From: "Lancaster, James" <JLancaster@nas.edu>
Subject: NRC Reports' Conclusions, Recommendations re FESAC Subcommittee
Date: August 14, 2012 9:43:00 AM CDT
To: "'Robert Rosner'" <r-rosner@uchicago.edu>
Cc: "Lang, David" <DLang@nas.edu>, "'mauel@columbia.edu'" <mauel@columbia.edu>

Dear Professor Rosner:

I am writing on behalf of the National Research Council's (NRC) Plasma Science Committee (PLSC). At its last meeting in March 2012, the PLSC, then chaired by Dr. Michael Brown (Swarthmore), discussed in open session some of the issues that are before your committee and, in particular, the potential impact that the anticipated budget profile for the ITER project might have on the DOE Office of Fusion Energy Sciences' (OFES) budget. As you might be aware, several NRC studies make recommendations that are related to these issues, as follows -

Burning Plasma: Bringing a Star to Earth (2004),
Plasma Science: Advancing Knowledge in the National Interest (2007),
A Review of the DOE Plan for U.S. Community Participation in the ITER Program (2008).

Pursuant to its charge to serve as stewards of NRC reports in its discipline, the PLSC requested that NRC staff compile the conclusions and recommendations from those past NRC reports that are relevant to the issues before your committee and forward this information to your committee. The information is included as an attachment to this letter and has also been provided to the NRC's Board on Physics and Astronomy, which oversees the activities of the PLSC. A separate attachment provides the Summaries from each of these three reports.

I hope that your committee finds this information useful in your deliberations.

Sincerely,

Jim Lancaster

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THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Division on Engineering and Physical Sciences
Board on Physics and Astronomy
Plasma Science Committee

Via Electronic Mail

August 14, 2012

Professor Robert Rosner
Chair, FESAC Subcommittee on a Review of Priorities for Magnetic Fusion Energy
The University of Chicago
5735 South Ellis Avenue
Chicago, IL 60637

Re: NRC Reports' Conclusions, Recommendations

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Jim Lancaster
Director, Board on Physics and Astronomy

Attachments: Summary of relevant recommendations and Summaries from the following NRC reports:

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BURNING PLASMA

BRINGING A STAR TO EARTH

Burning Plasma Assessment Committee

Plasma Science Committee

Board on Physics and Astronomy

Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

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Summary

Fusion energy holds the promise of providing a significant part of the world's long-term, environmentally acceptable energy supply. At the center of all schemes to make fusion energy is a plasma—an ionized gas that, like the center of the Sun, is heated by fusion reactions. The plasma is said to be burning when alpha particles from the fusion reactions provide the dominant heating of the plasma. All fusion reactors require a burning plasma. The key challenge is to confine the hot and dense plasma while it burns.

The search for a means of controlling thermonuclear fusion has been based on the study of high-temperature plasma physics; it has led to the development of both magnetic and inertial confinement systems to contain the plasma. Carried out in the United States under the sponsorship of the Department of Energy's (DOE's) Office of Fusion Energy Sciences (OFES), fusion research (referred to herein as the U.S. fusion program) has made remarkable progress in recent years in understanding and controlling turbulence and instabilities in fusion plasmas, which in turn has led to improved plasma confinement. Theory and modeling are now able to provide useful insights into instabilities and thus to guide experiments. Experimental diagnostics can extract useful information about the processes occurring in high-temperature plasmas.

The successes of the U.S. fusion program can be attributed to its science-centered approach, aimed at three goals:

- To advance plasma science in pursuit of national science and technology goals;
- To develop fusion science, technology, and plasma confinement innovations as the central theme of the domestic program; and
- To pursue fusion energy and technology as a partner in the international effort.[1]

Experiments that have been carried out on the suite of U.S. and foreign tokamaks have been successful in significantly advancing the scientific and technical knowledge base for fusion. Research in innovative and alternate magnetic fusion concepts is contributing to an understanding of how to design, implement, and control future fusion devices. Theory and simulation have contributed significantly to progress in understanding the behavior of fusion plasmas—for example, in the area of turbulence and nonlinear physics. The university-scale efforts within the fusion program have enabled the advances in the fusion effort and provided personnel for the program as a whole. The question now is, What is the next major step for the U.S. fusion effort?

It is widely agreed in the plasma physics community that the next large-scale step in the effort to achieve fusion energy is to create a burning plasma—one in which alpha particles from the fusion reactions provide the dominant heating of the plasma necessary to sustain the fusion reaction. The objective of creating a burning plasma is to understand the physics of the confinement, heating, and stability of burning plasmas as well as to explore the technical problems connected with the development of a power-producing fusion reactor. A burning plasma experiment is a key scientific milestone on the road to the development of fusion power.

The Burning Plasma Assessment Committee was charged with analyzing and reporting on the following topics: the importance of a burning plasma experiment, the readiness of the U.S. fusion community to undertake a burning plasma experiment, and the DOE's plan for a burning plasma experimental program. The committee was also asked to make recommendations on the program strategy that would maximize the output of such a program for the future development of fusion as an energy source. Because the committee's charge was limited to the consideration of magnetically confined burning plasmas, none of the inertial confinement fusion programs are considered in the report.

The development of fusion as a source of power is a multidecade enterprise. It

[1]U.S. Department of Energy, *Strategic Plan for the Restructured U.S. Fusion Energy Sciences Program*, DOE/ER-0684, Washington, D.C., August 1996, p. 3.

is subject to many unknowns—both technical and societal—that are beyond the scope of this committee's charge. Indeed, the DOE has not yet established a clear program strategy for fusion (and hence did not present one to the committee), in part because the plans for an international burning plasma experiment have been in flux for the past few years. The committee's goal is, nevertheless, to define a program approach that will optimize the near-term productivity of the U.S. fusion program and position it for development in the future at levels deemed appropriate at that time. With this task in mind, the committee offers here a short précis of the main elements of this report and then presents its recommendations and their rationale.

- A burning plasma experiment is critically needed to advance fusion science. The committee is pleased that the U.S. government has rejoined the International Thermonuclear Experimental Reactor (ITER)[2] negotiations, which the committee expects will be successful. If the negotiations are not successful, progress toward fusion energy will require moving ahead with some other kind of international burning plasma experiment.
- Undertaking a burning plasma experiment cannot be done on a flat budget. If the United States is interested in the long-term goal of fusion as a source of economical, sustainable energy and not only in the ITER effort, the nation needs a science program based on some of the existing facilities; a technology program; a computation, simulation, and theory program; and a university program. At a minimum, to capture the benefits of a burning plasma experiment, an augmentation of the U.S. program covering all of the U.S. ITER construction and operating costs would be required in the near term.
- If negotiations proceed successfully, the fusion science program will move ahead with the ITER endeavor. In doing so, the fusion community should focus on the opportunities that this development will present and accept limitations on the level of activity possible within reasonable budget constraints. It is necessary to recognize that some of today's facilities will have to be shut down over time and that not all alternate concepts are affordable. Priorities will be set. Although this committee was not tasked to set them, it

[2]ITER will be a burning plasma experiment based on the tokamak concept—the leading magnetic-confinement fusion configuration, whose name comes from the Russian word for a toroidally (or doughnut) shaped magnetic field. ITER is expected to be larger than existing tokamaks, with a major radius of 5 to 8 m, and is expected to use superconducting magnets to confine the hot plasma. The negotiations to start the ITER project are being attended by the European Union, Russia, Japan, China, South Korea, Canada, and the United States.

does recommend that the community take part in a real prioritization process for the fusion program. The Office of Fusion Energy Sciences must take the lead and bring the community to consensus.

On the basis of its own assessments and deliberations, the committee concludes that the progress made in fusion science and fusion technology has increased overall confidence in the readiness to proceed to the burning plasma step, allowed the development of more reliable operational projections, and reduced the estimated cost of such an experiment. An important goal of the burning plasma experiment is to explore operating regimes that are not so predictable and that are likely to give rise to instabilities in the self-heated burning plasma. Such experimentation will make critical contributions to the understanding of how to optimize future directions in fusion research and development.

The committee makes the following specific recommendations and observations:

- **The United States should participate in a burning plasma experiment.**

Participation in a burning plasma experiment is a critical missing element in the U.S. fusion program. The scientific and technological case for adding a burning plasma experiment to the U.S. fusion science program is clear. There is now high confidence in the readiness to proceed to the burning plasma step because of the progress made in fusion science and fusion technology. Progress toward the fusion energy goal requires this step, and the tokomak is the only fusion configuration ready for implementing such an experiment.

- **The United States should participate in the International Thermonuclear Experimental Reactor (ITER) project. If an international agreement to build ITER is reached, fulfilling the U.S. commitment should be the top priority in a balanced U.S. fusion science program.**
- **The United States should pursue an appropriate level of involvement in the ITER project, which at a minimum would guarantee access to all data from ITER, the right to propose and carry out experiments, and a role in producing the high-technology components of the facility consistent with the size of the U.S. contribution to the program.**
- **If the ITER negotiations fail, the United States should continue, as soon as possible, to pursue the goal of conducting a burning plasma experiment with international partners.**

Of the alternatives proposed for U.S. participation in a burning plasma experiment, ITER, with the United States as a significant partner, is the best choice. The ITER design is the most mature and is also sufficiently conservative to provide great confidence in achieving burning plasma conditions while being flexible enough to test critical advanced tokamak operating regimes in near-steady-state burning plasma conditions. It also allows tests of several fusion-relevant technologies. Participation by the United States in ITER also very effectively leverages the U.S. investment in its own fusion science program.

The pace of the ITER program will be decided by the participants through the negotiating process. The U.S. component will be settled as the negotiations proceed and as procurement packages are assigned and construction preparations commence. These negotiations will determine the U.S. financial contribution to ITER construction as well as the role for and demands on the U.S. program as an ITER partner. Once a U.S. commitment is made to help construct and to participate in ITER, fulfilling this commitment will necessarily become the highest priority in the U.S. fusion science program. It is reasonable to expect that the larger the commitment, the more U.S. participation in the ITER program will be able to meet the nation's interest in progressing toward fusion energy.

A preliminary and successful review of the ITER construction costs has been conducted by DOE.[3] This is an important first step in understanding the potential costs of the ITER program for the United States. Furthermore, DOE is carrying out an analysis of the various work packages of primary interest to the U.S. fusion science program, and it has engaged the fusion community in this effort by establishing the Burning Plasma Program Advisory Committee and holding an ITER forum for community input. These, too, are welcome developments.

Notwithstanding the goodwill of all of the negotiating parties and the significant progress made to date, the ITER negotiations could conceivably fail. In that case, in order to progress with the development of fusion energy, it would be necessary to look for an alternative approach to a burning plasma experiment, and that most likely would become an international collaboration. In such a scenario, the United States should reassess its options before developing an alternative strategy. Because a burning plasma experiment is a key step on the necessary scientific critical path toward fusion energy, any delays in realizing such an experiment—such as failure in the ITER negotiations—would necessarily delay the domestic program's ability to address and understand fusion science questions that must be answered before practical fusion power can be developed.

[3] *Department of Energy Assessment of the ITER Project Cost Estimate*, November 2002. Available online at http://fire.pppl.gov/doe_iter_lehman.pdf. Accessed December 12, 2003.

- **A strategically balanced U.S. fusion program should be developed that includes U.S. participation in ITER, a strong domestic fusion science and technology portfolio, an integrated theory and simulation program, and support for plasma science. As the ITER project develops, a substantial augmentation in fusion science program funding will be required in addition to the direct financial commitment to ITER construction.**

Although the scale of U.S. participation in the ITER program is as yet undetermined, it is clear that the U.S. fusion effort requires a strategically balanced program in the context of participation in ITER. In structuring the U.S. fusion program with participation in ITER, it will be important to maintain the fusion science program as a diversified one that includes science, technology, theory, simulation, and experimentation conducted using the domestic and the international suite of current and planned tokamak and non-tokamak facilities.

In this context, the committee has not found particularly useful the common characterization of the U.S. fusion program as a "base program" and a burning plasma program. All of the elements of the U.S. fusion program—advancing plasma science; developing fusion science, technology, and plasma confinement innovations; and pursuing fusion energy science and technology as a partner in the international effort—are essential and coupled.

The ITER program should not be the only determinant in the effort to achieve a new balance for the entire U.S. fusion program. For instance, a technology program without a strong science base, or a science program without a strong technology base, will leave the United States unable to build effectively on the developments coming from more advanced programs abroad as well as from the ITER program. In addition, the pursuit of fusion as an attractive energy source requires the investigation of critical plasma physics and stability issues, which are discussed in more detail later in this report (see the section entitled "Scientific Importance of a Burning Plasma for Fusion Energy Science and the Development of Fusion Energy" in Chapter 2). Many of the scientific and technical issues of importance to the long-range development of the fusion program will be best addressed by non-burning-plasma facilities with tokamak and non-tokamak machines. Thus, the U.S. fusion program must continue a domestic effort in parallel with the ITER project focused on developing the scientific base for promising fusion reactor concepts.

The committee emphasizes the need for a robust program of theory and simulation, coupled with experimental verification, to maximize the yield of scientific and technical understanding from a balanced fusion program. Theory and simulation are essential components in gaining understanding of large-scale fusion systems and have contributed significantly to progress in understanding the behavior

of fusion plasmas—for example, in the area of turbulence and nonlinear physics. Going forward, a program in theory and simulation must rely on a marriage of advances in experimental fusion science, information technology, plasma science, applied mathematics, and future developments in software.

The internationalization of fusion research is increasing along with the development of the ITER project. It is important that some of the pre-ITER research and development in the U.S. fusion science program be coordinated with international partners and the ITER process. The U.S. tokamak programs are already loosely integrated with major facilities in the European Union and Japan through the International Tokamak Physics Activity, which identifies and promotes areas of cross-fertilization and comparative experiments. The international effort should not be limited only to ITER activities, or indeed to collaborations on the large tokamaks in the global fusion portfolio. International partnerships for developing alternative fusion configurations have been and will continue to be important.

- **The U.S. fusion science program should make a focused effort to meet the need for personnel who will be required in the era of the burning plasma experiment. This effort should have the following goals: to attract talent to the field; to provide broad scientific and engineering training, specialized training, and training on large devices, as required; and to revitalize the fusion workforce.**

The recruitment, training, and retention of scientific and technical talent are crucial elements of the U.S. fusion program. The success of the U.S. fusion effort will depend on strong programs in plasma and fusion science. Among the continuing and future roles of universities are those of maintaining the workforce supply and serving as research centers that can generate and nurture new scientific and technological ideas, as well as leverage extensively the latest knowledge from other fields of science. The roles that university programs play in meeting needs for personnel and in providing new ideas and training opportunities can be expected to continue throughout the era of the burning plasma experiment and farther along the path to practical fusion energy. In addition, postdoctoral research programs at the national facilities provide critical advanced training in detailed fusion science issues. The technology component of the U.S. program will be the training ground for the fusion engineers and for those developing the industrial skills needed for the future.

- **Undertaking a burning plasma experiment cannot be done on a flat budget.**

As with any vibrant research program, the development of a scientifically and programmatically balanced program for fusion energy research and development must be matched with a credible and achievable funding plan. The plan should have a multiyear focus and fit within federal spending constraints. However, a flat budget for the OFES will inevitably lead to decay in facilities and a decline in research opportunities and will virtually guarantee that the United States will not gain the desired benefits from its investment. Such a reduced effort in the critical activities that the U.S. fusion community needs to pursue will increase the risk that the United States will play a following rather than a leading role in the ITER scientific program and the development of fusion energy.

A funding trajectory that avoids these risks would provide the support to capture the long-term benefits of joining the international ITER collaboration while retaining a strong scientific focus on the long-range goal of the domestic program. This approach would support fusion research as a vibrant and exciting enterprise with opportunities for attracting the best young talent into the field, as well as increasing the connections of fusion research to the other fields of science and engineering in academia. As important, such an approach will position the U.S. contingent in the ITER program to be leaders in significant fractions of the overall program.

- **Although active planning has been undertaken by the U.S. fusion community in recent years, the addition of so major a new element as ITER requires that, to ensure the continued success and leadership of the U.S. fusion science program, the content, scope, and level of U.S. activity in fusion should be defined through a prioritized balancing of the program. A prioritization process should be initiated by the Office of Fusion Energy Sciences to decide on the appropriate programmatic balance, given the science opportunities identified and the budgetary situation of the time. The balancing process also could be guided by multiyear budget planning that projects funding growth and should involve significant community input. The prioritization process should be organized with three elements of the fusion program in mind:**

  —To advance plasma science in pursuit of national science and technology goals;
  —To develop fusion science, technology, and plasma confinement innovations as the central theme of the domestic program; and
  —To pursue fusion energy science and technology as a partner in the international effort.

These program elements are indeed the three goals of the U.S. fusion program as outlined by the OFES in 1996. The committee affirms these elements as substantive and appropriate for a strategically balanced program.

The merit of any of the U.S. fusion science program activities now under way or envisioned does not mean that every activity can or even should be supported unconditionally. Any funding scenario that can be reasonably expected will necessitate deciding the relative priority of activities to pursue at any given time. The choice of which opportunities to pursue—and which program activities not to pursue—must be determined by the usual federal government process, advised by the fusion community and cognizant of international fusion efforts.

A rigorous evaluation of the U.S. fusion program priorities should be undertaken by the OFES with broad-based input from the fusion community. This priority-setting process should be guided by the objective of maintaining a balanced program, as discussed in this report, and it should result in a clear, ordered list of activities to be pursued. Such a list would identify those areas of science and technology that either have the greatest uncertainty or that promise the greatest impact for the future of the fusion program.

As with the planning done for other areas of science such as for high-energy physics, the fusion community should identify and prioritize the critical scientific and technology questions to address in concentrated, extended campaigns. A prioritized listing of those campaigns, with a clear and developed rationale for their importance, would be very helpful in generating support for their pursuit, while also requiring the development of a clear decision-making process in the fusion research community.

There are many unknowns as the fusion community embarks on this great scientific challenge. The elements required for the long-term health and vitality of this part of the U.S. research enterprise are not entirely clear, but this report strives to provide guidance for balancing the U.S. fusion program through an elucidation of the key scientific, technical, and programmatic issues that need to be addressed in the coming years as it enters the burning plasma era. What is clear is that whatever strategy is adopted, it should be flexible, innovative, and inclusive in achieving the required balance for success.

Having concluded that the United States is ready to take the next critical step in fusion research, the committee recommends the implementation of a burning plasma experiment through participation in the ITER program as part of a strategically balanced U.S. fusion program. The opportunity for advancing the science of fusion energy has never been greater or more compelling, and the fusion community has never been so ready to take this step.

PLASMA SCIENCE

Advancing Knowledge in the National Interest

Plasma 2010 Committee

Plasma Science Committee

Board on Physics and Astronomy

Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

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Summary

Plasma science is on the cusp of a new era. It is poised to make significant breakthroughs in the next decade that will transform the field. For example, the international magnetic fusion experiment—more exactly, the International Thermonuclear Experimental Reactor (ITER)—is expected to confine burning plasma for the first time, a critical step on the road to commercial fusion. The National Ignition Facility (NIF) plans to ignite capsules of fusion fuel to acquire knowledge necessary to improve the safety, security, and reliability of the nuclear stockpile. Low-temperature plasma applications are already ushering in new products and techniques that will change everyday lives. And plasma scientists are being called on to help crack the mysteries surrounding exotic phenomena in the cosmos. This dynamic future will be exciting but also challenging for the field. It will demand a well-organized national plasma science enterprise. This report examines the broad themes that frame plasma research and offers a bold vision for the future.

Principal Conclusion: The expanding scope of plasma research is creating an abundance of new scientific opportunities and challenges. These opportunities promise to further expand the role of plasma science in enhancing economic security and prosperity, energy and environmental security, national security, and scientific knowledge.

Plasma science has a coherent intellectual framework unified by physical processes that are common to many subfields. Therefore, and as this report shows, plasma science is much more than a basket of applications. The Plasma 2010 Committee believes that it is important to nurture fundamental knowledge of plasma

science across all of its subfields in order to advance the science and to create opportunities for a broader range of science-based applications. These advances and opportunities are, in turn, central to the achievement of national priority goals such as fusion energy, economic competitiveness, and stockpile stewardship.

The vitality of plasma science in the past decade testifies to the success of some of the individual federally supported plasma science programs. However, the emergence of new research directions necessitates a concomitant evolution in the structure and portfolio of programs at the federal agencies that support plasma science. The committee has identified four significant research challenges that the federal plasma science portfolio as currently organized is not equipped to exploit optimally: fundamental low-temperature plasma science; discovery-driven, high-energy-density plasma science; intermediate-scale plasma science; and crosscutting plasma research.

Notwithstanding the success of individual federal plasma science programs, the lack of coherence across the federal government ignores the unity of the science and is an obstacle to overcoming many research challenges, realizing scientific opportunities, and exploiting promising applications. The committee observes that effective stewardship of plasma science as a discipline will likely expedite the applications of plasma science. The need for stewardship has been identified in many reports over two decades. The evolution of the field has only exacerbated the stewardship problem, and the committee concluded that the need for a new approach is greater than ever.

Recognizing the need both to provide an integrated approach and to connect the science to applications and the broader science community, the committee considered a number of options. After weighing relative pros and cons, the committee recommends as follows:

> **Principal Recommendation: To fully realize the opportunities in plasma research, a unified approach is required. Therefore, the Department of Energy's Office of Science should reorient its research programs to incorporate magnetic and inertial fusion energy sciences; basic plasma science; non-mission-driven, high-energy-density plasma science; and low-temperature plasma science and engineering.**

The new stewardship role for the Office of Science would extend well beyond the present mission and purview of the Office of Fusion Energy Sciences (OFES). It would include a broader portfolio of plasma science as well as the research OFES currently supports. Two of the thrusts in this portfolio would be new: (1) a non-mission-driven, high-energy-density plasma science program and (2) a low-temperature plasma science and engineering program. The stewardship framework would not replace or duplicate the plasma science programs in other agencies; rather, it would enable a science-based focal point for federal efforts in plasma-

based research. These changes would be more evolutionary than revolutionary, starting modestly and growing with the expanding science opportunities. The committee recognizes that these new programs would require new resources and perhaps a new organizational structure for the Office of Science.

A comprehensive strategy for stewardship will be needed to ensure a successful outcome. Other guidance for implementing this vision appears in the main report. Among the issues to be addressed in planning such a strategy are these:

- Integration of scientific elements,
- Development of a strategic planning process that not only spans the field but also provides guidance to each of the subfields, and
- Identification of risks and implementation of strategies to avoid them.

There is a spectacular future awaiting the United States in plasma science and engineering. But the national framework for plasma science must grow and adapt to new opportunities. Only then will the tremendous potential be realized.

A Review of the DOE Plan for U.S. Fusion Community Participation in the ITER Program

Committee to Review the U.S. ITER Science Participation Planning Process

Plasma Science Committee
Board on Physics and Astronomy
Division on Engineering and Physical Sciences

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Executive Summary

ITER, a planned next-generation fusion research facility, presents the United States and its international partners with the opportunity to explore new and exciting frontiers of plasma science while bringing the promise of fusion energy closer to reality. The ITER project has garnered the commitment and will draw on the scientific potential of seven international partners—China, the European Union, India, Japan, the Republic of Korea, Russia, and the United States—countries that represent more than half of the world's population. The success of ITER will depend on each partner's ability to fully engage in the scientific and technological challenges posed by advancing the understanding of fusion.

The National Research Council's Committee to Review the U.S. ITER Science Participation Planning Process was asked to assess the current U.S. Department of Energy (DOE) plan for U.S. fusion community participation in ITER, evaluate the plan's elements, and recommend appropriate goals, procedures, and metrics for consideration in the future development of the plan.[1] The committee found that:

- The 2006 DOE plan for U.S. participation in ITER is operating and has proven effective in beginning to coordinate U.S. research activities and the development of the ITER program. U.S. scientists have

[1]U.S. Burning Plasma Organization, *Planning for U.S. Fusion Community Participation in the ITER Program*, June 7, 2006. The DOE plan is available at http://www.ofes.fusion.doe.gov/News/EPAct_final_June06.pdf, last viewed on July 22, 2008.

been well engaged in the planning for ITER, and the United States should endeavor to maintain this level of activity. The plan, in its current form, is well aligned with DOE Office of Fusion Energy Sciences goals.

- The U.S. ITER research program is at least as organizationally and technically mature as that of the other ITER participants at the time of this writing.[2]
- The U.S. research program for ITER as described in the DOE plan is appropriate and justified, and the committee notes that the domestic program will evolve as the international research program is developed. U.S. involvement in developing the research program for ITER will be crucial to the realization of U.S. fusion research goals.
- The committee underscores as its greatest concern the uncertain U.S. commitment to ITER at the present time. Fluctuations in the U.S. commitment to ITER will undoubtedly have a large negative impact on the ability of the U.S. fusion community to influence the developing ITER research program, to capitalize on research at ITER to help achieve U.S. fusion energy goals, to participate in obtaining important scientific results on burning plasmas from ITER, and to be an effective participant in and beneficiary of future international scientific collaborations.
- Consistent with previous National Research Council and Fusion Energy Sciences Advisory Committee reports, the committee emphasizes that a vigorous and strategically balanced domestic program is required to ensure that U.S. participation in ITER is successful and valuable for the U.S. fusion program.
- The DOE plan for U.S. participation in ITER includes well-thought-out metrics for measuring progress toward development of fusion energy as a power source.
- The DOE plan includes well-thought-out metrics to measure the robustness of U.S. participation in the ITER program.

Based on these findings, the committee makes the following recommendations:

- **The Department of Energy should take steps to seek greater U.S. funding stability for the international ITER project to ensure that the United States remains able to influence the developing ITER research program, to capitalize on research at ITER to help achieve U.S. fusion energy goals, to participate in obtaining**

[2]As of April 8, 2008.

important scientific results on burning plasmas from ITER, and to be an effective participant in and beneficiary of future international scientific collaborations.

- **Important considerations that are not reflected in the current DOE plan for U.S. participation in ITER should be addressed during the further development of the DOE plan. These considerations include:**
  —Existing gaps in planning for a Demonstration Power Plant,
  —Dissemination of information on and the results of ITER research activities to the broader scientific community, and
  —Planning for the recruitment and training of young scientists and engineers.

- **The committee recommends that the following goals be adopted as the foundation of DOE planning activities for U.S. participation in ITER:**
  —Ensuring broad academic and industry participation in ITER,
  —Enabling the United States to contribute substantially to and reap the rewards from ITER, and
  —Recruiting and training young fusion scientists and engineers.

- **The committee recommends the following procedures to accomplish the U.S. planning goals recommended above, and to facilitate the further development of the DOE plan:**
  —DOE should create a long-term strategic plan for the U.S. burning plasma fusion program within the context of global fusion energy development activities.
  —The U.S. Burning Plasma Organization should continue to be an essential point of communication, and serve as a home team to encourage broad cooperation and collaboration among all U.S. participants in the ITER project.
  —DOE should maintain a vibrant domestic fusion program through strong support for basic research and facilities.
  —The DOE plan for U.S. participation in ITER should consider what capabilities exist and need to exist at U.S. plasma science facilities.
  —The DOE plan should consider the needed operating availability of domestic tokamaks.

- **The committee recommends that the following five metrics be considered for inclusion during the future development of the DOE plan for U.S. fusion community participation in ITER:**

—Periodic evaluation by expert and knowledgeable members of the scientific, engineering, and industrial community regarding the U.S. return on its ITER investment.
—Periodic assessments by independent, external bodies of the effectiveness of domestic project management.
—Balance in the fraction of U.S. published research conducted on ITER according to authors' institutional affiliations (university, national laboratory, and industry).
—Number of research and technology publications documenting results obtained on ITER that are cited by or produced in collaboration with U.S. researchers, students, and technologists across U.S. plasma science and physics.
—Achievement of predictive capability, to be evaluated by peer review.

Recommendations from Previous NRC Committee Reports Relevant to Issues before the FESAC Subcommittee on a Review of Priorities for Magnetic Fusion Energy

From ***Burning Plasma: Bringing a Star to Earth*** **(2004)**

From p. 3:

"Undertaking a burning plasma experiment cannot be done on a flat budget. If the United States is interested in the long-term goal of fusion as a source of economical, sustainable energy and not only in the ITER effort, the nation needs a science program based on some of the existing facilities; a technology program; a computation, simulation, and theory program; and a university program. At a minimum, to capture the benefits of a burning plasma experiment, an augmentation of the U.S. program covering all of the U.S. ITER construction and operating costs would be required in the near term."

From p. 8:

"Although active planning has been undertaken by the U.S. fusion community in recent years, the addition of so major a new element as ITER requires that, to ensure the continued success and leadership of the U.S. fusion science program, the content, scope, and level of U.S. activity in fusion should be defined through a prioritized balancing of the program. A prioritization process should be initiated by the Office of Fusion Energy Sciences to decide on the appropriate programmatic balance, given the science opportunities identified and the budgetary situation of the time. The balancing process also could be guided by multiyear budget planning that projects funding growth and should involve significant community input. The prioritization process should be organized with three elements of the fusion program in mind:

- To advance plasma science in pursuit of national science and technology goals;

- To develop fusion science, technology, and plasma confinement innovations as the central theme of the domestic program; and
- To pursue fusion energy science and technology as a partner in the international effort."

From ***Plasma Science: Advancing Knowledge in the National Interest*** **(2007)**

From p. 1:

"Principal Conclusion: The expanding scope of plasma research is creating an abundance of new scientific opportunities and challenges. These opportunities promise to further expand the role of plasma science in enhancing economic security and prosperity, energy and environmental security, national security, and scientific knowledge."

From p. 2:

"Principal Recommendation: To fully realize the opportunities in plasma research, a unified approach is required. Therefore, the Department of Energy's Office of Science should reorient its research programs to incorporate magnetic and inertial fusion energy sciences; basic plasma science; non- mission-driven, high-energy-density plasma science; and low-temperature plasma science and engineering."

From p. 3:

"A comprehensive strategy for stewardship will be needed to ensure a successful outcome. Other guidance for implementing this vision appears in the main report. Among the issues to be addressed in planning such a strategy are these:

- Integration of scientific elements,
- Development of a strategic planning process that not only spans the field but also provides guidance to each of the subfields, and
- Identification of risks and implementation of strategies to avoid them."

From p. 149:

"While the scientific opportunities, the promising methodologies, and the program elements are clear, the detailed program structure is not. Although the ITER site was decided on only in mid-2005, the recent establishment of the U.S. Burning Plasma Organization is a positive step. However, the U.S. fusion program does not have a strategy for its evolution over time periods longer than the yearly budget cycles. In particular, it has not responded adequately to a program recommendation of the Burning Plasma Assessment Committee: 'A strategically balanced U.S. fusion program should be developed that includes U.S. participation in ITER, a strong domestic fusion science and technology portfolio, an integrated theory and simulation program, and support for plasma science. As the ITER project develops, a substantial augmentation in fusion science program funding will be required in addition to the direct financial commitment to ITER construction.' This recommendation has not yet been adequately addressed beyond participation in ITER."

From ***A Review of the DOE Plan for U.S. Community Participation in the ITER Program*** **(2008)**

From p. 2:

"Consistent with previous National Research Council and Fusion Energy Sciences Advisory Committee reports, the committee emphasizes that a vigorous and strategically balanced domestic program is required to ensure that U.S. participation in ITER is successful and valuable for the U.S. fusion program."

From p. 24:

"The committee agrees with the following relevant statement from the NRC Burning Plasma report: 'A strategically balanced U.S. fusion program should be developed that includes U.S. participation in ITER, a strong domestic fusion

science and technology portfolio, an integrated theory and simulation program, and support for plasma science. As the ITER project develops, a substantial augmentation in fusion science program funding will be required in addition to the direct financial commitment to ITER construction.' The strong U.S. participation in the ITER design review demonstrates the importance of a vibrant base program, including personnel and facilities, that can engage in the scientific issues to be explored at ITER. It is critical that these domestic capabilities be maintained. The overall strategy of the domestic program currently is to develop a predictive understanding of the plasma science associated with magnetically confined plasmas, which the committee believed to be very appropriate to the long-term health of the U.S. fusion program, and specifically to its involvement in the ITER project. The ability to carry out detailed experimental studies of relevant plasma scenarios coupled with theory/simulation provides the framework for progress in this predictive ability, which is best accomplished with a vigorous domestic research program. Longer-term research efforts may well be directed toward reactor design, alternative approaches to magnetic confinement, and materials development in accord with DOE's strategic plan. However, each of these research areas needs to be based on improved predictive capability.

Finding: Consistent with previous National Research Council and Fusion Energy Sciences Advisory Committee reports, the committee emphasizes that a vigorous and strategically balanced domestic program is required to ensure that U.S. participation in ITER is successful and valuable for the U.S. fusion program."