panel had reviewed the charge solely with the financial constraints in mind. Dr. Baldwin responded that this was so. Dr. Parker indicated that in the original letter of charge, the maximum cost envelope had contained an increase of 5% above cost-of-living. Today, the committee had been presented with a cost enveolpe that contained an increase of 9% above cost-of-living. He questioned the wisdom of charting a course based upon a figure that had now changed and might change again. Dr. Conn said that he would like the DOE to consider this uncertainty and advise FEAC. Dr. Davies responded that the growth percentage was based upon a $400 million device and not upon a $600-700 million device. The DOE felt that a project at $400 million was appropriate at the present time and the Secretary of Energy and Dr. Happer were aware of this. If FEAC wished to recommend a more expensive machine, it was at liberty to do so, but that was not what had been asked for.

Dr. Baldwin emphasized that the "integration" loss would be serious if ITER did not proceed to construction. Dr. Weitzner added that it was not just the integration loss that would be serious but that there would be significant high-Q physics losses and other important losses as well. Dr. Baldwin concurred.

Dr. Parker pointed out that Panel II had combined two elements of the strategy suggested by FPAC in their recommended program, viz. a steady-state facility and an advanced tokamak facility. He asked which issue the panel had viewed as being the more important? And, could the issues be separated? Dr. Baldwin responded that the panel had viewed the coupling of the advanced tokamak facility within a steady-state regime as being the factor of prime importance. The answer therefore was that the panel viewed both issues as being equally important.

Dr. Conn asked what were the cost implications of a machine that could provide a 10-seconds pulse length in comparison with one that could provide a 100-seconds pulse length, and again in comparison with the machine that would provide the 1000-seconds pulse length that the panel had recommended? Dr. Sheffield responded that this issue would be dealt with in detail later in the day and said that he would prefer it if the committee would wait until later for the answer.

Dr. Rosenbluth asked if the panel had reviewed the relative merits of a superconducting machine and a resistive machine. Dr. Baldwin responded that the DOE needed a mission that was consistent with the cost envelope. It had not asked for a recommendation on what sort of magnets to use. Dr. Sheffield amplified this response indicating that Panel II had kept within the constraints that had been placed upon it. It was up to FEAC to make the connection between the panel's recommendations and the National Energy Strategy. He emphasized that Panel II had not discussed strategy, cost, and budgets, nor whether DEMO would be on time.

Report of the New Initiative Task Force

Dr. Sheffield, Chairman of the New Initiative Task Force, presented the task force's report to FEAC. The task force had been appointed by Dr. Ron Davidson, Director of PPPL. It was charged with providing oversight and ensuring broad national participation in the development of design concepts for a new experimental device in the $400 million (FY92) class that would investigate improvements in tokamak plasma regimes with a view to development of a more economically attractive DEMO, that would support ITER, and that would provide a scientific focus with which to maintain the vitality of the national program. The task force was also asked to provide technical guidance on the programmatic mission and technical objectives of such a device, on critical physics issues relating to plasma configuration and operating mode, on critical engineering and technology issues, on criteria for technical evaluation of candidate concepts, and on a methodology for costing candidate concepts.

Dr. Sheffield said that the task force had looked at three categories of devices. These were:

- SSAT: A steady-state advanced tokamak to develop improved performance (H-D and maybe D-T).
- BPX-AT: A reduced cost version of BPX, with D-T operation, capitalizing on potential for improved performance.
- SBX: A steady burn experiment having an SSAT mission as its first phase, and full D-T operation (Q ~ 1) as its second phase.

Dr. Weitzner asked if just those three variants had been looked at, and who had selected them. Dr. Sheffield responded that a number of different variants had been looked at, some of which had eventually merged together. The task force had ended up with four "white papers"; "advocates" of each device had fueled the process. Dr. Weitzner asked if all of the variants had emerged as a result of addressing a common mission statement, or whether no restriction had been placed upon the process. Dr. Sheffield responded that the fusion community had been asked to indicate what it considered was the most important machine, at $400 million, that would advance the tokamak physics program. He pointed out that the task force had not been asked to consider alternative paths for the U.S. program, such as higher-cost programs or a combination of lower-cost programs, new devices and up-grades, or alternatives to the tokamak. Most of the proposals that the task force had received pointed to a steady-state machine. Some of the proposals offered additional features, for example significant D-T operation.

Dr. Sheffield reviewed the task force's findings for each of the three machines, and started with the SSAT, which was the machine that the task force had preferred. Dr. Conn asked if the task force had done enough work during its review process and if Dr. Sheffield was confident that the costs of the project would not escalate. Dr. Sheffield responded that he thought the task force had done a very thorough job. He did not think that the cost would escalate very much and would certainly not exceed $500 million (FY92). Dr. Davidson added that the task force had used a fairly rigid set of algorithms for the costing process. He anticipated that the cost would be correct to within 10%. He stated that the same algorithms had been used at PPPL to cost BPX and that the result had agreed with that of an estimate made by an independent source to within 1.5%.

Dr. Parker asked if the task force had provided costing for equipment and a program that the U.S. would not be happy with. Dr. Sheffield answered that he had no doubt that in time a lot more money would be spent on the project than was presently contemplated. For example, at an on-going rate for the operating program of $100 million per year plus construction, the total cost would be about $1.5 billion over 10 years. Equipment up-grades would be included in this expenditure. Dr. Sheffield anticipated that up-grades would occur almost every year; he pointed out that, historically, this was what had occurred in the fusion program. He expected the new machine would be started up for about $400 million (FY92 dollars) but one would then seek the best means of heating, implementation of which would require up-grades, possibly followed by improvements in diagnostics, requiring further up-grades, and so on.

Dr. Weitzner asked if the proposed machine would achieve the 1000-second pulse length with inductive drive. Dr. Sheffield gave a negative answer and indicated that current drive would be used. Dr. McCrory asked what factor drove the 1000-second limit? Dr. Sheffield responded that it was not a limit: The pulse length was determined by the present cryogenic capabilities of the TFTR beam lines. These would permit eight shots of 16 minutes duration each to be undertaken in a day. Dr. Parker asked how long it took to regenerate the system. Dr. Keith Thomassen (in the audience) responded that it would take about a day. Dr. Sheffield continued that superconducting and resistive copper coil variants appeared feasible: Copper coils could be water cooled and could also provide true steady-state operation.

Dr. Sheffield stated that the task force had reviewed the capabilities of present machines, worldwide, in relation to TPX/SSAT, and had added to the review the latest information from overseas laboratories concerning their up-grade intentions. He provided a table showing what the U.S. understood had been committed. Dr. Conn pointed out that the Japanese had no firm plans for the device beyond the JT-60 up-grade at present. He stressed that FEAC should not assume that if the U.S. chooses not to pursue a certain path, the Japanese will fill the gap. Dr. Parker asked if there were any plans to put a divertor in Tore Supra. Dr. Sheffield responded that there were none.

Dr. Sheffield then turned to the findings on the BPX-AT machine, the primary mission of which was to produce short-pulse Q-values of about 5. It would be an inertially-cooled machine which would permit an advanced tokamak program to be undertaken at reduced field with pulses of about 400-seconds duration. The consensus of the task force was that this was an interesting alternative but one that, even in its primary phase, would fall outside the cost guidelines.

Dr. Sheffield described the SBX device as one with a primary mission of steady-state Q~1 nuclear testing at the 0.1 MW-yr/m^2 level; this level was comparable with that planned for ITER. Such a machine would require a new site, since the fluence was too high for the PPPL site. Since the machine would exceed $400 million and would require a new site, the task force viewed it as falling outside its charter although it appeared to present an interesting longer-term concept. Dr. Weitzner asked why the cost for this machine should be higher than for the others. Dr. Sheffield responded that the cost of the infrastructure required at a green field site must be added to the device cost, together with the cost of providing higher-energy neutral beams. Dr. Conn asked for the value of the true site credits at PPPL. Dr. Davidson responded that, excluding the buildings, the site credits had been estimated at $260 million. Dr. Parker added that the buildings had been valued at $100 million. Dr. Overskei raised the issue of site credits with respect to equipment. He pointed out that the equipment was going to be taken apart and moved anyway, even if it remained on the same site. He suggested that the equipment credits should be viewed as program credits rather than as true site credits; The equipment just happened to be at PPPL.

Dr. Sheffield reviewed lower cost options and indicated that the task force had concluded that it would not be possible to provide the minimum elements of the combined advanced-tokamak/steady-state mission within a significantly reduced cost ceiling. Dr. Sheffield then presented a summary table that compared the capabilities of the devices that had been reviewed.

Dr. Ripin asked, if the SSAT mission was the one that was pursued, and if it was subsequently wished to introduce tritium into the machine for a small number of shots, would this change in program be consistent with the PPPL site? Dr. Sheffield responded that it would be possible to make this change provided that it was not of such a magnitude that it would interfere with the overall mission. Dr. Berkner asked what rationale he could use to "sell" a new $400 million machine to his colleagues? He pointed out that the fusion program was already supported by ITER. What was it that this machine would do that was unique? Dr. Sheffield responded that ITER will be relatively inflexible. The proposed $400 million machine would be very flexible and the program would not be restricted throughout its life-time by its initial characteristics. For example, the machine could be used to check out different current drives quickly and relatively inexpensively.

Mission and Role of a Steady-State Advanced Tokamak

Dr. Robert Goldston of the TPX Core Physics Team presented the rationale for an SSAT and summarized the role of such a machine. He discussed steady-state advanced concepts including steady-state power and particle handling, steady-state current drive with high bootstrap fraction, disruption control, extended energy confinement times and high β. He pointed out that there were no steady-state divertor tokamaks in the world program but that two stellarators were planned. Dr. Parker asked if Dr. Goldston would define the difference between the ITER and DEMO loads. Dr. Goldston provided numbers that indicated that the DEMO divertor power load would be 3 to 4 times that of ITER. Dr. Parker then asked if part of the mission of the SSAT was to assist with the development of ITER and of DEMO? Dr. Goldston responded that this was so.

Dr. Goldston reviewed the steady-state mission elements of the program. Dr. Parker asked if the maximum value of 10^6 sec/year quoted for high duty factor operation was the site limit. Dr. Goldston responded that it was. Dr. Parker then asked why it was intended to run at lower than this maximum value. Dr. Goldston indicated that the value of 2×10^6 sec/year indicated in the program had been selected due to the need to develop and establish a maintenance regime. Dr. Parker then requested confirmation that once the maintenance regime had been established, it would be possible to go to the full site limit. Dr. Goldston responded that this would indeed be so.

Dr. Goldston continued by reviewing the advanced-tokamak mission elements of the program, which comprised steady-state operation with ~66% bootstrap current fraction in the first stability regime, high aspect-ratio operation, second stable regime operation with ~90% bootstrap current, and steady-state high β and enhanced confinement modes. He concluded that an AT reactor would be an attractive addition to the fusion program. Dr. Goldston provided a table of comparison between the characteristics of several machines: The ITER CDA machine, ITER at the β limit, a standard reactor, a small AT reactor and a larger AT reactor. He concluded by summarizing the status of steady-state issues, particularly with respect to power and particle control.

Dr. Parker asked if the topics that had been discussed really represented advanced concepts or whether they were prosaic? Dr. Goldston responded that the concepts were not prosaic at all; it was essential that they be explored. He presented additional data that summarized the capabilities of existing fusion devices and that outlined the advanced tokamak physics of which they were capable. Dr. Overskei commented that the advanced tokamak physics that had been presented was particularly subjective and that some of the presumptions were very questionable.

Dr. Conn said that the presentation implied that other machines could address parts of the advanced tokamak physics issues, but not for operating times of meaningful duration. He questioned whether the base of knowledge gleaned from these machines and from ITER as well, would be sufficient to permit a sound translation to DEMO. Dr. Goldston did not think so; he considered that the program needed the long operating times that the proposed SSAT machine would provide.

Dr. Parker asked Dr. Goldston, how confident would he be, following completion of the proposed program, in making the extrapolation from 1 MA to 12-14 MA in a fusion machine? Dr. Goldston responded that issues of which he was not currently aware might arise at high current. However, he was confident that the proposed machine would be able to address all of the physics issues that are presently known to require investigation.

Dr. Parker stated that the SSAT relied very heavily upon high bootstrap current. He asked how it was intended to achieve this? Lengthy discussion led to no clear cut answer. Dr. Conn did point out, however, that aspect ratio is critical to bootstrap current. Dr. Overskei criticised the presentation for dwelling upon what already existed. He said that only two points had been made concerning what the new machine would do. He suggested that it would help if future presentations made the assumption that FEAC was familiar with what had already been done and concentrated instead on what such a new machine could accomplish.

Change of Agenda

Dr. Conn opened the afternoon session by saying that, over the lunch break, FEAC had decided to change the meeting agenda in order to provide more time for deliberations. He indicated that rather than receive the presentations that had been planned for the afternoon, the co-chairmen of Panel II would answer FEAC's questions. He apologised to Dr. Keith Thomassen and Dr. Bruce Montgomery for this change which affected their prepared presentations.

Discussion of Panel II Findings

Dr. McCrory asked what the strongest arguments were for adopting the 1000 second pulse length for the new machine. Dr. Sheffield responded that the SSAT would be designed for steady-state operation: A pulse length of 1000 seconds was only the first step to steady-state. Many time periods are important in a reactor. MHD times are short. A key time is the "skin time" which in SSAT leads to an equilibration time of about 200 seconds. Other times, for example wall-effect times which involve outgassing, can be longer. While one can define a timescale for a reactor, one cannot determine what are likely to be all the time-dependent effects. Impurity formation and interaction with the divertor are important factors.

Dr. McCrory asked what the SSAT could do that ITER could not. Dr. Sheffield replied that the SSAT could be used to develop a divertor to handle the heat loads expected in ITER and DEMO. Dr. Baldwin added that two small tokamaks had already been operated for prolonged periods. In each machine, the plasma "wandered" for 10 minutes or more before settling down. The national laboratories had addressed a class of issues that would be relevant to any tokamak. These would probably be addressed in ITER. The SSAT would address an entirely different class of problems, all of which would be affected by current profile control. Dr. Goldston interjected that the difference in cost between a machine with a 200-seconds pulse length and one with a 1000-seconds pulse length was negligible: But, effects due to pulse lengths of 1000-seconds have never been looked at. Dr. Thomassen added that, since the problem areas with existing machines were known, it would be possible to avoid these in the new machine.

Dr. Ripin asked if the shorter-time issues of existing physics problems could be investigated on present machines, possibly after suitable up-grading, and longer-time issues be investigated on ITER. Dr. Sheffield responded that ITER will not be operational until later than 2005. Furthermore, there was no clear provision yet for current profile control on ITER. Dr. Ripin then asked if adding extra physics tasks to ITER's mission would affect its technical mission. Dr. Baldwin answered affirmatively. Dr. Sheffield added that if one had been able, early enough, to undertake tests concerning current drive on a machine like the SSAT and had obtained good results, then one would certainly have applied those results to ITER: The situation for divertor testing would be similar.

Dr. Conn asked the panel's co-chairmen to make their best argument for how the proposed machine would fit into the fusion program, in particular with repect to ITER and with a view to making fusion reactors better. Dr. Baldwin responded that ITER would be designed based on widely accepted data and presently known physics, and would operate in the first confinement regime. If one was to design DEMO using these same rules, then one would end up with a machine that was substantially larger than one was prepared to contemplate at present. The proposed SSAT machine would provide data that would result in a DEMO of more acceptable size. The mission of the smaller machine kept getting confused by looking at everything else that it might do. Whether ITER went forward to construction or not, the smaller machine still made good sense. If ITER was not constructed, then the program would need another machine to do what ITER was intended to do. Dr. Sheffield emphasized the sheer physical magnitude of ITER. It would be an inflexible machine that would be handled fully remotely. It would be difficult, expensive and time consuming to modify it. The SSAT had no such restrictions.

Dr. Overskei raised the question of profile control, for both pressure and current, in the SSAT. He indicated that beams were being proposed for this, which would require large sources. He claimed that the beam width would be a substantial fraction of the plasma diameter. Hence, why did the New Initiative Task Force feel that beams would help when they would provide merely crude control over the pressure and current profiles? Dr. Sheffield conceded that this was a good point that the task force had not had time to explore in depth. He pointed out, however, that it was hoped the machine could capitalize on bootstrap current to the extent that only a small injected power would be required; later, RF drive would be added.

Dr. McCrory asked if the SSAT would be sufficiently user-friendly that the heating scheme could be changed on a timescale of weeks? Dr. Sheffield replied that it would not. He anticipated, however, that once the machine was fully established, combinations of heating regimes would be available.

Dr. Weitzner returned to the issue of cost comparisons for machines with a 200-seconds-pulse length versus a 1000-seconds pulse length. He asked specifically what one could expect to get for $300 million. Dr. Thomassen, from the audience, responded that the machine that was being proposed was the smallest that everyone was happy with: But, its cost was estimated at $430 million and not $400 million. Dr. Sheffield added that it would be difficult to reduce the cost by $30 million since $50 million was one third of the cost of the tokamak, if the heating and peripherals were ignored.

Dr. Conn asked why was it always machine size that was related to cost? He pointed out that there were many peripheral systems that could be eliminated to bring down the cost of the machine without reducing the size of the machine itself. Dr. Baldwin agreed that non-size-related reductions were possible: Everything that was going to be required for the program did not have to be in place on "day one", but enough had to be there to make the machine operable in a worthwhile manner. It would always be possible to up-grade the facility later. What was undertaken when, and at what cost, was a matter of judgement. Dr. Sheffield added that one could, for example, elect to handle half of the ITER divertor load in the machine rather than the full load.

Dr. Conn asked what was the highest priority issue for the machine? He suggested that it was possible that the ITER divertor load problem could be tackled in a machine other than a tokamak. Dr. Sheffield responded that the mission of the machine was to investigate DEMO-relevant scenarios.

Dr. Holdren stated that there was a potential conflict of rationales between ITER and the proposed advanced tokamak, for example with regard to divertor loads and current control. It would make most sense to undertake the mission of the smaller machine first and then to pursue ignition and systems integration in ITER. Dr. Baldwin responded that the decision to participate in ITER was taken in order to "internationalize" the program and to share cost: This had led to a conservatism in the approach to the machine since it was necessary to obtain the agreement of all parties on each issue. Progress was much slower than for a national program, and would be more costly overall. But, the U.S would pay for one quarter of the project only, which would still be much less expensive than if the U.S. undertook the entire program as a national project. He continued that the U.S. would be pursuing a more aggressive program if it were proceeding alone: It was simply not possible to obtain the same degree of program flexibility and rapid response time from an international program that one had come to expect from a national program.

Dr. Rosenbluth stated that if one were to use the SSAT machine to investigate all of the possible variations before starting to use ITER, the proposed start of ITER would have to be postponed. Dr. Holdren countered that the U.S. Congress would question why everything should be completed before the start up of ITER and would suggest just pushing on with ITER, regardless. Dr. Sheffield stated that if a concept did not work, it would be better to have it fail on a small machine rather than on ITER. Dr. Conn said that if the fusion program wished to start up DEMO in 2025, then ITER was needed now! He stressed that ITER cannot afford to fail, and that was the main reason it would be built conservatively.

Dr. Holdren pointed out that ITER would leave the world fusion community with significant shortfalls: ITER would not provide all the information required in a variety of fusion physics problem areas. Neither would ITER fulfil all of the nuclear technology requirements. In fact, the biggest gap in knowledge could be in technology and not in physics. Fusion had other machines that could provide needed answers in physics but had little hardware that would help with nuclear technology testing. Dr. Baldwin stated that every letter from FEAC to the Director of Energy Research had dealt with technology/materials issues. However, the physics issues were more exciting and must lead the program, even though technology issues, and low activiation materials in particular, are vital to the development of fusion energy.

Dr. Holdren stressed that the fusion program had yet to make a start on fusion technology but still was determined to dot all the "i's" and cross all the "t's" in physics. Dr. Sheffield concurred, adding that ITER would not address all the technology issues in depth. He concluded that FEAC needed to flesh out the entire strategy for the U.S. fusion program.

Dr. McCrory asked what the mission of the SSAT was, and what was viewed as the highest priority task. Furthermore, what were its second and third priorities? Dr. Goldston responded that the need was to develop and investigate steady-state advanced tokamak operating modes. Dr. Thomassen added that the ultimate goal was to permit the construction of a smaller, better and less expensive DEMO with higher β, better confinement and higher bootstrap current. Dr. McCrory commented that this mission did not excite him. Dr. Thomassen responded that, exciting or not, that was the mission that the program needed.

Dr. Conn stated that the significant impact of this machine will be to lower the cost of the core of a fusion reactor. Dr. McCrory asked why it was necessary to start now. Why not wait? Dr. Conn replied that if the results from a new machine were to have an impact on a device that was due to operate in 2025, then that machine was needed now. If one was prepared to permit the start date for DEMO to slip, then one could delay the start date for the SSAT by an equal period of time. But, if one wished to retain the start date for DEMO and not build the SSAT, then the DEMO device would be a very expensive one indeed.

Dr. Dean commented that from the U.S. fusion physics community's point of view, it was far more important that the proposed program be undertaken in a small U.S. machine than in ITER. The advantages of the small machine were rapid response time, modest cost and ready access since it would be under U.S. control. He reminded the committee that there was still the issue of the technology machine to be dealt with. He pointed out the inflexibility of ITER and claimed that ITER was of lesser importance to the U.S.

Public Comment

Dr. Bill Fulkerson, Oak Ridge National Laboratory, discussed the ORNL point of view on the direction of the U.S. fusion program. He provided the members of FEAC with a written outline of his remarks. In summary, these called for the early establishment of a national nuclear site at which to focus the U.S. development of fusion technology. He suggested that the national site be the home for the next major facility built by the U.S. fusion program and, in fact, that this facility should be a nuclear technology machine such as that proposed for the "steady burn experiment" (SBX). He considered that building the SSAT at a non-nuclear qualified site would be an extravagance that the U.S. fusion program could not afford, and that would foreclose future options for a significant time and make declining budgets more likely. The nuclear site, on the other hand, could also be used to house ITER, DEMO and a 14 MeV neutron source.

Since the course that Dr. Fulkerson was advocating would involve spending more than $400 million on the SSAT, Dr. Weitzner asked Dr. Fulkerson what he would suggest FEAC should do regarding the $400 million budget constraint. Dr. Fulkerson replied that FEAC should ignore it: FEAC should recommend what was in the best interests of the U.S. program.

Dr. Rosenbluth asked whether ORNL would present itself as a candidate if the U.S. were to decide to look for a site for ITER. Dr. Fulkerson responded that ORNL would look hard at whether it could supply the site but he felt it was possible that it could not. He stressed, however, that there simply had to be a suitable site somewhere in the USA. Dr. Conn asked how ORNL had fared as a potential site for BPX. Dr. Fulkerson responded that ORNL had been considered a good site for BPX. He pointed out, however, that the proposed national site must house the SSAT, DEMO, a 14 MeV source and possibly ITER; it must therefore be a very large site.

Dr. Dean referred to the wisdom of responding seriously to the DOE within the present guidelines. He indicated that both FEAC and FPAC had suggested that the fusion budget be increased, but to no avail. He asked why one should expect FEAC to exert any greater influence now? Dr. Fulkerson responded that the U.S. must have excitement in the fusion program. The states should be encouraged to compete for the national site, and there should be a competition for the design and construction of the machine. These competitions would raise the enthusiasm of the nation for the fusion program which, in turn, could lead to increased budgets.

Dr. Overskei stated that the institutional, personnel and cost assets, although not necessarily the hardware assets, of the fusion program must be protected at one major site, possibly PPPL. Adding a national site would make this task more difficult. Dr. Fulkerson agreed and raised the possibility of establishing a non-profit corporation, led by PPPL with industry partners, to accomplish this. But, he stressed that in the future there would be support for fewer, larger fusion-oriented institutions.

Dr. Davidson said that he was in favor of seeking a candidate site for ITER. He added that in his presentation, Dr. Fulkerson had made SBX the "driver" for that site. He asked Dr. Fulkerson where his priorities lay. Dr. Fulkerson stressed that all of the new machines must be capable of being constructed on one site. The site must permit the U.S. to pursue its own program. He added that he would like to see two small U.S. machines on the site - a physics machine and a technology machine - but realized that the U.S. could not afford both. Dr. Davidson stated that ITER should drive the site. Dr. Fulkerson responded that if the U.S. was unsuccessful in winning the ITER site competition, then nothing would go on the site and it would generate no excitement.

Dr. Davidson then suggested that one could start by constructing the 14 MeV source at the site. He asked why it was necessary that the SSAT machine be first on the site? Dr. Fulkerson responded that the SSAT machine was the U.S. program's first priority. The subsequent conversion to SBX that had been suggested for the machine was critical to the fusion program. The SSAT must therefore be constructed at a nuclear qualified site and not at one that wasn't. Dr. Overskei asked Dr. Fulkerson for clarification that he was in fact suggesting that TPX should start out as presently envisaged but be capable of up-grading for D-T operation at a later time. Dr. Fulkerson answered affirmatively. Dr. Ripin expressed concern that the establishment of such a site would give the U.S.'s ITER partners the impression that the U.S. was not seriously interested in ITER and was preparing to pursue its own destiny. Also, preparing the site would add to the cost of the fusion program at a time when ITER was going to require more financial support also.

Dr. McCrory referred to the suggestion that a nuclear mission should be added to the physics mission of the next machine. The initial cost of the machine and site would far exceed the budget. Splitting the physics and nuclear missions would enable one machine to go forward now. Dr. Fulkerson agreed with this logic but reiterated that two machines would then be needed and he doubted that the U.S. could afford two machines. In his opinion, it would be better to construct the machine for an initial physics mission but to ensure that it was capable, subsequently, of up-grading to a technology mission. However, such a machine must be constructed on a nuclear site. Dr. Sheffield interjected that FEAC would need to look carefully at the level of funding that could be obtained for the fusion program and at the amount of money that the site would consume. Dr. Dean stated that he doubted whether the proposed machine could fulfil all it was claimed it would. He suggested that missions involving physics, burning physics and technology would actually require three machines. The fusion program should take the $400 million opportunity now, and worry about other matters later.

Dr. Ronald R. Parker, Massachusetts Institute of Technology, asked if he could make a number of remarks to FEAC concerning the proposed new machine, as part of the session for Public Comments. He stated that the steady-state tokamak should be driven by a programmatic need rather than as a goal unto itself. The steady-state and advanced tokamak components of the mission were in conflict. The advanced tokamak mission should receive priority. He pointed out that the AT issues that were being considered were compatible with the timescale of resistive diffusion rather than the timescale involved with wall-heating physics issues. An inertially cooled device could therefore be used to satisfy the requirements of an AT mission since such a machine would provide pulse lenghts of a few skin times which would be more than sufficient for the program. Placing emphasis on an AT mission in this manner would yield substantial cost savings, since a device that employed inertial cooling would be relatively inexpensive. Dr. Parker provided a cost estimate, that totalled $281 million, for an inertially-cooled machine of 1.6 meters major radius and a pulse length of between 100 and 200 seconds.

Dr. Goldston questioned the validity of the cost figures that Dr. Parker had presented. The resulting discussion reached no clear conclusion.

Dr. Dean asked if Panel II had considered the inertially-cooled machine in its review, and if the panel had looked at the possibility of treating the steady-state and advanced tokamak aspects as separate issues. Dr. Baldwin responded that the panel had felt that the steady-state and advanced tokamak features should be combined in a single machine. Dr. Dean stated that the cost of the machine that was finally agreed upon was not as important as ensuring that the next step taken by the program was the correct one. Dr. Baldwin emphasized that the reaction of the panel to the inertially-cooled device was that it looked very much like an up-graded DIII-D machine. Dr. Parker disagreed, stating that the machine that he was proposing had much more capability than DIII-D.

Dr. Ripin asked why the AT mission was considered to be the most important one. He asked that it be put into context. Dr. Parker replied that the AT mission was important from the physics point of view. However, the mission could be undertaken in a less expensive machine than the proposed SSAT machine. He continued that it was the SBX mission that drove the requirement for steady-state operation. Hence, the steady-state mission should be a part of the SBX program. However, the SBX program would not incorporate an advanced physics mission; rather, the SBX device would be used for advanced technology testing. Dr. Conn pointed out that because in this scenario two machnies would be involved, the SS and AT missions would not be phased but could run concurrently, in contrast to Dr. Fulkerson's proposal.

Dr. Ripin asked how Dr. Parker envisaged that the machine that he was proposing, even though its projected cost was lower than that of the SSAT, would help to overcome the budgetary problems that FEAC was facing, when it would necessitate the construction of a second machine with SBX capability. The total dollars involved in this scenario were greater than for the one in which the SSAT stood alone. Dr. Parker responded that he was no more clairvoyant than anyone else but suggested that what a program eventually received was somewhat dependent upon what the program asked for.

Dr. Dean summarized that if the steady-state and advanced tokamak missions were separated, and the steady-state mission was included in that of the SBX device, the SBX machine would in effect become the parallel test machine that was discussed at the last FEAC meeting. Dr. Parker agreed with Dr. Dean's conclusion. Dr. McCrory commented that the steady-state mission was not very compelling and would be difficult to "sell". Dr. Parker agreed that the advanced tokamak mission was the compelling part of the program. Dr. McCrory asked Dr. Parker if he considered that the cost of the SSAT was too high. Dr. Parker said that in his opinion it was.

Dr. Parker indicated that the SBX should be viewed as a national initiative supporting ITER and DEMO. He reviewed the timescale for ITER, the relationship between ITER and DEMO, and where the SBX would contribute. Dr. Weitzner indicated that he was unhappy with the magnitude of the combined budgets for the SBX and ATX machines. Dr. Parker responded that ITER would unlock more funding for the fusion program: If it did not, then the U.S. would have no meaningful fusion program. Dr. Goldston questioned the proposed timeframe for the SBX, indicating that it would be too late to contribute, for example, to the solution of the divertor problem. Dr. Parker responded that the divertor problem would be tackled in machines other than the SBX. Dr. Conn pointed out that in the timetable that Dr. Parker had presented, he had made the assumption that other programs would go forward and be successful in solving the divertor problem and so there would be no need to tackle it in the SBX.

Dr. Parker made a number of recommendations to FEAC concerning the next machine:

- Emphasize the advanced tokamak aspects of the mission.
- Define an inertially-cooled advanced tokamak that would be constructed at Princeton Plasma Physics Laboratory as a PPPL project with national participation.
- Develop the SBX as a national project at a nuclear site.
- Where possible adopt ITER technology approaches so that the SBX effectively becomes an RTDAX.

FEAC Deliberations

Dr. Baldwin referred the meeting to the draft recommendations of the panel that were summarized in the document accompanying the presentation he had made earlier in the day. Dr. Conn pointed out that while these recommendations were not in the panel's report, they were what the panel would have recommended to the Department of Energy if the panel had in fact been the FEAC. He suggested that, as at the last meeting, the committee review each one briefly to determine where agreement existed and where more discussion would be required.

Recommendation #1

This called for an immediate start to the conceptual design of an optimized TPX to meet the SS/AT mission, but observing a budgetary constraint of $400 million when related to FY92 dollars.

Considerable discussion took place over the $400 million constraint, which had emerged from the combination of the SEAB letter and FEAC's charge letter. Dr. Davies indicated that the proposed machine should be viewed as being in the $500 million class at the time of construction. This would ensure that it would not consume all of the financial growth that was likely to be experienced by the program. Dr. Ripin asked to be told the magnitude of the available budget if all of the growth did indeed go into one pot. Dr. Davies responded that, through the year 2000, this would amount to approximately $960 million if current projections were realized.

Dr. McCrory commented that FEAC may not be doing the magnetic fusion community justice by accepting the constraint. Dr. Weitzner emphasized that FEAC should only recommend a program because it was needed, not because it was all that one could afford to do within the constraint. Dr. Conn stressed that FEAC knew what good programs were and that FEAC also knew what had to be done. The question that FEAC needed to answer was whether what needed to be done could be done thoroughly enough to be of value, and of help to ITER.

Dr. Rosenbluth said that he was unhappy with the phraseology used in the recommendation. Dr. Conn responded that the wording would be cleared up later. He was more concerned now with reaching a consensus on the content of the recommendation.

Dr. Dean suggested that FEAC take a vote on whether the machine should pursue an SS/AT mission or should confine itself to an AT mission. This invoked a lengthy discussion over the duration of pulse that should be viewed as being long enough to permit the establishment of steady-state conditions. Dr. Baldwin pointed out that it was intended that the TPX should have a pulse length of 1000 seconds upon initial commissioning and that this should increase to infinity later on. Dr. Weitzner stated that, on technical grounds, it was arguable that a pulse length of 200 seconds could represent steady-state conditions. Dr. Parker agreed that FEAC must define steady-state, adding that a pulse length of 200 seconds represented the break point between an inertially-cooled machine and a superconducting one.

Dr. Sheffield considered that this argument had gone far enough. He stressed that the total value of the integrated program - the capital cost plus the operating cost for 15 years - would exceed $2 billion. Yet FEAC was arguing over $100 million, which was 5% of the entire program, concerning matters which were absolutely vital to DEMO. Dr. Dean pointed out that FEAC did not need to micro-design the machine: It was up to FEAC to provide guidance. Dr. Weitzner countered that there was a big difference between a machine that could provide a pulse length with a minimum of 200 seconds' duration and one with a maximum of 200 seconds' duration.

Dr. Parker commented that, at a total cost of $2 billion, the SS/AT would, to all intents and purposes, be the entire U.S. program over the full life-time of the machine. Dr. Conn disagreed, pointing out that the cost would be spread out over 23 years; eight years for design and construction and a further 15 years for operations. Dr. Dean suggested that perhaps some of the committee members should recuse themselves from the vote since he considered that the discussion had entered into areas where institutional vested interests lay.

Dr. Conn stated that while the SS/AT mission needed to be more clearly defined, it was the correct mission to pursue. He asked whether the committee was ready to vote on the recommendation yet or whether members wished to reflect on matters for a while longer. Dr. Dean said that the AT mission was more important than the SS mission in the early stages.

Dr. Conn pointed out the danger that as time progressed, more and more persons would want more and more to be accomplished by the machine, and that process would force its cost up. He suggested that once FEAC had agreed upon the mission and upon the cost of pursuing that mission, the two should become synonymous. If subsequently an issue arose that, if addressed by the machine, would drive the program cost up, the issue should either be modified to bring it back to an acceptable cost or it should be ignored. Program cost should be inviolate: It should be viewed as an immovable cap. Dr. Parker agreed that this was a good strategy. Once the cap was in place it would force the prioritizing of mission components. He added that his preference was to quantify steady-state in terms of skin relaxation times rather than pulse length.

Dr. Overskei stated that the problem of fiscal responsibility should be combined with that of programmatic responsibility. Dr. Conn commented that this was a good suggestion, but since it related to an operational matter it was not one that FEAC should impose upon DOE. Dr. Overskei said he felt it wrong to call out the $400 million restraint in the letter report that would follow the meeting. He suggested that the restraint should be inserted only when Congress was asked to fund the machine. Dr. Conn disagreed stating that he would be unhappy if FEAC did not establish this number now because it could not be known what would be the future impact upon the balance of the fusion program of a floating number for this project. He reminded the committee members that they had worked with this constraint from the outset; he considered it would be irresponsible for FEAC to abandon it now, possibly opening the way for the SS/AT program to expand to $600 million or so. Dr. Davidson pointed out that the budget would need some flexibility in order to ensure the excellence of the program. Dr. Parker was unhappy with this, stating that the upper limit needed to be fixed: He was concerned that the "the camel would get its nose under the tent". Dr. Conn reiterated that one way to ensure that the upper limit was not exceeded was through the sacrifice of some "day one" capability. He emphasized that any reductions in capability would have to be considered carefully since one ran the risk of losing too much for the machine to be of any value. Dr. Sheffield pointed out that the fusion community had been well aware of the constraints at the time that their proposals had been made. He suggested that the collective views of the community concerning what could be achieved were worth more than those of any one individual.

Dr. Dean considered that there was no need to spell out the $400 million figure in the letter since the DOE was already well aware of it. Dr. Conn disagreed. He stated that the letter should outline the rules under which the panel had operated. Dr. Ripin reminded the committee that Panel II had reviewed five devices, viz. the SS/AT, AT, BPX-AT, SBX and the 14 MeV source. The panel had recommended pursuing the SS/AT, had defined its mission and had conclded that the price was about right. Dr. Conn asked if Dr. Ripin was suggesting that FEAC's letter should state "on the order of $400 million". Dr. Ripin responded affirmatively. Dr. Rosenbluth asked why not use the phrase "in the $500 million class".

Dr. Conn summarized that most of the committee members agreed that a price should be stated and a spending "cap" placed upon the program. He indicated that he had no objection to using the word "about" in the letter but would be unhappy to see a $400 million program balloon to $800 million. Dr. Holdren added that this was a good reason for capping the program. He pointed out that if the budget were to grow at 5% a year, then a $400 million project would still leave room for other programs, such as materials testing, whereas an $800 million project would not.

Dr. McCrory suggested that FEAC take a vote on the $400 million cap. Dr. Conn concurred. The committee voted unanimously to accept the cap but there was no clear consensus on the choice of phraseology - "$400 million" versus "in the $500 million class". Dr. Dean added that he objected to the device being referred to as a national facility.

Recommendation #2

This suggested the pursuit of three priority activities for the U.S. confinement program in the near future: full D-T operation in TFTR, a strong DIII-D program and the design of TPX.

No consensus was reached on the role of DIII-D. Dr. Parker asked if other machines should be added to the list.

Recommendation #3

This suggested that after the FEAC position on alternates had been established, a specially constituted technical panel be chartered to recommend on priorities among the remaining facilities and activities for the medium-term confinement program to 1998; that the total balance in the base program be re-examined; and that an orderly plan be established for the conduct of a national program involving fewer, larger facilities.

Dr. Conn felt that this recommendation was far too broad. He suggested that it be narrowed.

Recommendation #4

This suggested that a low level of design effort continue to be applied to concepts having nuclear capability, either for burning-plasma physics or moderate nuclear testing.

No comments were made.

Recommendation #5

This suggested that the U.S. program develop and implement a strategic plan for the nuclear phase of MFE development, including preparing for selection of a nuclear-capable site, accelerating development of long-life and low-activation materials and their testing in a 14 MeV neutron spectrum, and pursuing related nuclear activities in parallel with ITER.

No comments were made.

Recommendation #6

This suggested that with the adoption of the SS/AT mission, TPX be renamed ASSET - Advanced Steady-State Experimental Tokamak.

No comments were made.

Thursday, March 19, 1992

FEAC Deliberations

Dr. Conn called the meeting to order and stated that, overnight, Dr. Baldwin had prepared a number of viewgraphs relating to Recommendation #1 of Panel II. He said that he would like FEAC to review these and bring to closure the discussion of this recommendation, that had commenced at the end of the previous day, before moving on to review and discuss the remaining recommendations. He indicated the the document that FEAC would publish as a result of this meeting would have only the report of Panel II appended to it. The report of the New Initiative Task Force would not be appended: The study had been sponsored by Princeton Plasma Physics Laboratory and publication of that report would be handled by PPPL.

Dr. Baldwin presented four viewgraphs which were reviewed briefly, as a set, before each was studied in more detail. Dr. Weitzner said that his initial reaction was that the same dollar number for project cost should be used throughout. Dr. Davidson concurred and added that, based upon his experience with BPX, he would recommend using escalated dollars that took account of inflation rather than base year dollars. Dr. Dean commented that the emphasis seemed to have been placed upon the steady-state aspects of the project: Many members had expressed a preference for emphasis being placed upon the advanced tokamak aspects. Dr. Sheffield suggested that the written recommendation should acknowledge the work of the New Initiative Task Force.

Dr. Conn indicated that there were five items that he wished to discuss. He suggested that the committee review the viewgraphs, in more detail, paragraph by paragraph. The charge was:

> "Within the envelope of available funding, identify what follow-on experimental devices for the U.S. fusion program might be planned for use after the completion of experiments at TFTR and before the planned start of ITER operation."

Paragraph 1:

> *In responding to this request, we have assumed the 5%-real-growth case of your letter. For concreteness, this was interpreted as setting for a new device a TPC constraint of about $400 million (FY92).*

Dr. Conn said that he would be unhappy if the phrasing of the Total Project Cost constraint was changed. He would prefer to leave it as $400 million in 1992 dollars and not escalate the number to "as spent" dollars. The SEAB report talked in terms of "the $500 million class". Dr. Conn suggested that DOE be permitted to handle inflation. Dr. Davidson countered that BPX had been costed at $1.4 billion in 1991 dollars but that this number had escalated to $1.9 billion when converted to as-spent dollars. At first glance, this gave the impression that a large cost increase had occurred.

Dr. Baldwin said that perhaps FEAC should use the larger number after all. Dr. Sheffield suggested using both numbers. He made the point that if the project was delayed, the cost could escalate above the larger number. It would then be necessary to go back to the base number in order to calculate what the inflated cost of the delayed project should be. Dr. Sheffield also recommended adding the word "about" whenever costs were referred to. Dr. Davidson asked that this be worded as "in the range of". Dr. Conn disagreed, stating that "in the range of" did not have an upper bound whereas the constraint placed upon FEAC definitely implied that an upper limit existed. Dr. McCrory suggested using the phrase "total estimated project cost".

Dr. Parker asked if the cost figure included any R&D that may prove necessary for defining components of the machine. Dr. Thomassen responded that the figure did not include potential R&D costs. Dr. Parker stated that the figure should be amended to reflect R&D costs. Dr. Conn stated that the uncertainty associated with R&D costs provided the reason for using the word "about" when referring to the cost of the project. He said that FEAC should state that it sees real value in this project at the approximate cost, and that including "about $400 - 500 million in 1992 dollars" would provide a self-consistent solution that FEAC was enthusiastic over.

Dr. McCrory did not like the use of the word "about". He preferred using ± 10%. Dr. Dean argued that the project could be facing a 30% threat: It was already slightly over the constraint now and could escalate even higher. Dr. Ripin suggested leaving out the word "constraint" since the project already exceeded the $400 million figure. Dr. Parker did not agree that the project cost exceeded the constraint. He pointed out that the project did not yet have even a conceptual design, adding that the device could be adjusted to bring it in at the price. Dr. Weitzner agreed with Dr. Ripin's suggestion to leave out "constraint". Dr. Conn countered that he was comfortable with the use of "about" and "constraint" and would be unhappy to see them removed. Dr. Parker agreed with Dr. Conn.

Paragraph 2:

> *The FPAC plan for MFE discussed two important tokamak physics issues that could potentially be addressed in a facility of this class: "advanced tokamak" and "steady-state" issues. Knowledge of this plan lay behind the SEAB Task Force rrecommendation for a machine of the "$500 million class" to address such issues.*

Dr. Conn referred to Dr. Weitzner's earlier comment concerning the need for consistency between the numbers that were quoted in different paragraphs of the letter. He pointed out that if FEAC were to adopt Dr. Sheffield's suggestion to include both numbers in the first paragraph, then the letter would read consistently. He suggested that the actual words used in the SEAB letter be included in the paragraph in order to tie it back to SEAB's recommendations.

Paragraph 3:

> *Advanced-tokamak issues generally fall into three areas, all of which require confirmation in steady-state:*
>
> - *Operation at high beta (e.g. in the "second-stability" regime) with enhanced confinement, which would permit a smaller DEMO (or reactor) size.*
> - *Stable operation with a high fraction of self-sustained plasma current ("bootstrap" current), which would permit low recirculating power in a steady-state DEMO.*
> - *Successful disruption control, which would maximize availability in a DEMO.*
>
> *The common thread to all these issues is control of the current profile, which must be demonstrated for longer than its greatest natural relaxation time scale. These studies fit very naturally with studies of more conventional "steady-state" issues:*
>
> - *Investigation of power and particle handling strategies and technologies.*
> - *Studies of efficient current-drive and current-profile control techniques.*
>
> *The above advanced-tokamak features have been identified in the ARIES reactor studies as those leading to a very attractive reactor.*

Dr. Conn reminded FEAC that they had held a lengthy discussion on the previous day concerning the issue of steady-state. The requirement that had emerged was really for a pulse length of considerable duration, although there had been disagreement over whether this should be 200 seconds or 1000 seconds. Hence, the paragraph should refer to "long pulse" rather than to "steady-state". Personally, he would like to see the phrase "confirmation in long pulse or, hopefully, steady-state" used. Dr. Parker agreed that the term "long pulse" should be used in the paragraph. Drs. Rosenbluth and Weitzner concurred. Dr. Weitzner pointed out that the U.S. fusion program had a history of not living up to its acronyms. Dr. Parker agreed and suggested that the "SS" be removed from the acronym.

Dr. Conn stated that he would like to see a number given to the length of the pulse that the device should achieve. Dr. Parker felt there was no need for this. Dr. Weitzner and Dr. Parker discussed relaxation timescales and wall effects. This discussion led to a more general one concerning whether or not to quantify the pulse length in the letter. Dr. Weitzner expressed concern that the letter was becoming sloppy, with too many "abouts" being included in it. Dr. Sheffield recommended that the letter indicate that the New Initiative Task Force had been set up to review the issue and had provided guide lines. Dr. Conn agreed that FEAC could use the task force's results to give some specificity to the letter. Dr. Parker disagreed with this, stating that the issue of time scale had become very contentious during the task force's deliberations.

Dr. Conn stated that FEAC needed to come to a consensus on this issue: He had no difficulty in including the task force's number in the letter. Dr. Weitzner was not happy with this. He stated that FEAC could put the number in the letter and agree with it, or put the number in the letter and disagree with it, but FEAC could not put the number in the letter and ignore it. Dr. Dean pointed out that the report of the task force had contained some well-crafted words on this issue: He suggested that FEAC should include these same words in their letter rather than re-writing them. Dr. Parker disagreed, stating that FEAC should not be too definitive concerning pulse length. Dr. Sheffield reaffirmed that the wording in the report of the New Initiative Task Force was very clear. Dr. Conn agreed that this was so; the issue was whether to include it or not. Dr. Parker reminded the committee that there was a natural time-scale associated with current relaxation problems that the device must accommodate; with respect to other issues the letter could suggest that a pulse length of 1000 seconds was highly desirable. Dr. Holdren pointed out that the program could only afford one machine and that it must address both sets of time-scale issues. Dr. Conn reminded members that they had agreed on the previous day that it might become necessary for them to select a priority, and that if that occurred, the priority would be to emphasize the advanced physics aspects of the program. Dr. Ripin protested that what had made the device appealing to him was the prospect of operating it under steady-state conditions. He would be unhappy with wording that would permit a pulse length of 200 seconds to become the goal.

Paragraph 4:

> *Based on its review of considerable pre-conceptual design work, FEAC concludes that a viable device addressing the combined steady-state/advanced-tokamak (SS/AT) mission can fill an important need in the program, that is not currently being met by any device in the world program, and that it can be built within the cost constraint.*

Dr. Baldwin made a further response to Dr. Sheffield's suggestion concerning the work of the New Initiative Task Force and indicated that this paragraph should be the one in which appropriate reference to the work of the task force was made.

Dr. Sheffield commented that the device could only be brought in at the $400 million figure if it were constructed in the TFTR test cell, and used the site credits such as the existing equipment. Dr. Weitzner suggested that the letter state that the machine could be built at PPPL within the cost constraint. Dr. Conn said that the statement should be stronger; the device could only be constructed within the constraint if it was built at PPPL using the site credits. He added that the letter should use the phrase "advanced tokamak and its long pulse mission" as opposed to SS/AT. Furthermore, the paragraph should be presented as a positive statement and not as a conditional one. Dr. Rosenbluth suggested that the word "important" be replaced by a stronger one, such as "essential".

Dr. Overskei pointed out that the discussion was, in fact, revolving around one fact, viz. Dr. Parker's concern over a "copper option" machine. If it had been agreed that the new machine should be superconducting, FEAC would not be having this argument. Dr. Conn reminded the meeting that the machine did not need to have its full capability at "day one". Dr. Overskei countered that while that was indeed so, the machine must be capable of appropriate up-grade; hence it must be superconducting. Dr. Conn disagreed, stating that several potential versions of the machine had been discussed, and that some of these had copper coils which could be superconducting. He added that FEAC should not recommend which type of machine should be constructed; rather, that was the prerogative of the machine designers. Dr. Rosenbluth agreed that FEAC should avoid the issue of resistive steady-state design versus superconducting design.

Dr. Dean asked if FEAC had a consensus on the minimum machine that it would recommend at the cost. He indicated that he would be prepared to approve an inertially-cooled machine with a 200-seconds pulse length. Dr. Sheffield stated that he would not support such a machine. Dr. Conn reiterated that issues such as that should be resolved by the technical design committee. He called for a vote of the committee to determine the number of members who were in favor of an inertially-cooled machine with a 200-seconds pulse length. Two members were in favor; nine members were opposed, although several indicated that they would like a further review of the matter.

Dr. Ripin emphasized the fact that an inertially-cooled machine would not be capable of subsequent up-grade to steady-state operation in the future. Dr. Conn pointed out that the appropriate DOE persons were present at the meeting and that they were fully aware of the implications of the discussion that was taking place. Dr. Overskei reviewed the aspects of the proposed machine that were new or different from those of existing machines: There were only two; an aspect ratio of 4 1/2, and the potential for steady-state operation. Everything else that was being proposed was "better than" presently existed, but was not new. He suggested that FEAC take a strong stand on the issue of steady-state capability; if the machine could not provide steady-state operation, then it should not be built. Dr. Conn felt that this would be going too far, adding that he thought the letter was satisfactory. He continued that if a design emerged, the capabilities of which were questionable within the spirit of the letter that they were writing, then FEAC would review the matter again.

Paragraph 5:

> *The FEAC, therefore, strongly recommends that design and construction of an SS/AT device be initiated for operation starting in 1999-2000. The approximately $400 million (FY92) cost constraint should continue to be observed. {In evolving the design within this constraint, when choices exist, priority should be given to maximizing the unique SS/AT capability of the machine - even at the expense of some of its more conventional tokamak features.} Throughout all of its phases, the facility should be operated as a national facility.*

Dr. Baldwin indicated that he did not have a good sense of where matters stood with respect to cost/performance trade-offs; hence his use of parentheses in the paragraph. Dr. Conn suggested that FEAC should not discuss potential trade-offs in the letter since one or other mission could suffer because of perceived preferences.

Dr. Baldwin emphasized that the unique feature of the machine was its ability to undertake an advanced-tokamak physics mission in a long-pulse environment. Dr. Conn was unsure whether FEAC needed to include such words in the letter. He indicated that the paragraph contained three distinct ideas and suggested that FEAC review each separately. He stated that FEAC needed to make a clear statement on a fundamental problem: The first sentence was only true if one accepted the $400 million constraint. If that constraint were nor there, then this machine would not be what FEAC would recommend. Hence, any recommendation needed to be tied back to the charge letter.

Dr. Rosenbluth disagreed. He felt it would be inadvisable to keep repeating the constraint and that the committee should refrain from saying that it would prefer a different machine if more money were available. Dr. Weitzner said that it was very important that FEAC state that this device would be good for the fusion program. FEAC would weaken the case for the device if the letter were to say that one could, and would, have done better if more money was available. Several committee members concurred that the constraint should not be repeated.

Dr. Dean stated that if FEAC were to recommend a device, the committee should be robust in that recommendation. If members had any thoughts that the machine under consideration would not fit in thoroughly with the strategy that might be employed later on in the fusion program, then they should not recommend the machine. Dr. Weitzner commented that he liked the proposed device at the anticipated cost. If the price were to increase, however, he would like to review the situation. He felt that the price constraint should be kept. Dr. Ripin stated that the second sentence of the paragraph was defensive and should be omitted. Dr. Parker disagreed: This was the "bold" bottom-line response and it must jump out at the reader.

A further discussion followed concerning the the mission and cost of the machine. It was suggested that these matters should wait upon the final design.

Dr. Conn asked a number of committee members to write up and revise those portions of the paragraphs that had been reviewed and agreed upon, and the meeting adjourned while this was undertaken.

FEAC Deliberations

When the meeting reconvened, Dr. Conn informed FEAC that Ms. Debbie Lonsdale of DOE was typing up what had been written so far. When this was complete, members would have the opportunity for further review of the paragraphs. Dr. Conn indicated that FEAC should restart by finishing its discussions regarding Paragraph #5 of Dr. Baldwin's viewgraph, and that they needed to review Dr. McCrory's concerns over the changes in manpower mix that would result from the new program.

Returning to the discussion of Paragraph #5, Dr. Parker stated that the copper steady-state device offered more performance than the superconducting one. He asked whether the panel was favoring the superconducting machine because of its relevance to ITER. He asked, in addition, whether the panel had ignored technology issues deliberately. Dr. Sheffield responded that the machine would be a wonderful "driver" for technology but that the panel had viewed the SSAT mission as being of paramount importance. Dr. Baldwin added that in making the selection of a machine, one should choose a technology for it that looks to the future. Dr.

Conn added that when, in the design of a machine, a choice exists between technologies, and there is little cost or perfomance difference between those choices, FEAC should recommend pursuing the technology most relevant to a DEMO reactor.

Dr. Davidson said that he felt it was beyond FEAC's capability to make a judgement on the issue of whether to pursue a copper option with higher performance or a superconducting version with more forward-looking technology. While not disagreeing with this statement, Dr. Baldwin indicated that it was FEAC's responsibility to rank and "weight" the factors that would be used in any judgement. Dr. Parker asked if Dr. Baldwin could outline the thought that the panel had been seeking. Dr. Baldwin responded that two thoughts had been pursued: With respect to physics, that the mission should be steered towards steady-state, and, with respect to technology, what the mission should be. Dr. Conn suggested that the actual choices should be left in the hands of the project organizers, since this would be a national project. Dr. Parker disagreed, stating that the project would be narrowly focused and would not relate to the fusion program as a whole. FEAC needed to provide guidance. Dr. Conn responded that the letter would provide guidance. Dr. Davidson added that the task force had already used the correct terms of reference in its study to define the project. Dr. Parker pointed out that there might, in time, arise a desire to test graphite walls or beryllium walls, and that many such experiments might ensue that would compromise the advanced-tokamak portion of the mission. He reiterated the need for FEAC to provide guidance.

Dr. Rosenbluth asked if it was intended that the task force should continue in existence. Dr. Davidson replied that it would continue, as presently composed, for several months. However, its nature might change with time. Dr. Rosenbluth suggested that the inclination of the machine builders and designers would be towards technology. Dr. Conn then asked if the machine should push forward the use of low-activation materials or if it should push the second stability regime. Dr. Davidson supplied a viewgraph of the make-up of the task force. Dr. Conn commented that the group was comprised almost entirely of physicists. Dr. Parker reiterated that FEAC must treat the mission of the machine as a policy issue. He was prepared to swing in favor of an advanced-tokamak mission as opposed to a steady-state one should the need arise. He suggested that FEAC vote on the advanced-tokamak versus steady-state issue. Dr. Conn stated that if FEAC were to start selecting priorities now, then the outcome would be the loss of the steady-state portion of the mission. The letter embraced both missions and allowed room to maneuver. He suggested leaving the matter alone.

Drs. Conn and Baldwin discussed how the national facility should operate. They suggested the establishment of a high level national steering group that would be responsible for design decisions affecting the project. Dr. Weitzner stated that this steering group should be put in place before the down-selection of options occurred. Dr. Rosenbluth suggested that the first body put in place should be an executive committee that would establish the necessary administrative procedures. He stressed that this was not the body that should recommend on design matters.

Dr. Davidson stated that he had already given thought to the way in which the TPX activity should be organized. It was intended to establish a multi-institutional team that possessed wide expertise, that would be involved both in the design of the machine and in work at their respective home sites on sub-system projects. Technical leaders from institutions with experience in device construction would be involved in the project, as would technical leaders from "user" institutions. Together they would form a "Partner Committee" with oversight responsibilities for the project. Dr. Conn proposed that FEAC discuss this suggestion.

Dr. Dean stated that one sentence in the letter relating to a national facility was not enough. Furthermore, the management concept that had just been raised had not been reviewed by Panel II. He felt that FEAC had two options: To say nothing on the matter, or to develop the complete management structure for the project. He continued that he did not like the PPPL proposal at all. He felt that while it might be marginally legal, it fell outside the spirit of what the TPX project should be. He added that the situation was fraught with the danger of conflicts of interest, since committee members would strive to feed sub-contracts back to their home institutions. He considered that it would be presumptuous of FEAC to deal with this issue without giving it considerable thought. Dr. Conn responded that matters involving oversight of the project should be dealt with at the site and not by FEAC. Dr. Dean reaffirmed his contention that the host laboratory must manage the project.

Dr. Weitzner said that the statement proposed for the letter lacked any means for providing clear control for the project. While Princeton must have management responsibility for the project, other institutions must also be able to exert control over it. Dr. Davidson pointed out that the proposed Council of Partners would do that. Dr. Conn responded that while control by the Council of Partners would indeed occur once the project was established, his concerns related to the design phase. That was why he had suggested that a steering committee be established to oversee the design. Dr. Baldwin agreed with Dr. Conn. He pointed out that there had been many aspects of BPX with which he did not agree. But, a steering committee, established late in the process, had still been able to exert an influence on the project. He stressed, however, that a steering committee was different from a council of partners.

Dr. McCrory expressed puzzlement at the peculiar response of the committee to the leadership position proposed for the program. He failed to see why it should not work. He stated that it was necessary to develop a strategy for running a national program and felt that the project had made a good start. Dr. Rosenbluth asked who should have oversight responsibility for the final design of one of the principal parts of the U.S. fusion program. He suggested that FEAC should have that responsibility and make the final decisions. He pointed out that a matter of major importance was the selection of the project manager. The person who turned out to be the most suitable would depend upon whether a superconducting machine or a copper machine was selected. Dr. Conn considered that FEAC should not be involved at that level of detail. Dr. Rosenbluth responded that the problem of selecting the best person to manage the project was very real.

Dr. Parker suggested that FEAC should take more responsibility at the beginning of the design and in setting up the steering committee. Dr. Conn disagreed and pointed out that this approach would turn FEAC into the initial steering committee. Dr. Parker suggested that an alternative approach would be to establish a panel to review the project at frequent intervals and to report to FEAC either quarterly or at each of its meetings. This activity could diminish with time. Dr. Conn responded that this approach would still result in FEAC becoming the steering committee. He suggested that if members of FEAC wished to join the steering committee, they should make their desires know to Dr. Davidson who should ensure that they were co-opted on to it. Dr. Decker indicated one solution could be for FEAC's role in this project to parallel that of HEPAP for the SSC. HEPAP is provided with regular status reports on the SSC. When a problem arises, DOE asks HEPAP to review the matter: This process includes the review of design changes that affect the mission.

Dr. Conn stated that there were two machines that fell within the cost envelope. He considered that the steering committee should decide which machine to construct rather than having FEAC make the choice. Dr. Rosenbluth indicated that there were important performance matters to be decided. Dr. Conn suggested that those members of FEAC who were concerned about performance issues should arrange to join the steering committee and deal with the matter there. He repeated that this was not an issue for FEAC to deal with.

Dr. McCrory suggested that FEAC should lead the project, perhaps through the selection of a small team of members who would review the details. Dr. Overskei reminded the committee that FPAC had placed a constraint upon BPX. Now, FEAC had placed a constraint upon the SS/AT. If a design was recommended that exceeded the constraint, then it would be up to FEAC to raise the ceiling of the constraint or to modify the mission of the machine. This was not a matter that should be left to the steering committee. Dr. Ripin suggested that FEAC should play the major role early on, and that this should be taken over later on by the management team that Princeton would establish. Dr. Dean agreed that the early stages should be FEAC's responsibility. Once the program had been determined and the management structure established, community participation in the conceptual design, and again at the "user" stage, would be acceptable. However, he felt that distributed community control in the detailed engineering design and in the machine construction would be entirely inappropriate.

Dr. Davidson said that it was important that the management plan be developed early. Also, the steering committee should be made up of persons who truly represented the breadth of the national fusion program. He suggested that the chairman of that committee report to FEAC. Dr. Conn agreed that the management plan for the national project needed to be developed as soon as possible. He saw no difficulty with the steering committee approaching FEAC for advice and guidance. Dr. Parker suggested that the time-frame for developing the management plan should be included in the letter. It was generally agreed that both the management plan and the steering committee should be in place by the time of the next FEAC meeting. Dr. Conn suggested that the letter should include phrasing such as: "The DOE together with the host site, should take the lead to form the management plan by the next FEAC meeting in May. This plan should include the establishment of a National Steering Committee to provide the SSAT project with guidance on issues related to mission, machine concept, cost and schedule." Dr. Overskei stated that the description of the mission was not sufficiently explicit. Dr. Conn pointed out that Dr. Weitzner was working on the sentences that described the mission and that, when he had finished, there would be an opportunity to review the mission statement again.

Public Comment

Dr. Keith Thomassen, Lawrence Livermore National Laboratory, discussed the funding of the SSAT project. He indicated that he felt comfortable with the estimate of $430 million for the project cost, which represented the total amount that would be spent from KD-1. But, the money would actually start to be spent from KD-0, and the anticipated annual rate of spending for this project would be $20 million while the fusion community waited for Congress to approve it. Because this money would be charged against the project, a delay of several years would impact the device very severely since it would reduce the amount left for construction of the actual machine.

Dr. Conn agreed that it was necessary to get the project off to a timely start and to specify, and hold to, a maximum period for the conceptual design. Dr. Berkner expressed skepticism that there was anything that FEAC could say or do that would speed up the congressional process.

FEAC Deliberations

Dr. Conn stated that he would like to combine Recommendations #4 and #5 of the panel and to relate them to the "global plan". He suggested that the section in the panel's report that dealt with the resiliency of the program might be added. Dr. Holdren pointed out that the U.S. would be unable to meet the goals of the National Energy Strategy under the proposed budget scenario. Dr. Dean asked when FEAC was going to inform Admiral Watkins of this. Dr. Conn responded that FEAC had done so, in their last letter. Dr. Baldwin pointed out that in that letter FEAC had only dealt with the slippage in time that would occur.

Dr. Conn stated that FEAC needed to add a paragraph to the letter concerning how the personnel needs of the program might change over time. Dr. McCrory was suggesting: "The DOE should provide an estimate, by fiscal year, of the number of scientists, engineers, and technical and non-technical staff, required to carry out the magnetic fusion program between 1992 and 2005."

Dr. Sheffield suggested that in the process of combining Recommendations #4 and #5, care be taken to ensure consistency with the previous letter, especially with repect to parallel facilities. Dr. Rosenbluth felt that FEAC needed a briefing on the status of the materials development program, on its projected cost, and on the cost of materials testing, before making any recommendations on a 14 MeV neutron source. He suggested that the letter should talk in terms of implementing a plan for the development of low-activation materials and indicated that he would like to see the low-activation aspect highlighted. He continued that FEAC should add a review of materials development options to its agenda, stating that this was a key area in fusion research that was being neglected. Dr. Holdren agreed that this was an important topic and suggested that FEAC should, early on, be given a briefing and obtain background matter on the materials development situation. Dr. Conn said that he would ask DOE to provide a review of the materials development program at the beginning of the next FEAC meeting. In particular, he would like to see answered questions such as "What do we need?" and "When do we need it?" He suggested that DOE request that the presentation be made by DOE-funded representatives of the materials development community. The general reaction of the committee members was that this would be a good thing to do.

Dr. Parker commented that if the U.S. fusion program intended waiting for low-activation materials for DEMO, it would be a long wait. Dr. Rosenbluth stated that FEAC must take a position on this topic soon. Dr. Sheffield agreed. Dr. Conn stated that he could not see how FEAC could proceed any faster than it was at present.

Dr. Holdren commented that FEAC had made a ringing statement on the need for advanced fusion physics. It now needed to make a ringing statement to the effect that the reason nuclear technology and improved materials are important, is that an attractive DEMO cannot be developed without them. Dr. Holdren stated that it was dangerous to make the assumption that ITER would perform a significant amount of nuclear testing. He was uncertain that ITER, even if it should eventually proceed to construction, would provide sufficient nuclear testing to meet the nuclear technology requirements of DEMO. He stressed that FEAC should not rely upon any conditional program for ITER since there was no guarantee concerning what ITER would do.

Dr. Ripin pointed out that the proposed statement concerning parallel test facilities gave the impression that FEAC endorsed those facilities. He suggested that FEAC treat the parallel facilities issue in the same manner as it had in the previous letter, thus to provide consistency. Dr. Berkner asked that FEAC review the relevant statement in the previous letter. After discussion, Dr. Conn concluded that any statement on the topic should be phrased similarly to the previous one.

Dr. Rosenbluth raised the issue of the relationship between the U.S. national program and the international program. Dr. Weitzner pointed out that this matter had been dealt with in the previous letter. Dr. Conn added that there was no reason to raise the issue of international cooperation again. Dr. Ripin asked what item, in these combined recommendations, represented new material when compared with the content of FEAC's letter of February 14. Dr. Conn replied that the difference was that the current letter specifically asked the DOE to start doing some planning in the areas concerned. Dr. Weitzner suggested that if FEAC was going to reaffirm anything from the previous letter, then it should reaffirm everything in the letter. Not to do so would be to degrade those items that had not been reaffirmed.

Dr. Parker indicated that he would anticipate any new plan taking into account international programs and the possibilities of international cooperation. Dr. McCrory stated that he was opposed to including such a sentiment in the letter, since it would give DOE an opportunity to procrastinate. Dr. Conn agreed with Dr. McCrory, and Dr. Parker then withdrew the suggestion. Dr. Parker asked if, in the letter, FEAC intended to raise the subject of a national nuclear site without calling for a plan. Dr. Conn confirmed that this was so.

Dr. Conn drew the attention of the committee to Recommendation #3, which dealt with the issue of priorities among the smaller facilities and activities for the medium-term confinement program. He was unsure whether or not the recommendation should be included, since he felt it was too broad. He suggested that, when Panel II had reported to FEAC, the DOE should set up a separate technical panel to review the situation. Dr. Weitzner said that he was not sure that a technically-oriented panel could handle the political issues. Dr. Baldwin explained the reasons for Recommendations #2 and #3. He pointed out there there was much overlap in what the many existing machines were able to offer to the fusion program. If the fusion budget reached a level at which it was unable to fund all of them, then the attributes of all would need to be reviewed. This was what had led to Recommendation #3 becoming so broad. Dr. Rosenbluth suggested that this matter should be dealt with by Panel II since the members of that panel would appear to be the appropriate persons to undertake the task. Dr. Overskei pointed out that during its deliberations Panel II had only looked at half of the U.S. fusion program. It had not considered the needs of materials development. Dr. Conn pointed out that Panel II had been given a specific set of charges to which to respond: Materials development had not been included.

Dr. Parker reminded the committee that they had dealt with TFTR and the parallel facilities issue in their letter of February 14. He asked that FEAC not weaken that letter by down-selecting portions of the program now. He stated that what in fact FEAC would be doing by including Recommendations #2 and #3 was stating that, in the event of a budget cut, TFTR, DIII-D and the new design activity should be protected. Dr. Conn agreed that that was indeed what FEAC would be saying. He suggested that FEAC might like to consider omitting the first portion of Recommendation #3 from their letter. Dr. Dean agreed that it should be left out.

Dr. McCrory said that the determination of the relative priorities of existing machines and proposed up-grades should not be left to a panel. He pointed out that these devices were at the heart of the fusion program and their disposition should be dealt with by FEAC itself. Dr. Conn said it appeared that Dr. McCrory was suggesting that FEAC should not deal with this matter now. Dr. McCrory agreed that this was so. He pointed out that any selection of priorities was likely to result in fewer, larger facilities. Dr. Conn agreed that there was no pressing reason why FEAC should settle this issue now. He suggested that if the DOE wanted FEAC to deal with the matter, they could charge the committee with it. Dr. Baldwin stated that if FEAC were to drop Recommendation #3, then it should drop Recommendation #2 also. Dr. Conn disagreed, stating that Recommendation #2 referred to work that had already been completed by Panel II. Dr. Berkner asked why FEAC did not take the lead in this matter. Dr. Davies responded because it was the law that committees such as FEAC could only respond to charges.

Dr. Overskei pointed out that the original letter of charge had in fact asked FEAC to review this matter, and to respond by March 1992. Dr. Conn commented that FEAC would have to ask for an extension. Dr. Davies reminded the committee that the formulation of the charge had occurred in September, immediately following the meeting of the SEAB task force. The formulation process had been hurried and the charge that resulted was not sufficiently specific in every area. She did not agree with Dr. Overskei's interpretation that Dr. Happer required a detailed review of machine priorities by March. Dr. Weitzner asked Dr. Davies if she was recommending that FEAC omit both Recommendations #2 and #3 from the letter. Dr. Davies responded that she would be happy to receive the letter in whichever way FEAC decided to write it.

Dr. McCrory pointed out that the panel had worked hard in arriving at Recommendation #2. It should not be omitted. Recommendation #3 could be omitted. Dr. Parker stated that this suggestion gave the impression that FEAC was leaning towards shutting down the C-MOD machine at MIT. Dr. Davidson disagreed. He emphasized that Recommendation #2 came from a hardworking panel. He stressed that FEAC would be unable to appoint a panel if it took no notice of them.

A lively discussion ensued on the issue of selecting priorities among the smaller machines. Dr. Davies reminded the committee that during the last major budget reduction, TFTR was retained in the program because of the high priority given to its mission. At that time, the alternative technologies had been cut. It might prove necessary to make additional difficult program reductions. Dr. Parker stated that he saw no sense in retaining the design team for a new project if this meant shutting down a new $50 million machine that has yet to start operation. Dr. Baldwin indicated that the two highest priorites in the program were TFTR and DIII-D. Both were listed in Recommendation #2. He suggested that the design of TPX, which was listed in Recommendation #2 as the third priority could be omitted to satisfy Dr. Parker's objections. Dr. Conn suggested that FEAC adopt Dr. Baldwin's suggestion for Recommendation #2.

Returning to Recommendation #3, Dr. Sheffield said he would be unhappy if it were not included. He raised the issue of fusion-program priorities again and suggested that FEAC should review overall strategy. Another lively discussiion ensued but no clear consensus was reached.

Dr. Dean said that FEAC was in danger of micromanaging the fusion program at too low a level. He pointed out that the committee had identified the two most important items in the program and felt that that should be enough. Dr. Sheffield agreed. He added that once Panel III has provided the criteria for selection of alternative devices, the DOE could co-opt panels that would help to sort out the priorities.

Dr. Conn stated that FEAC had dealt with all the "panel" issues but that a few other matters still remained. He pointed to the need to indicate how TPX would fit in with the world program. Dr. Weitzner referred to the suggestion that TPX be compared with the Japanese and European stellarators. He saw no need to mention the word "stellarator" and suggested saying instead that devices of comparable size were being built elsewhere in the world. This would reinforce FEAC's choice of TPX.

Dr. Conn raised the question of the resiliency of the selected project if ITER did not proceed to construction. Dr. Parker asked if TPX was the device that FEAC would recommend for the U.S. program if ITER did not materialize. Dr. Dean responded that he viewed TPX as being totally independent of ITER. Dr. Parker then asked if TPX was the first machine that FEAC would build in the absence of ITER. Dr. Dean responded positively again, adding that TPX was the only machine that the U.S. program could afford. Dr. Rosenbluth asked what would be done to study burning plasma physics. Dr. Dean responded that this type of study could be undertaken upon completion of the original mission for TPX. Dr. Parker pointed out that if ITER did not exist, and if the U.S. fusion budget achieved its present projections, then the U.S. program could afford a much more expensive machine than TPX since none of the funding would be required for ITER. Dr. McCrory countered that if ITER were not to continue, then the whole fusion energy program, worldwide, would be in trouble. The U.S. needed an SS/AT machine that could be justified in its own right. The machine had its own needs; FEAC still had not defined them.

Dr. Davidson cautioned that whatever FEAC said in its letter, it must not look as if the committee was backing away from its support of ITER. Dr. Dean suggested that the letter should state that, given the budget, this is the machine that FEAC recommends the U. S. build, and that the U.S. program will continue to require this machine, whatever happens to ITER. Dr. Conn pointed out that if the ITER ceased to exist, a lot of the congressional support that the fusion program is currently enjoying would also cease to exist. He suggested deleting all reference to this matter. The committee members agreed with this.

At this stage the committee began reviewing those portions of the letter that had already been drafted. Dr. Parker asked why the letter needed to request that DOE undertake a skill/mix exercise. Dr. McCrory responded that the mix of skills required by the fusion program would change significantly over the next few years. For example, the demand for physicists would decrease as such persons were replaced by others with different skills. Dr. Weitzner suggested that the program could not be sufficiently well defined to permit this to be done. Dr. McCrory countered that the program was not sufficiently well defined as far as the requirements for hardware were concerned either, yet FEAC was attempting to recommend optimized machinery. Dr. Overskei interjected that once the project started, irrespective of the machine or program, the first four years would entail pouring concrete and cutting metal. He asked what one would do with the scientists during that period. Dr. Conn concluded that the skill/mix analysis would be a useful exercise.

The committee entered into a general discussion of the materials development/nuclear technology phase of the fusion program. Dr. Conn said that he would like FEAC to be provided with an understanding of the factors involved in the development of a new material. He pointed out that it was possible to develop a reactor from the physics that was already known and understood, but it could not be built without the appropriate materials. Dr. Dean stated that there were still half-adozen physics areas where improved understanding was vital to a good reactor, too. The relative merits of materials development and physics investigations ensued but no conclusions were reached.

The letter report that was eventually presented to Dr. Happer is given as Appendix I to these minutes.

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