Report of the FESAC Panel on

A Burning Plasma Program Strategy to Advance Fusion Energy

Presented by S.C. Prager

Charge

To recommend a strategy for burning plasma experiments

The Panel report builds upon

- The 2000 FESAC panel on burning plasma physics (Freidberg et al)
- The 2002 Fusion Summer Study (Snowmass)

Panel Membership

Charles Baker, *University of California, San Diego*
David Baldwin, *General Atomics*
Herbert Berk, *University of Texas at Austin*
Riccardo Betti, *University of Rochester*
James Callen, *University of Wisconsin – Madison*
Vincent Chan, *General Atomics*
Bruno Coppi, *Massachussetts Institute of Technology*
Jill Dahlburg, *General Atomics*
Steven Dean, *Fusion Power Associates*
William Dorland,* *University of Maryland*
James Drake, *University of Maryland*
Jeffrey Freidberg, *Massachussetts Institute of Technology*
Robert Goldston, *Princeton Plasma Physics Laboratory*
Richard Hawryluk, *Princeton Plasma Physics Laboratory*
Richard Hazeltine, *University of Texas at Austin*
E. Bickford Hooper, *Lawrence Livermore National Laboratory*
Amanda Hubbard, *Massachussetts Institute of Technology*
Thomas Jarboe, *University of Washington*
Joseph Johnson, *Florida A & M University*
Martin Lampe,* *Naval Research Laboratory*
John Lindl, *Lawrence Livermore National Laboratory*
Grant Logan, *Lawrence Livermore National Laboratory*
Earl Marmar, *Massachussetts Institute of Technology*
Michael Mauel, *Columbia University*
Kathryn McCarthy, *Idaho National Eng and Env Laboratory*
William McCurdy,* *Lawrence Berkeley National Laboratory*
Dale Meade, *Princeton Plasma Physics Laboratory*
Wayne Meier, *Lawrence Livermore National Laboratory*
Stanley Milora, *Oak Ridge National Laboratory*
George Morales, *University of California at Los Angeles*
Farrokh Najmabadi, *University of California, San Diego*
Gerald Navratil, *Columbia University*
William Nevins, *Lawrence Livermore National Laboratory*
David Newman, *University of Alaska at Fairbanks*
Ronald Parker, *Massachussetts Institute of Technology*
Francis Perkins, *General Atomics*
Cynthia Phillips, *Princeton Plasma Physics Laboratory*
Miklos Porkolab, *Massachussetts Institute of Technology*
Stewart Prager (Chair), *University of Wisconsin – Madison*
Marshall Rosenbluth,* *University of California, San Diego*
Ned Sauthoff, *Princeton Plasma Physics Laboratory*
Kurt Schoenberg,* *Los Alamos National Laboratory*
John Sheffield, *Oak Ridge National Laboratory*
Ronald Stambaugh, *General Atomics*
Edward Synakowski, *Princeton Plasma Physics Laboratory*
George Tynan, *University of California, San Diego*
Nermin Uckan, *Oak Ridge National Laboratory*

*Not present at panel meeting in Austin, Texas

- Panel met August 6 - 8 , Austin
- Report endorsed by 40 out of 41 attending members (one dissension)

A remarkably strong and enthusiastic consensus

Basis for the Strategy

(Findings from which the strategy is derived)

The need

A burning plasma program is needed as a crucial element in the development of fusion energy.

frontier science and technology, key demonstration

Readiness

The U.S. and world fusion programs are now technically ready to proceed with the construction of a burning plasma experimental facility.

essential unanimity in the fusion science community

Fusion program integration

A burning plasma experiment would be an integral part of the fusion energy sciences program. Underpinning this program is a strong core science and technology element that will greatly benefit from, and contribute to, the burning plasma experiment.

In addition to a burning plasma experiment, development of fusion energy requires

fundamental understanding
configuration optimization
steady-state plasma studies
materials and technology development.

The current level of effort within the core S & T program, following the major budget reduction in 1996, is insufficient to meet these challenges.

The ITER facility is proposed as an international project at power-plant scale with a comprehensive science and technology program. It has a well-developed engineering design, and negotiations for construction are underway. U.S. participation in ITER would have substantial domestic benefits.

ITER would investigate strongly coupled, nonlinear physics phenomena that dominate self-heated plasmas, in near steady-state conditions.

The operation and study of a power-plant scale facility that integrates burning plasmas, near steady-state, and key fusion technologies would constitute a huge step toward commercial fusion power.

The FIRE facility is proposed as a smaller scale, U.S.- based project with a broad science program. It has anadvanced pre-conceptual design. Conceptual and engineering designs are needed prior to construction. International participation in FIRE would provide substantial benefits.

Would investigate the strongly coupled physics phenomena that dominate self-heated plasmas, under quasi-stationary conditions.

The burning plasma science learned would constitute a large step forward in fusion energy development

IGNTIOR has a well-developed design and is moving forward in Italy. Its operation would provide valuable insight into burning plasma science, although it is not designed to be the sole burning plasma facility in the world.

Aimed at an early study of the strongly coupled physics phenomena that dominate self-heated plasmas, enabled by a smaller size and less extensive technical capability.

ITER and FIRE are each attractive options for the study of burning plasma science. Each could serve as the primary burning plasma facility, although they lead to different fusion energy development paths.

Figure 1 — Development Path With ITER

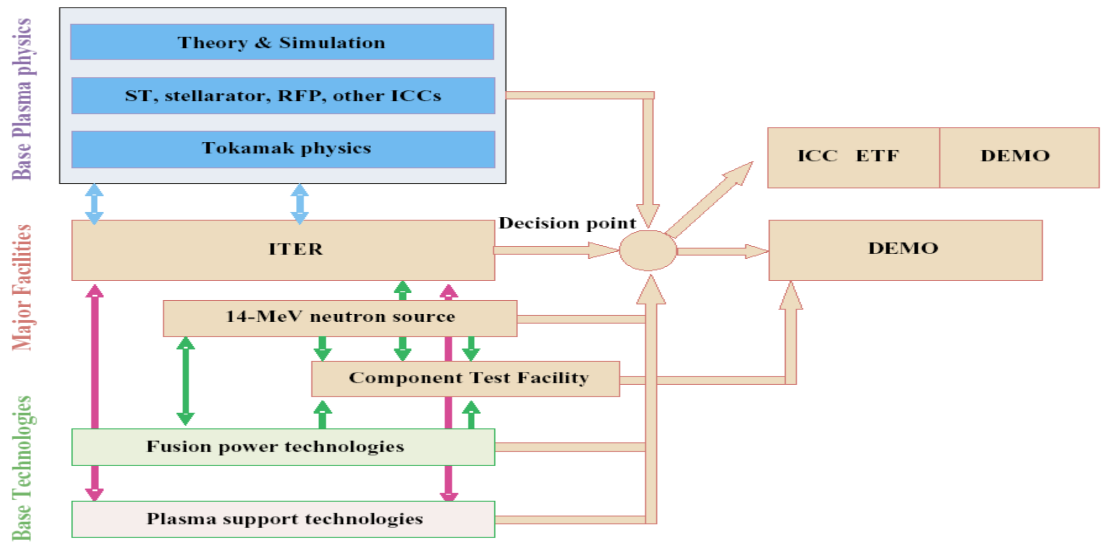
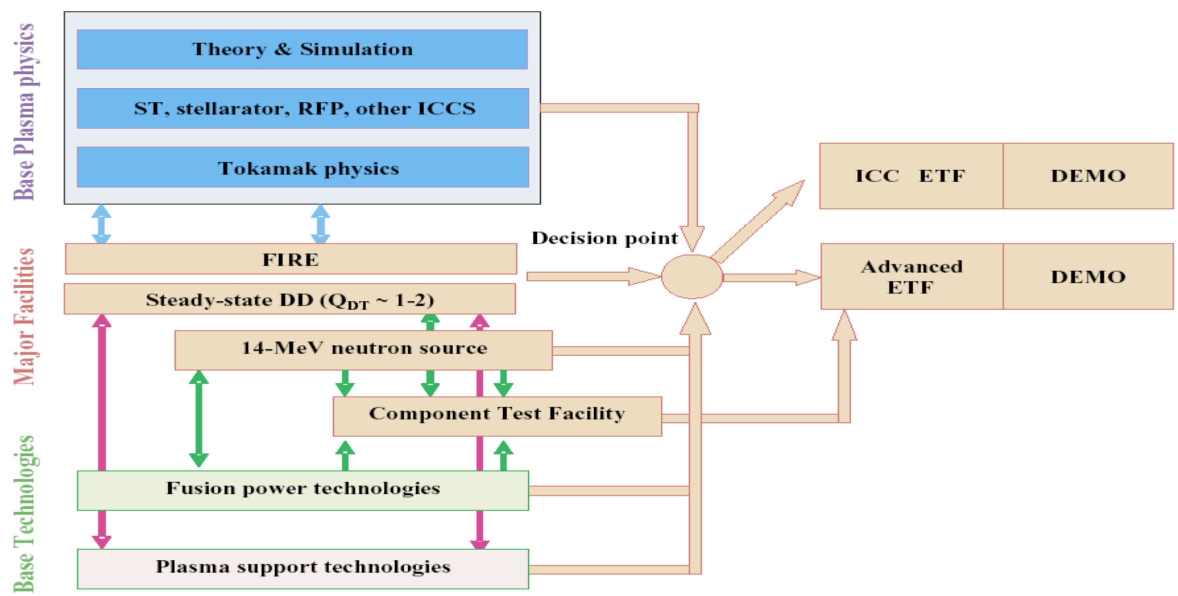


Figure 2 — Development Path With FIRE



Because additional steps are needed for the approval of construction of ITER or FIRE, a strategy that allows for the possibility of either burning plasma option is appropriate.

Major Recommendations

Since ITER is at an advanced stage, has the most comprehensive science and technology program, and is supported internationally,

we should now seek to join the ITER negotiations with the aim of becoming a partner in the undertaking, with technical, programmatic and timing considerations as follows:

- *The desired role is that the U.S. participate as a partner in the full range of activities, including full participation in the governance of the project and the program. We anticipate that this level of effort will likely require additional funding of approximately $100M/yr.*

- *The minimum acceptable role for the U.S. is at a level of effort that would allow the U.S. to propose and implement science experiments, to make contributions to the activities during the construction phase of the device, and to have access to experimental and engineering data equal to that of all partners.*

- *The U.S. performs a cost analysis of U.S. participation and reviews the overall cost of the ITER project.*

- *The Department of Energy concludes, by July, 2004, that ITER is highly likely to proceed to construction with terms acceptable to the U.S. Demonstrations of likelihood could include submission to the partner governments of an agreement on cost-sharing, selection of the site, and a plan for the ITER Legal Entity.*

In prioritized order, U.S. objectives for participation in a burning plasma experiment are:

(1) to perform research on burning plasmas in the tokamak configuration, to contribute to the science base for the full range of toroidal confinement configurations;

(2) to develop enabling technology that supports the burning plasma research and positions the U.S. to more effectively pursue burning plasma research;

(3) to advance fusion energy technologies, to contribute to the technology base necessary for a demonstration fusion power plant;

(4) to increase involvement of U.S. industry in the fusion program, both in design and fabrication of components for burning plasma experiments and in preparation for U.S. design and construction of a demonstration fusion power plant.

Achievement of the highest priority U.S. objectives requires that negotiated terms assure the following minimum roles and opportunities:

(a) a significant U.S. role in the decision-making regarding the ITER research program, including overall research directions and selection of experiments;

(b) opportunities for U.S. researchers from all segments of the U.S. fusion community (universities, laboratories, and industry) to propose, plan, conduct and participate in experiments as members of the ITER research team;

(c) opportunities for U.S. researchers to play leadership roles and participate in ITER's topical task forces, with access to all data from all available systems for all ITER experiments;

(d) opportunities to apply theory and integrated modeling in design and analysis of experiments and in benchmarking of models against ITER data;

(e) opportunities for the U.S. to develop and contribute equipment during the construction and operations phases of the device, and to have access to engineering data equal to that of all partners;

(f) opportunities to propose/develop/design/fabricate/install/operate advanced diagnostics and enabling technology (e.g., plasma control tools) beyond the baseline;

(g) opportunities to participate in fusion energy technology activities such as the development and testing of blanket modules.

Since FIRE is at an advanced pre-conceptual design stage, and offers a broad scientific program,

we should proceed to a physics validation review, as planned, and be prepared to initiate a conceptual design by the time of the U.S. decision on participation in ITER construction.

If ITER negotiations succeed and the project moves forward under terms acceptable to the U.S., then the U.S. should participate. The FIRE activity should then be terminated.

If ITER does not move forward, then FIRE should be advanced as a U.S.-based burning plasma experiment with strong encouragement of international participation.

If IGNITOR is constructed in Italy,

then the U.S. should collaborate in the program by research participation and contributions of related equipment, as it does with other major international facilities.

U.S. Candidate Roles in Burning Plasma Experiments

Candidate Task	Task Description	Contributes to US Plasma Science	Contributes to US Fusion Technology	Existing US Expertise	ITER --- Potential US Role	FIRE --- Potential US Role	IGNITOR --- Potential US Role
Plasma Diagnostics	Design, fabricate and operate instrumentation that enables studies of plasma behavior; design both instruments and supporting infrastructure (associated shielding, components such as mirrors and windows and radiation-tolerant cable, etc.)	High - key enablers of plasma understanding that also position the provider to play leading roles in plasma studies	Moderate - Plasma diagnostics are an enabling technology applicable to a wide range of potential spin-offs;	High - The US is a world leader	US should emphasize diagnostics that enhance understanding and enable knowledge-based innovation; Diagnostics R&D and design/fabrication is a key method for involvement of physics community during the design and construction phases	US has the lead responsibility and would define the scope of the diagnostic systems. This would be a major scientific driver for long term University and National Laboratory programs in the US. There would be some international collaboration e.g., *NINB* diagnostic neutral beam.	US could lead in sub-set of diagnostics that enhance understanding and enable knowledge-based innovation; Diagnostics R&D and design/fabrication is a key method for involvement of physics community during the design and construction phases
Plasma Control Systems	Provide for basic control of plasma equilibrium parameters (current&pressure profile, fueling, heating,etc) and active control of MHD stability. Includes design and operation of data acquisition and real-time computer analysis to support broad Plasma Control mission.	High - central to enabling research and applying BP experience to other configurations	Low	High - US a world leader	Design Lead/Integrator/Equipment Supplier followed by co-leadership role in operations and analysis. Would naturally couple to key active control diagnostics, e.g. (q-profile, MHD,…)	US would define and provide for basic control of plasma equilibrium parameters (current&pressure profile, fueling, heating,etc) and active control of MHD stability. Includes design and operation of data acquisition and real-time computer analysis to support broad Plasma Control mission.	Design Lead/Integrator/Equipment Supplier for selected control systems followed by potential leadership role in operations and analysis in (tbd) areas.
Plasma Performance Modeling	Develop and apply a wide variety of plasma and system modeling codes to predict performance, analyze data, test understanding, etc.	High – central to component design and applying BP experience to other configurations	Low	High – US a world leader	Integrator/participant of plasma modeling effort US would develop and apply a wide variety of plasma and system modeling codes to predict performance, analyze data, and test understanding. Strong coupling with the ongoing program.	US would define and develop and apply a wide variety of plasma and system modeling codes to predict performance, analyze data, test understanding. Strong coupling with the ongoing program.	Integrator/participant of plasma modeling effort
Analyis of AT Modes	Draw on extensive AT experience to develop AT scenarios for PBs, analyze results, etc.	High – central to BP higher performance operations and research	Low	High – US a world leader	Integrator/participant of AT physics program	The US is the leader internationally. The US fusion community would define the FIRE AT program, and has the responsibility for all aspects .	Experimental lead of AT physics program

etc

A strong core science and technology program is essential to the success of the burning plasma effort, as well as the overall development of fusion energy.

Hence, this core program should be increased in parallel with the burning plasma science initiative.

A burning plasma science program should be initiated by the OFES with additional funding in FY 04 sufficient to support this strategy.