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

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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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Preface

The development of a plan for the participation of the U.S. fusion community in the ITER program was mandated by the Energy Policy Act of 2005 (EPAct). The EPAct, in Section 972 (c)(4)(B), also directed that, after completion of the plan, the U.S. Department of Energy (DOE) request an external review of its content. Accordingly, on August 10, 2006, the DOE Under Secretary for Science submitted the completed plan to the National Academy of Sciences for review (see Appendix A). In response, the National Research Council (NRC) organized the committee to review the DOE plan with the following charge:

> The committee will prepare a short report addressing the following tasks:
>
> 1. Review the document "Planning for U.S. Fusion Community Participation in the ITER Program." Determine whether the plan provides a good initial outline for effective participation of U.S. plasma scientists in research at ITER.
>
> 2. Evaluate the following required elements of the plan: (1) an agenda for U.S. research at ITER, (2) methodologies to evaluate ITER's contribution to progress toward a power source, (3) description of the anticipated relationship between the U.S. ITER research program and the overall U.S. fusion program.
>
> 3. The committee will recommend next steps in the development of the plan, including: (a) appropriate elements and/or goals for the plan; (b) procedures to facilitate further development of the plan; and (c) metrics for measuring progress in establishing robust U.S. participation in the ITER research program.

The committee was appointed on October 1, 2007, and met in Washington, D.C. on December 14-15, 2007. Soon after, the FY2008 Consolidated Appropriations Act became law, under which U.S. contributions for ITER were unexpectedly eliminated. Although this committee was not specifically tasked to assess the implications of the FY2008 budget, it believes that the budget will necessarily affect U.S. researchers' ability to participate fully in the ITER project, and it therefore felt obliged to address this issue.

This report reviews and evaluates the DOE plan and the status of DOE planning based on the above criteria, and recommends next steps in the development of the plan. The committee observes that domestic planning activities have been effective thus far. However, as the ITER project progresses, the organizational landscape will likely change, as will the developing international research agenda. The committee therefore presents a snapshot of the ITER project as it exists at the present time. The full value of the committee's guidance lies in its recommended elements and procedures to help position the United States to maximize its participation in and reward from the important international scientific and technical endeavor embodied in ITER.

The committee thanks its guest speakers at its December 14, 2007 meeting, including Kathryn Beers, Office of Science and Technology Policy; Earl Marmar, Massachusetts Institute of Technology; Stanley Milora, Oak Ridge National Laboratory; Erol Oktay, Department of Energy; Ned Sauthoff, Oak Ridge National Laboratory; and James Van Dam, University of Texas at Austin. Special thanks are due to our foreign colleagues who participated in the meeting despite the long distances, namely, David Campbell, ITER Organization; Shinzaburu Matsuda, Japan Atomic Energy Agency; and Jerome Pamela, European Fusion Development Agreement. The committee greatly appreciates the time and effort that all of these individuals put into preparing their remarks and participating in discussions.

Patrick L. Colestock, *Chair*
Committee to Review U.S. ITER Science Participation Planning Process

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Gordon Baym, University of Illinois at Urbana-Champaign
Michael Brown,Swarthmore College
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Ronald C. Davidson, Princeton University
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Charles F. Kennel, University of California at San Diego
Christopher Llewellyn-Smith, UKAEA–Culham Division
David Meyerhofer, University of Rochester, and
John Peoples, Jr., Fermi National Accelerator Laboratory
Clifford Surko, University of California at Berkeley.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by John F. Ahearne of Sigma Xi and Duke University. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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Executive Summary

ITER 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 itself in the scientific and technological challenges posed by advancing our understanding of fusion.

The NRC Committee to Review the U.S. ITER Science Participation Planning Process was tasked 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 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 project.

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**

[1] U.S. Burning Plasma Organization, "Planning for U.S. Fusion Community Participation in the ITER Program," June 7, 2006, p.330. The DOE plan is available at http://www.ofes.fusion.doe.gov/News/EPAct_final_June06.pdf.
[2] As of April 8, 2008.

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.

- **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 industrial 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 author's institutional affiliation (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.

1

Introduction

History of the ITER Project

The idea to utilize a controlled, sustainable, magnetically-confined plasma to generate energy by fusing together light nuclei was first envisioned in the 1950's following research stemming from the Manhattan Project. In 1958, fusion energy research was declassified, triggering a decade of nascent research efforts around the world. In 1968, the Soviet Union reported a major breakthrough in magnetically-confined fusion, consisting of a confinement concept called a "tokamak": an acronym composed of Russian words meaning "toroidal magnetic chamber." Following this breakthrough, fusion developed rapidly, consistently doubling fusion performance every year, as countries competed to improve the performance of the tokamak concept over successive generations of experiments.

As technical capabilities expanded, worldwide interest in the potential impact of fusion research on society increased. Harnessing fusion energy for domestic energy production became an element of U.S. energy policy during the energy crisis of the 1970's. As the crisis continued, President Carter's Administration highlighted the importance of fusion energy in the Magnetic Fusion Energy Engineering Act of 1980, which committed to aggressively pursuing fusion research. However, just as the Act was enacted, the energy crisis began to retreat due to a variety of world events. As a consequence, the recommendations of the 1980 Act were never implemented by the U.S. government. Later on, at the Geneva Summit in 1985, the United States joined the Soviet Union, European Union, and Japan to undertake a joint design of a tokamak experimental reactor. This design provided the early foundations for the current ITER project.

By the mid-1990's, two tokamak devices achieved the generation of controlled fusion power of more than ten megawatts for of order several seconds. The devices were the Tokamak Fusion Test Reactor (TFTR) in Princeton, New Jersey and the Joint European Torus (JET) in the United Kingdom. The experimental milestones achieved at these facilities in the confinement, heating, control and the first use of tritium fuel were significant. Scientifically a critical finding was that the energetic helium ions produced by the deuterium-tritium (D-T) fusion reaction were well-confined and behaved as expected, i.e. they "gave back" essentially all their energy to the plasma itself. These experiments provided the technical and scientific confidence that a burning plasma could be achieved in a next generation device, the device presently designated as ITER. In such "burning plasma" devices the 20% of the energy generated by the fusion reactions found in the He ions mentioned above is used to maintain the necessary high temperatures, i.e, the fusion reactions will self-heat and sustain the plasma. This is the fundamental feature of an energy-producing tokamak plasma that will be found in fusion reactors, but not in present devices.

Although the U.S. was one of the original ITER parties, in 1998 Congress ordered DOE to withdraw from the international collaboration. In spite of the U.S. withdrawal, partners in Europe, Russia, and Japan continued to advance the design of the project. These efforts resulted in a slight de-scoping of technical objectives, but led to the present ITER design that provided access to burning plasma regimes at a reduced cost. In parallel, the U.S. fusion community held a series of workshops that found broad support for advancing a burning plasma experiment. Several burning-plasma options were examined, and the community gave the new ITER design a favorable technical assessment. The committee also noted that the ITER project had adopted changes advocated by the U.S.. Motivated by the renewed perspective concerning the next step in magnetic fusion research, the DOE Fusion Energy Sciences Advisory Committee voiced its support for the U.S. to rejoin the ITER negotiations. Similarly, the U.S. National Research Council's Burning Plasma Assessment Committee in 2002 reaffirmed this recommendation to rejoin talks and stated that "the U.S. fusion program, after many years of research, is poised to take a major step toward its energy goal. It is clear that a burning plasma experiment is a necessary step on the road to fusion energy and of scientific and technical interest to the U.S. fusion program and beyond." (Burning Plasma, p. 38). On January 30, 2003, President Bush released a Presidential Initiative[1] announcing that the U.S. would rejoin the collaboration. The project by then consisted of the original 1996 members: Russia, the U.S., the European Union (EU), and Japan; and also included new members the People's Republic of China, and the Republic of Korea (with India joining in 2005), indicating the broad international appeal and support of the project. In November 2003, Secretary of Energy Spencer Abraham announced that ITER would be the top priority in the 20-year facility development plan of the DOE Office of Science. The history of U.S. participation in the ITER project has been complicated, but it serves to highlight the resiliency of the ITER project, both in terms of its appeal as a science project, and also as a groundbreaking international collaboration. Lessons learned from earlier international collaborations, such as the Large Hadron Collider, have helped to effectively organize the ITER project. In fact, ITER is being considered as a model for future large-scale, international science projects.

The Present ITER Project

The objective of the ITER project, as given in the ITER Joint Implementation Agreement, is "to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes, an essential feature of which would be achieving sustained fusion power generation."[2] As stated on the ITER Web site, "ITER will accomplish this objective by demonstrating high power amplification and extended burn of deuterium-tritium plasmas, with steady-state as an ultimate goal, by demonstrating technologies essential to a reactor in an integrated system, and by performing integrated testing of the high-heat-flux and nuclear components required to utilize fusion energy for practical purposes."[3]

ITER currently plans to begin construction in 2008, seeks to achieve its first plasma in 2018, and is expected to operate for 20 years. It aims to produce 500 MW of fusion power for 400 seconds by 2024. The partners in the ITER project will provide in-kind contributions for construction of the project commensurate with their agreed-upon level of involvement. The host, the European Union, will provide 5/11 (45.4%) and the 6 non-hosts will provide 1/11 (9.1%) of these in-kind contributions, which for the largest part consist of components for the machine.

The formal site selection process for ITER began with Canada's proposal to site the experiment at Clarington in 2001, followed by proposals for a Japanese site at Rokkasho-Mura, a Spanish site at Vandellos, and a French site at Cadarache. The EU decided to consolidate the European site proposals to a single one for Cadarache, which ultimately proved successful on June 28, 2005.

On November 21, 2006, the United States, represented by Dr. Raymond L. Orbach, Under Secretary for Science of the U.S. Department of Energy (DOE), and its international partners signed the International Fusion Energy Agreement, cementing the seven member countries' participation in the project. Less than a year later, on October 24, 2007, with the signatures of the ITER parties, the ITER Organization was officially created, and the United States, along with its six foreign collaborators, became official, fully participatory members. The purpose of this organization is "to provide for and to

[1] George W. Bush, "Promoting Energy Independence Through Cooperative Research to Develop Fusion Energy," January 30, 2003.
[2] ITER Organization, "Agreement on the Establishment of the ITER International Fusion Energy Organization for the Joint Implementation of the ITER Project," Article 2, November 21, 2006. Available at http://www.iter.org/JIA_text.htm, last viewed March 6, 2008.
[3]As defined on the ITER Web site at http://www.iter.org/Objectives.htm.. Last viewed March 6, 2008.

promote cooperation among the Members . . . on the ITER Project."[4] As it becomes operational, the ITER Organization will coordinate the construction and operation of ITER, and will interface with the seven nations involved in the project. In addition to ITER, the EU and Japan negotiated a separate bilateral agreement (the "Broader Approach" agreement) to jointly construct and operate a number of fusion facilities in parallel with ITER to be sited in Japan.

Recent U.S. Developments

Since the U.S. decision to participate, domestic progress on the project has proceeded smoothly until recently. In the Energy Policy Act of 2005 (Public Law 109-58, August 8, 2005), Congress authorized negotiation of "an agreement for United States participation in the ITER," and participation in ITER is identified by the DOE Office of Science as its top priority for the next 20 years.[5]

However, in the FY 2008 U.S. Consolidated Appropriations Act, funding for the project was nearly eliminated for the year. Although DOE had requested from Congress "funding of $160.0 million in FY 2008," the FY2008 budget as appropriated allocates "$0 for the U.S. contribution to ITER, and $10,724,000 for Enabling R&D for ITER," adding that "[f]unding may not be reprogrammed from other activities within Fusion Energy Sciences to restore the U.S. contribution to ITER."[6] This eliminated funding for the U.S. "in-kind" equipment contributions to ITER, U.S. personnel to work at the ITER site, cash for the U.S. share of common expenses such as infrastructure, hardware assembly and installation, and contingency for the ITER Organization for FY2008. U.S. financial participation in the international project remains suspended at the time of this report's writing. While U.S. funding for the project appears to waver, Undersecretary for Science, Dr. Raymond Orbach, in a letter to ITER Organization Director General Kaname Ikeda stated that "the U.S. is firmly committed to meeting our obligations under the ITER Joint Implementing Agreement (JIA) and that we are doing everything possible to rectify the situation."[7] For FY08, at least, the implications of the FY08 appropriations as stated in Dr. Orbach's letter are that "there will be some limitations in our ability to fully participate in ITER activities", but that we will remain engaged in key technical, scheduling and planning activities.

U.S. participation in ITER in FY2008 will be at a minimal level and its cash and in-kind procurement contributions will be zero. The lack of the anticipated funding has implications for the U.S.' ability to participate in and influence the project, as the U.S. ITER Project Office has been reduced to a core team. It is also worth noting that the promised contributions will remain due under the JIA, as will contributions in the out-years, such that DOE will have to make up the difference.

The President's FY2009 budget request to Congress includes $214.5 million for the project. It should be noted that though this request, if appropriated, restores U.S. participation in FY2009, support for the project in the subsequent out-years is not guaranteed. It will take strong leadership from the Executive and Legislative branches to ensure the project's long-term health and success.

Origin of this Study

[4] ITER Organization, "Agreement on the Establishment of the ITER International Fusion Energy Organization for the Joint Implementation of the ITER Project," Article 2, November 21, 2006. Available at http://www.iter.org/JIA_text.htm, last viewed March 6, 2008.
[5] U.S. Department of Energy, "Four Years Later: An Interim Report on Facilities for the Future of Science: A Twenty-Year Outlook," August 2007, p.8.
[6] U.S. Government, "Consolidated Appropriations Act for FY2008," December 2007.

[7] U.S. DOE, Letter to Director General Kaname Ikeda, January 10, 2008.

In Sec. 972 (c)(4)(A) of the EPAct of 2005, Congress directed the Department of Energy to “in consultation with the Fusion Energy Sciences Advisory Committee, …. develop a plan for the participation of United States scientists in the ITER that shall include:

(i) the United States research agenda for the ITER;

(ii) methods to evaluate whether the ITER is promoting progress toward making fusion a reliable and affordable source of power; and

(iii) a description of how work at the ITER will relate to other elements of the United States fusion program.”

In February 2006, DOE asked the U.S Burning Plasma Organization (USBPO) to develop this plan. The resulting report, “Planning for U.S. Fusion Community Participation in the ITER Program,”[8] completed in June 2006, represents an important first step in organizing the U.S. ITER Project Office and the plasma science community in order to successfully participate in the project. The plan was submitted to Congress by DOE on August 10, 2006.

Similarly, DOE was directed in Sec. 972 (c)(4)(B) of the EPAct of 2005 to request a review of this plan by the National Academy of Sciences. The committee convened herein was tasked to review and evaluate the current DOE plan, “Planning for U.S. Fusion Community Participation in the ITER Program,” and then recommend elements for future development of the plan for U.S. plasma science participation in the ITER project.

ITER represents one of the largest international scientific endeavors ever undertaken, and offers all parties involved an opportunity to jointly work towards the understanding of fusion energy.

[8] U.S. Burning Plasma Organization, “Planning for U.S. Fusion Community Participation in the ITER Program,” June 7, 2006. Available at http://www.ofes.fusion.doe.gov/News/EPAct_final_June06.pdf.

2

Evaluation of the Current DOE Plan for U.S. Plasma Science Community Participation in ITER

Organization of the U.S. ITER Effort and Planning Status Assessment

The Department of Energy (DOE) plan provides defined structures for organizing the participation of the U.S. researchers in ITER research during the construction phase, and a phased U.S. research agenda for ITER. The plan also identified mechanisms for adapting and advancing the plan as ITER develops (see Figures 2.1 and 2.2). In the period since the report was submitted, the structures and mechanisms it described have been established and are operating. In addition, the ITER agreement came into force, the international ITER Organization (IO) was established, and an international technical review of the ITER design was conducted.

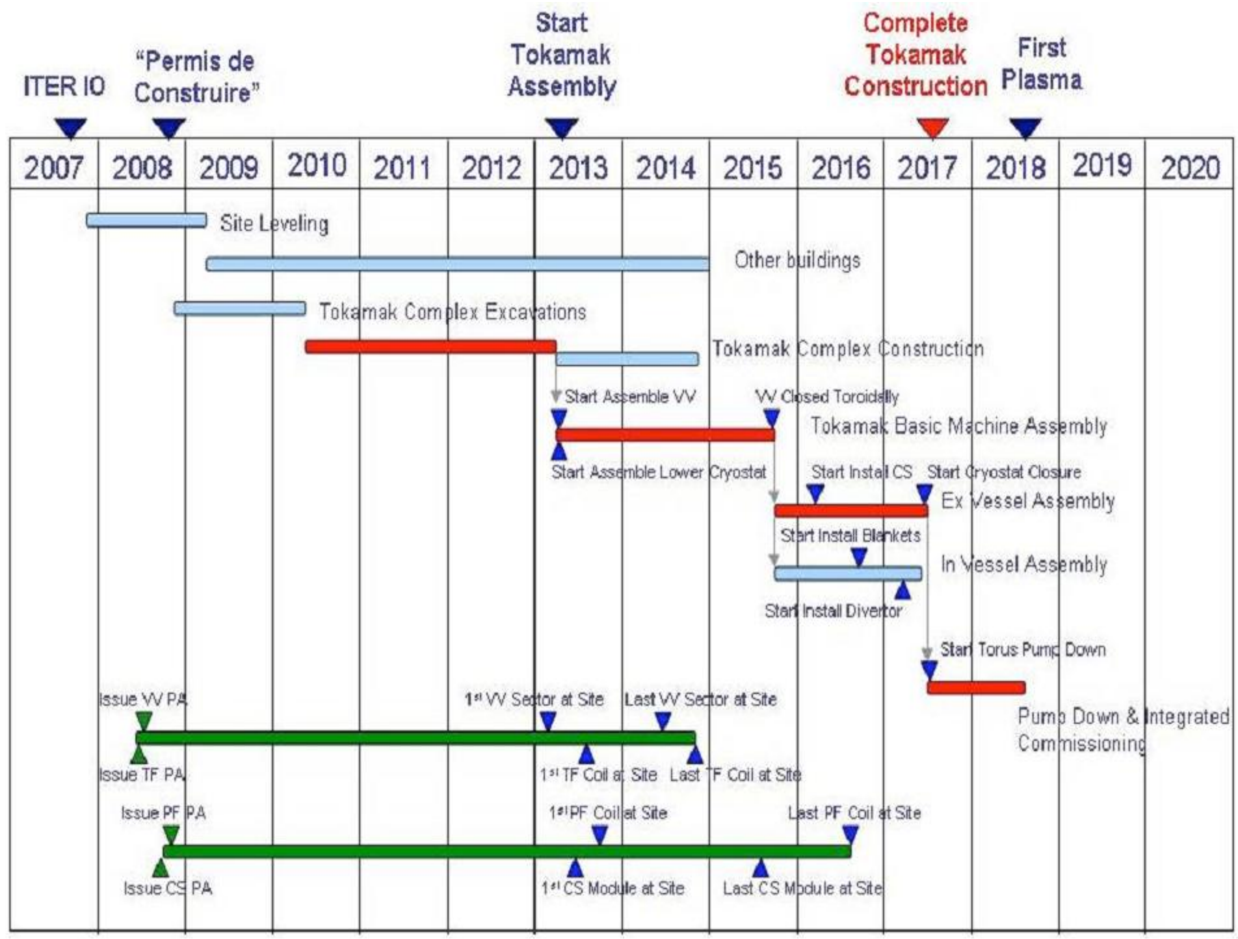

Figure 2.1: The revised ITER Project schedule, approved by the ITER Council for planning purposes in June 2008. Copyright by the ITER Organization. Reprinted by permission.

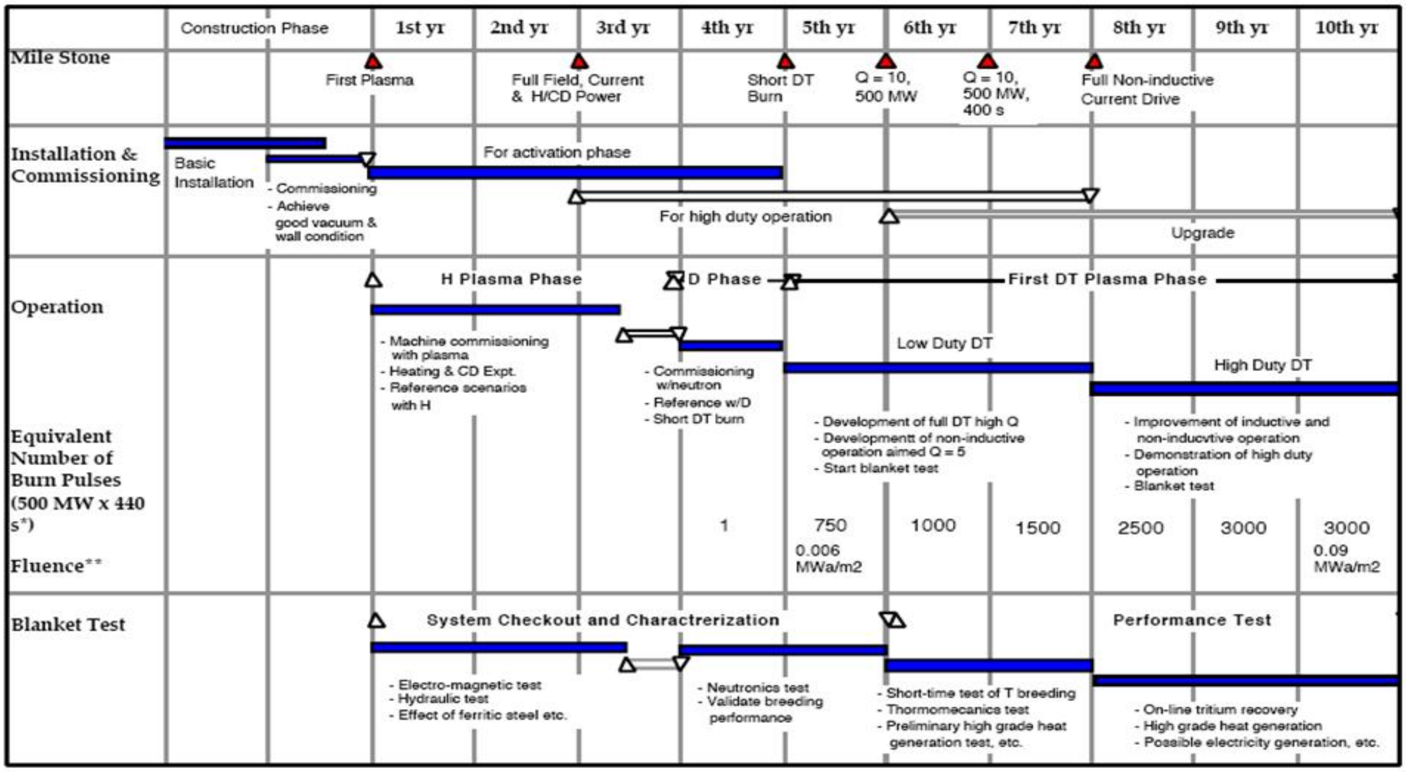

Figure 2.2: The current schedule of the ITER Operation Program. Copyright by the ITER Organization. Reprinted by permission.

The DOE plan provides effective mechanisms and guidance supporting U.S. participation in ITER research, addressing the U.S. research agenda. The plan has been elaborated and built upon in subsequent planning processes, including the ongoing FESAC strategic planning and U.S. participation in ITER Organization (IO) research planning.

The key structural elements of the U.S. participation in ITER are: the U.S. ITER Project Office (USIPO), the U.S. Burning Plasma Organization (USBPO), the Virtual Lab for Technology (VLT), the International Tokamak Physics Activity (ITPA), and the Office of Fusion Energy Science (OFES), as shown in Figures 2.3 and 2.4. The USIPO is the domestic project responsible for the U.S. contributions to ITER construction and it supports U.S. R&D needed for ITER construction. The USBPO is the recently formed (2005) organization for coordinating and advocating scientific research activities in support of ITER and preparing for exploitation of ITER. OFES coordinates the activities of the USIPO, USBPO, and VLT to effectively interface with the IO. The VLT is the U.S. organization responsible for directing and coordinating engineering science and technology activities in support of ITER, including a large number of ITER R&D tasks. The Director of the USBPO and the Director of the VLT are the chief scientist and the chief technologist for the USIPO, respectively, ensuring close coupling of all three organizations and coupling of ITER to the U.S. scientific and engineering communities. The ITPA has been the primary international scientific coordinating body for voluntary support of ITER, identifying critical issues and facilitating joint experiments across the ITER partners. U.S. members of the ITPA are members of the USBPO, helping ensure good communication and interaction amongst these groups. The ITPA provides a direct connection between the world-wide science communities and the ITER

Organization (IO), and will soon come under the auspices of the IO. The ITPA may be viewed as the precursor of the international research team for ITER exploitation. Similarly, the USBPO may be the precursor to the U.S. ITER research team or users group.

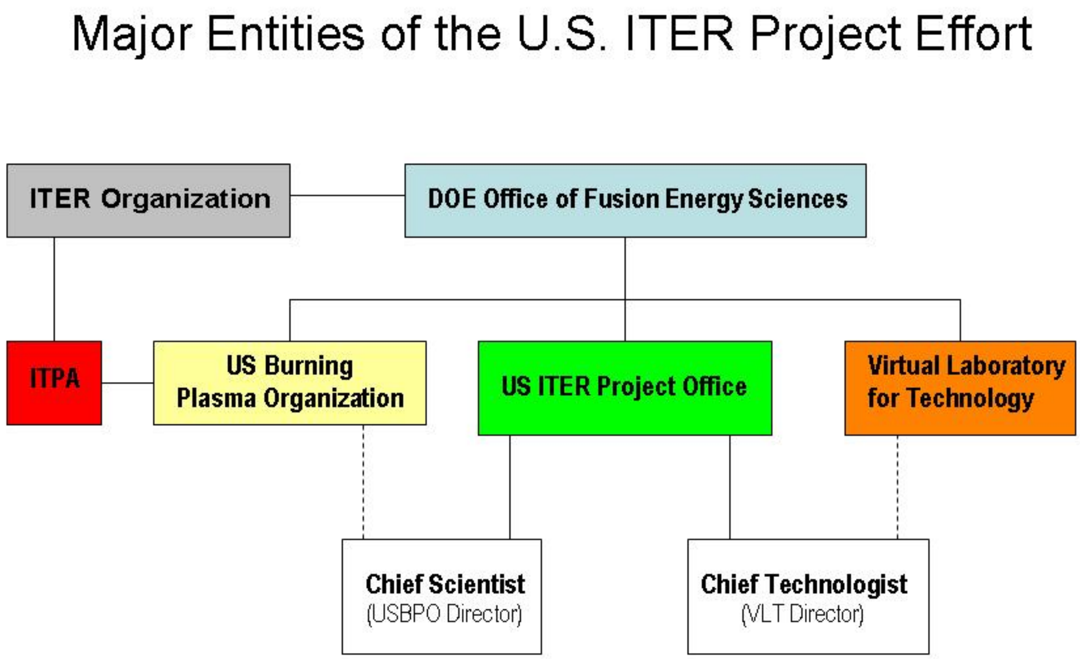

Figure 2.3: This figure shows the major U.S. activities of the U.S. ITER effort and how they are organized.

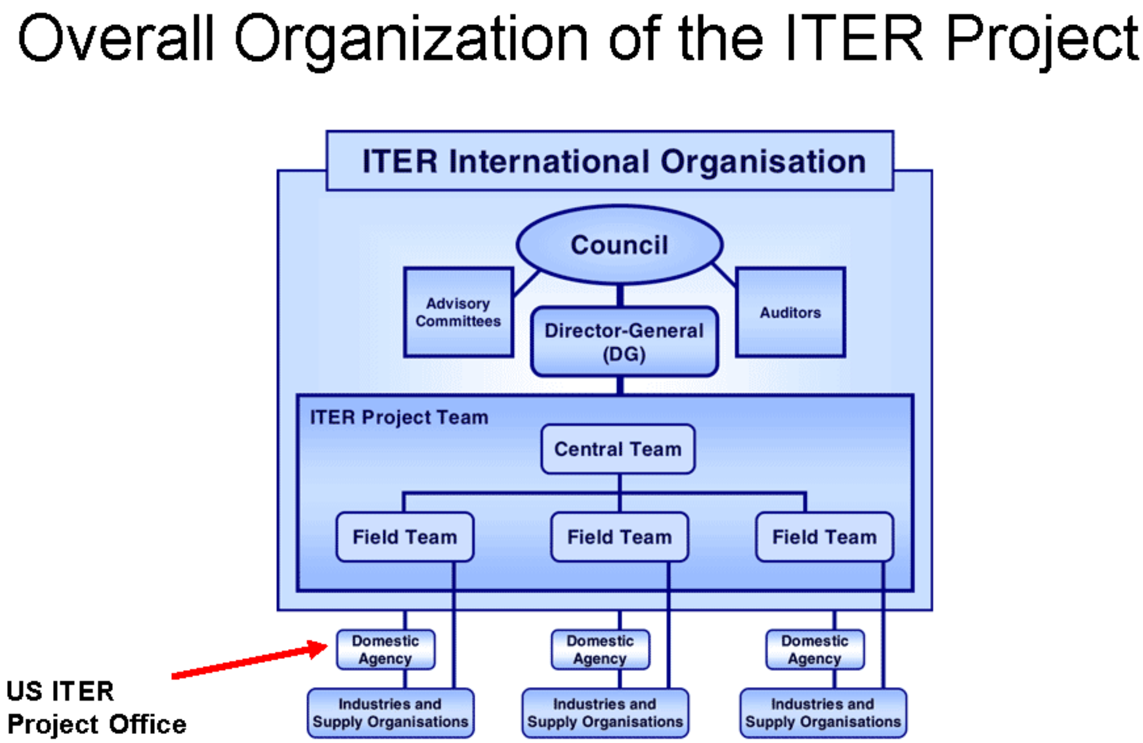

Figure 2.4: This figure depicts the overall organization of the ITER project. Courtesy of the ITER Organization.

The USBPO is the key organization for participating in ITER research in the U.S. It is an open organization with 289 members (as of December 2007) across the entire U.S. fusion community. The USBPO is organized into 10 research groups focused on high priority topical areas. The group leaders meet biweekly, via video-conferencing, to coordinate, prioritize and organize tasks on burning plasmas, focusing on ITER. The USBPO is led by a Director and Assistant Director, advised by a fourteen-member Council elected from the research community. Strong, effective leadership of the USBPO and its Topical Groups is key to its effectiveness. An example of the effectiveness of the USBPO was its role in the recent international ITER design review. The USBPO Topical Groups identified and documented high priority design issues, developed an objective prioritization system, and submitted the issues to the IO for consideration. The IO formed eight design review Working Groups, including U.S. members to consider all the issues submitted. Some of the issues required significant research and investigation. The USBPO, working with the members of the design review Working Groups, leaders of U.S. programs, the USIPO, and the OFES, identified U.S. performers for specific work packages for the review. The USBPO coordinated and completed a number of these tasks, and prepared documentation and informative debriefings for the U.S. members of the design review Working Groups and the IO Management and Science and Technology Advisory Committees (both which advise the ITER Council). Due to the effectiveness of the USBPO and other elements of the DOE plan for participating in ITER, the U.S. was the first ITER partner to identify performers and propose specific tasks for the U.S. in the design review process, ensuring that ITER continues to be able to address the U.S. research agenda. The U.S.

contributed 21% of the scientific manpower effort in completing the design review tasks, even though the U.S. will contribute 9% of the construction of ITER.

In addition, the IO formed an international working group to develop detailed plans for the ITER plasma commissioning and operation phases. It has established the international scientific framework and program for ITER exploitation. This includes identification of needed research developments, such as an improved comprehensive modeling capability. The USBPO is coordinating U.S. participation in this group, ensuring good communication with the U.S. research community, and recognition of the U.S. research agenda. The IO plans developed by this group also provide the structure for more detailed planning of U.S. activities on ITER in the coming years.

Finding: The committee finds 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.

Finding: U.S. scientists have been well engaged in the planning for ITER, and the United States should endeavor to maintain this level of activity.

Comparison to analogous efforts in other ITER parties

The committee believes that it is instructive to use the organizational efforts of the other ITER members as a benchmark against which to judge the U.S.' progress. The committee is only able to comment on the relationship of the U.S. program to the EU and Japanese research programs which were presented in detail during its deliberations.

Overall, the U.S.' international partners in ITER are explicitly organized toward developing fusion energy and a Demonstration Power Plant (DEMO). This gives them a clear goal for their development of fusion power. We also note the much larger funding profile for fusion energy research in the EU and Japan, which allows them to pursue the energy goal more aggressively. In spite of the funding differences, the present U.S. research plans for ITER are as mature as those of the other parties, and foreign parties even noted their interest in emulating U.S. organizational structure for U.S. participation in ITER (see Figure 2.3). It is unclear at this time how the elimination of funding for the U.S.' first-year contributions to ITER will effect the fusion community's ability to keep its research plan abreast of its foreign colleagues.

Strong integration of the U.S. domestic research activities with the IO, through the ITER domestic agency, is facilitated by the simultaneous appointment of USBPO director as U.S. ITER chief scientist within the U.S. ITER project office. The EU and Japanese representatives noted this as a particular strength of U.S. organization.

Finding: The committee finds that 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.[1]

Assessment of the U.S. research agenda at ITER

The research agenda for ITER that is detailed in the DOE plan addresses four overarching questions.

[1] As of April 8, 2008.

- "How does the large size of the plasma required for a fusion power plant affect its confinement, stability, and energy dissipation properties? (large-confinement-scale physics)
- Can a self-heated fusion plasma be created, controlled, and sustained? (burning plasma state)
- Can the tokamak confinement concept be extended to the continuous, self-sustaining regime required for future power plants? (toward steady-state burning plasma)
- What materials and components are suitable for the plasma containment vessel and its surrounding structures in a fusion power plant? (fusion technology)"[2]

The plan details six major fusion science and technology campaigns that will be undertaken to address these four questions:

1. Integrated burning plasma science,
2. Macroscopic plasma physics,
3. Waves and energetic particles,
4. Multi-scale transport physics,
5. Plasma-boundary interfaces, and
6. Fusion engineering science.[3]

Figure 2.5 from the DOE plan presents a timeline of the U.S. research agenda and divides ITER operation into six phases:

1. Design support
2. Pre-operations
3. Commissioning and initial H and D operations
4. High gain DT operations
5. Modest gain DT, long pulse, non-inductive operation.
6. Fusion technology tests

The DOE plan sufficiently explains the rationale for these research themes and how they address each research question. The plan also proposes a sequence of steps that organizes the campaigns according to the phases of ITER operation. The sequence includes the design support and pre-operations phases, which will comprise the majority of U.S. research activity in ITER over the next decade. It is important to note that to fully reap the results of ITER and achieve DOE's goals, the U.S. will need to remain participatory in ITER through the project's operational lifetime. The steps that the plan outlines, if achieved, would lead to fulfillment of the U.S. ITER research program objectives.

It is clear that the schedule and approach of the U.S. research plan's science campaigns will evolve because it is intrinsically tied to the developing international ITER research plan, as well as to the evolving domestic organizational efforts. Despite this evolution, the committee expects the four overarching research questions to remain the focus of the U.S. research agenda, given their applicability to the goals central to the ITER project itself.

A cohesive, international research plan for ITER will emerge in the future, as expected of a large international scientific project. International collaboration will be critical to the development of this research plan, and hence to the success of ITER. At the present time, it is expected that ITER experiments will be carried out by international teams, and so it is critical that the U.S. scientists are strongly engaged in this planning process. The scientific gain reaped by the U.S. will depend on our ability to participate. A nascent effort has been undertaken through the ITER Design Review (DR), in

[2] U.S. Burning Plasma Organization, "Planning for U.S. Fusion Community Participation in the ITER Program," June 7, 2006.
[3] Ibid.

which the U.S. has had strong participation and significant influence. This strong participation should continue.

Finding: The committee finds that 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.

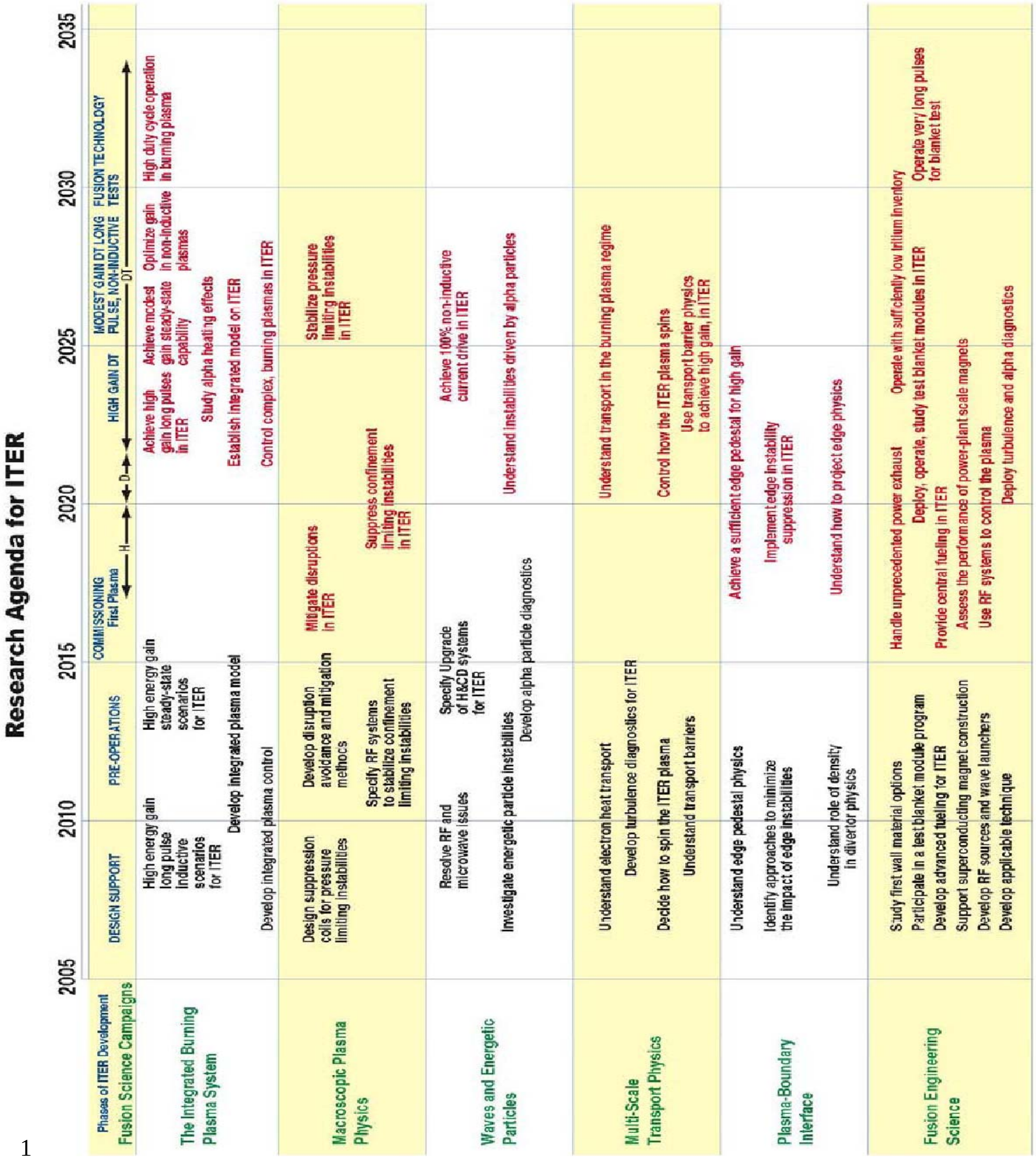

Fig. 2.5 The anticipated U.S. ITER research agenda and timeline from the DOE plan. Courtesy of the U.S. Burning Plasma Organization.

Alignment with DOE/OFES goals and previous NRC and FESAC advice

The overarching goal of OFES is to "[a]nswer the key scientific questions and overcome enormous technical challenges to harness the power that fuels a star, realizing by the middle of this century a landmark scientific achievement by bringing 'fusion power to the grid.'"[4] ITER is a central part of the DOE/OFES program and is consistent with its stated mission of developing the knowledge base needed for an economically and environmentally attractive fusion energy source.

Earlier NRC and FESAC advice strongly supported including ITER in the overall OFES program.[5], [6] In particular, we note the following recommendation from the NRC *Burning Plasma* report: the "U.S. should participate in a burning plasma experiment.,"[7] ITER will address this recommendation by sustaining the hot plasma mostly through its own fusion reactions.

Finding: The committee finds that the plan in its current form is well aligned with DOE Office of Fusion Energy Sciences goals.

Areas of concern

The committee is concerned that the lack of funding stability will make it difficult for the U.S. to effectively participate in ITER, and ultimately, to access and thus benefit from the valuable scientific and technical knowledge to be gained from the facility. ITER is the most globally participatory science project in history, and represents a significant step forward in the worldwide effort to develop commercially-viable fusion power. These funding developments threaten to keep the U.S. from being a participant in this important endeavor, and thus its ability to capitalize on advances made from ITER. It also, therefore, potentially impairs the U.S.' ability to participate effectively in and benefit from future fusion projects that will bring commercial fusion power closer to reality. It would be a tremendous loss if the U.S. were unable to participate, and thus severely limit the DOE/OFES' ability to achieve its overarching goal.

The committee notes the wise decisions taken by DOE to keep the U.S. engaged, to the extent possible, in the ITER project despite budget difficulties. As the IO develops its full functionalities it will be imperative that the U.S. establish itself as a stable and participatory partner if it is to accomplish the goals set forward by DOE, Congress, the President, and the plasma science community. The committee is concerned, however, about the ramifications that the FY08 appropriations will have on the continued progression of developing a U.S. plan for participation in the ITER project, as well as on the establishment of robust participation by U.S. scientists in the ITER research effort. As stated earlier, the FY08 budget does not allocate funds to ITER as planned. Such unexpected, dramatic oscillations in commitment not only adversely affect the U.S.' national standing amongst its peers in the ITER project, they deleteriously weaken the efficacy of careful planning that otherwise ensure balance across the nation's broad scientific enterprise. Stable and predictable funding has been recommended in numerous NRC and FESAC reports, and this committee echoes the sapience of those recommendations.[8] Failure to meet its obligations from the outset of the project will also jeopardize other countries' willingness to collaborate with the U.S. in future major scientific projects, possibly including a DEMO reactor. If the participation of U.S. scientists at ITER is a Congressional priority, the stability of the U.S.' contributions to the project needs to be ensured.

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[4] U.S. Department of Energy, "Office of Science Strategic Plan," p. 45, February 2004.
[5] FESAC "A plan for the development of fusion energy," 2003.
[6] NRC, "Burning Plasma: Bringing a Star to Earth," p.4, 2002.
[7] Ibid.
[8] See NAS, NAE, IOM, "Rising Above the Gathering Storm," 2007; NRC, "Plasma Science: Advancing Knowledge in the National Interest," 2007; NRC, "Burning Plasma: Bringing a Star to Earth," 2002;; FESAC, "Review of the Strategic Plan for International Collaboration on Fusion Science and Technology Research," January 23, 1998; and FESAC, "Report of the Panel on Criteria, Goals, and Metrics," October 8, 1999.

Finding: 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.

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

Other areas of concern are noted below:

- The committee found that gaps existed in the planning to DEMO.

The fusion community has recently started to address issues of evolving the domestic research program in the FESAC report "Priorities, Gaps, and Opportunities: Towards A Long-Range Strategic Plan for Magnetic Fusion Energy,"[9] which reiterates requirements for a vital and forward-looking domestic research program to exploit knowledge gained in ITER through international cooperation. This report suggests initiatives to bridge knowledge gaps to DEMO. The recent NRC report, *Plasma Science: Advancing Knowledge in the National Interest*, recommended the formulation and periodic updating of a 15-year strategic plan for burning plasma research, which this committee endorses. As described in *Plasma Science*, this plan would address several issues facing the U.S. magnetic fusion energy effort, and of particular note, “the growing gap between the newer, more capable intermediate-scale facilities being built abroad and the aging U.S. facilities.”[10] It will be difficult to carry out exploratory research on ITER or investigate opportunistic scenarios that may develop in the course of ITER’s operational lifetime without an underpinning of smaller tokamaks within the U.S. and abroad. Moreover, the U.S. fusion workforce will benefit from the training that operating such devices will provide.

The strategic plan would enable the U.S. to maintain synergy with research coming out of ITER throughout its long operational lifetime, and thus allow the U.S. to contribute to and follow through on ITER research. Additionally, the DOE plan for ITER will need to understand what operational capabilities will be required of domestic facilities to support ITER if it is to remain synchronized with the 15-year U.S. strategic plan.

- The dissemination of ITER research activities to the broader scientific community was not mentioned in the DOE plan.

The responsibility for the important role of public education about ITER’s mission should also be made clear. The committee notes recent efforts that begin to address these issues, such as the presentations at the recent meeting of the American Association for the Advancement of Science. The plan will need to formulate effective strategies to create standing lines of communication within the fusion sciences and with other disciplines, as well as with scientists and engineers in universities and industry. While the scientific isolation of the magnetic fusion community is decreasing, much can still be done to broaden the reach of research results in the field.[11]

[9] U.S. Department of Energy Fusion Energy Sciences Committee, "Priorities, Gaps, and Opportunities: Towards A Long-Range Strategic Plan For Magnetic Fusion Energy," 2007.
[10] National Research Council, “Plasma Science: Advancing Knowledge in the National Interest,” p. 151, The National Academies Press, Washington, D.C., 2007.
[11] National Research Council, “Plasma Science: Advancing Knowledge in the National Interest,” p. 150, The National Academies Press, Washington, D.C., 2007.

- The committee also noted that no comprehensive plan for the recruitment and training of young fusion scientists and engineers has been formulated, and is not considered in the DOE plan. A concern also arises with respect to other core disciplines necessary for burning plasmas such as nuclear engineering.

Past NRC and FESAC studies have voiced similar concerns, and DOE has taken some steps toward addressing this issue.[12] In fact, the European Union has begun to formally implement a program to address this issue as it develops its strategy to harness fusion energy.[13] Considering the expected success of ITER in the next decade, the aging of the fusion energy workforce, and the continued concerns of the U.S. and European fusion communities, this dictates that consideration be given to maintaining and strengthening the U.S. workforce on such timescales.

Recommendation: 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.

Assessment of methodologies to evaluate ITER's contribution to progress toward a power source

Two criteria for measuring the progress toward a power source have been emphasized: the achievement of predictive scientific understanding, and the achievement of plasma performance characteristics of a safe, reliable and affordable power source.

From the DOE plan:

> "The focus of the U.S. Fusion Energy Sciences program is the development of a predictive understanding of the fusion plasma system to support moving beyond ITER. A metric for progress in scientific understanding is whether the specific goals that collectively define the research agenda discussed above are achieved in the expected time frames. The level of agreement among theory, simulation, and experiment measures progress toward these goals. Another measure of scientific progress is the ability to use that knowledge to extend plasma performance toward that needed for fusion power. The ultimate measure of progress in scientific understanding, however, is obtained through periodic peer review of the research activities performed.
>
> Plasma performance metrics are derived from specific technical goals on ITER and fusion power plant studies that have identified the major scientific and technological goals for an attractive fusion power plant. They include issues such as fusion power, fusion power gain, plasma pressure, power density, power dissipation, and

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[12] National Research Council, "Plasma Science: Advancing Knowledge in the National Interest," p. 151, The National Academies Press, Washington, D.C., 2007; National Research Council, "Burning Plasma: Bringing a Star to Earth," p. 7, The National Academies Press, Washington, D.C., 2004; U.S. Department of Energy Fusion Energy Sciences Advisory Committee, "Fusion in the Era of Burning Plasma Studies: Workforce Planning for 2004-2014," March 29, 2004; U.S. Department of Energy Letter from Associate Director Anne Davies to FESAC Chair Dr. Richard D. Hazeltine, October 21, 2004; and National Research Council, "An Assessment of the Department of Energy's Office of Fusion Energy Sciences Program," p. 76, The National Academies Press, Washington, D.C., 2007."

[13] European Atomic Energy Community, "Seventh Framework Programme of the European Atomic Energy Community (Euratom) for Nuclear Research and Training Activities (2007 to 2011)," 2006.

neutron wall loading. Comparison of these parameters achieved in ITER to those required for a conceptual demonstration power plant provides an array of objective measures of the progress toward fusion power."

Both scientific and performance metrics are necessary and are mutually supportive: progress on increasing fusion performance will likely only be possible through predictive scientific understanding, and conversely, refinement of the scientific understanding will emerge when predictions are compared to measurements on a burning plasma. The history of the fusion program shows the value of both these metrics. Periodic peer reviews to measure scientific and performance progress will be important.

Finding: The committee finds that 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.

Relationship of the U.S. Fusion Program to the U.S. ITER Research Program

The committee considered the relationship of the domestic U.S. fusion program to the ITER research program. Considerable effort has been spent in structuring the domestic research program to be as relevant as possible to anticipated ITER operating scenarios, which serves the dual purpose of maintaining a trained workforce and maximizing our ability to contribute to the planning and achievement of ITER's scientific goals. The committee wishes to underscore the importance of maintaining a vigorous domestic program.

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."[14] Strong participation in ITER Design Review demonstrates the importance of a vibrant base program, including personnel and facilities, which can engage in the scientific issues of 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 felt is 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. This 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 the Department of Energy'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.

[14] NRC, "Burning Plasma: Bringing a Star to Earth," p.6, 2002.

3

Recommended Elements for Future Development of the Plan for U.S. Plasma Science Community Participation in ITER

Recommended Goals of U.S. ITER Planning Activities

It is clear that planning the U.S. involvement in the ITER project must be considered to be a dynamic and evolving process due to the lengthy construction phase of the experimental facilities. During the construction phase, technical advances will continue to be made, new problems are likely to be identified and political challenges will take place at the international and national levels. Accordingly, a successful plan must display flexibility, ingenuity and have continued access to a broad range of top experts from the U.S. fusion science and technology—and, more broadly, physics—community.

Consistent with previous advice, the committee suggests that the following goals be the underpinning of planning activities:

- Encouraging broad academic and industrial participation in ITER, to help ensure that the knowledge gained at ITER is brought back to the wider U.S. scientific community.
- Enable our ability to contribute substantially to ITER and maximize our ability to act upon the results produced by ITER, in order to fully reap the enormous scientific and technological reward provided by our involvement in the project.
- Rejuvenation of the U.S. fusion workforce by the recruitment and training of young fusion scientists and engineers.

Recommendation: 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 industrial 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.

Recommended procedures to facilitate further development of the plan

The committee suggests that the following procedures be implemented to accomplish the goals given above:

- A long-term strategic plan for the U.S. burning plasma fusion program should be created with ITER as an important, but not the only piece. It is essential to understand the long-term research goals in order to ensure that U.S. research activities on ITER adequately prepare the knowledge base for future fusion energy development. A broad, long-term, burning plasma fusion research strategy within the context of global fusion energy development activities will facilitate the achievement of the goals given above. The committee endorses the recommendation in *Plasma Science: Advancing Knowledge in the National Interest* encouraging the development of a 15-year U.S. strategic plan "for moving aggressively into the fusion burning plasma era…to lay out the main scientific issues to be addressed and provide guidance for the evolution of the national suite of facilities and other resources needed to address these issues."[1] The creation of this strategic plan will greatly help DOE maneuver the activities of the U.S. fusion program to interact synergistically with the ITER project, focus U.S. research strengths, and, ultimately, bring fusion power home.

- With the maturation of the plans, and as progress is made in construction of the experimental ITER facilities, the U.S. should maintain a home team to encourage broad cooperation and collaboration between all U.S. participants in the ITER project throughout ITER research and operations. The flexible and technically-encompassing U.S. Burning Plasma Organization (USBPO) has been serving in this role, and should continue to be relied upon as an essential point of communication between the U.S. fusion community, ITPA and OFES. A broadly-constituted home team would be most capable of bringing together elements from across the diverse U.S. plasma science community and other disciplines of physics. This home team could, also help DOE and the fusion community to implement this committee's guidance.
- In order to maximize the value of the ITER program, whose technical results are to come in on a scale of more than ten years, the DOE plan should consider how current U.S. plasma science facilities will support ITER research and what capabilities will be needed in the future, feeding into the long-range strategic plan for the U.S. burning plasma fusion program. Careful planning will be required to ensure continued relevance of U.S. facilities to ITER and beyond.
- It will be essential for the U.S. program to maintain a vibrant domestic fusion program, both in terms of basic research and facilities. "Transformation of the present portfolio of aging facilities into a new portfolio designed to expeditiously address key fusion scientific issues,"[2] through new domestic construction or partnering in new foreign facilities, will enable the U.S. to maximize its scientific return on investment and position it to be among the world's leaders in the development of fusion power and technology. To that same end, U.S. ITER research should be guided by advice from a program advisory committee, similar to other DOE science programs. A strong domestic program will also help maintain the skills of U.S. researchers at the forefront of the field and to maintain a level of interest among younger scientists and engineers and the general public.
- The current generation of large tokamaks operated by the international partners plays an important role in the ITER program. Experiments on these devices provided crucial input to the recent design review of ITER, and even after ITER is operational, improved scientific understanding will come from experiments done on both ITER and other experimental facilities. The importance of maintaining and operating smaller tokamaks among the international partners is underscored by the expected cost of running ITER and its extended operational planning process. Many physics and technical issues that may arise during ITER operation can be effectively addressed on smaller devices, which will help optimize ITER operations. Unfortunately, budget restrictions in recent years have not allowed the U.S. tokamaks to operate at full capacity, limiting their contributions. These facilities are unique and represent valuable test beds for ITER research ideas. Within the scope of the entire fusion enterprise and its budget, the DOE plan should consider if it would be beneficial to increase the operating availability of these tokamaks in support of ITER. This could yield a highly-leveraged opportunity to improve U.S. participation in the ITER program.

Recommendation: 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.

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[1] National Research Council, "Plasma Science: Advancing Knowledge in the National Interest," p. 150, The National Academies Press, Washington, D.C., 2007.
[2] Ibid.

- 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.

Recommended metrics for measuring robust U.S. participation in the ITER research program

Metrics included in the DOE plan

The committee finds that the plan includes well-thought-out metrics for evaluating the U.S. participation in the ITER research program. These metrics will help to inform policymakers and project leaders on the level of participation of the U.S. program in the ITER project.

The metrics given in the DOE plan are given below:

- "Number of U.S. researchers, students and technologists participating in ITER," and
- "Number of experiments and technology tests proposed or led by U.S. participants."

The level of participation of U.S. researchers in the ITER project, U.S. contributions to ITER experiments, and related research is indicative of the vitality of U.S. involvement in the research program. Conversely, these metrics will also provide volumetric information and insight on the contribution of ITER research to the U.S. fusion energy research program. As U.S. researchers continue to participate in ITER research and development activities, they will bring back their knowledge gained to apply to future advances in the U.S. base program.

- "Achievement of scientific and technology milestones on ITER."

ITER is a scientifically, technologically, and organizationally challenging project. Setting and then meeting ambitious, yet realistic, milestones will not only demonstrate progress on achieving the planned research, it will support and encourage the international partners in ITER.

- "Number of research and technology publications on ITER produced by U.S. participants," and
- "Citations of U.S. publications."[3]

Bibliometrics is a widely-recognized method of evaluating research impact, and it will allow policymakers and researchers to assess the health of the U.S. role in the ITER project and research. The committee emphasizes that the citation of U.S.-based research appearing in publications from ITER is a valuable metric because it directly reflects the U.S. influence on ITER research. However, program managers should not rely on bibliographical figures alone, but complement analyses by the metrics provided in this section and the next. It is understood that publication data is influenced by a variety of factors, and can vary from project to project, so having a suite of tools is critical.

In fact, the U.S. fusion community is already robustly engaged in the ITER research program and the design and construction process at all levels, through the Burning Plasma Organization, the VLT, and

[3] U.S. Burning Plasma Organization, "Planning for U.S. Fusion Community Participation in the ITER Program," June 7, 2006, p.330. The DOE plan is available at http://www.ofes.fusion.doe.gov/News/EPAct_final_June06.pdf.

the USIPO and their close affiliation with the other ITER organizations. Recently, the U.S. program has strongly participated in the international ITER Design Review, organized by the ITER Organization, to complete the ITER baseline design. The USBPO has evaluated some of the metrics in the DOE plan, based on recent activities:

- 278 U.S. researchers from 49 institutions are members of the USBPO. Approximately 124 U.S. researchers directly participated in the ITER Design Review.
- Approximately 50% of the experiments planned for 2008 on the largest U.S. experiments (C-Mod, DIII-D, NSTX), taken together, are in support of ITER.
- U.S. scientists constitute 73 of the 273 authors (27%) of the nine articles documenting the "Progress in the ITER Physics Basis", published in the journal "Nuclear Fusion" in 2007.[4]
- U.S. scientists constitute 30 of the 68 authors (44%) of the thirteen articles on diagnostics for ITER and burning plasmas, published in a special issue of the journal "Fusion Science and Technology" in 2008.[5]
- U.S. scientists were the lead authors on 10 of the 65 papers on ITER at the 2006 IAEA Fusion Energy Conference (Chengdu, China), and were co-authors on an additional 9 papers.

These activities came about from proactive engagement by the USBPO, the IPO, and OFES, and provide early evidence that the DOE plan is working well.

When evaluating these metrics, it is important to note the U.S.' 1/11 share of the project. It will be equally important to bear this in mind for future evaluations. The evaluation provides early evidence that the U.S. has been effectively engaging with international ITER planning activities, though this will remain contingent on support for the project.

Finding: The committee finds that the DOE plan includes well-thought-out metrics to measure the robustness of U.S. participation in the ITER project.

Recommended Additional Metrics

The committee recommends that five additional metrics be considered during the future development of the DOE plan, namely:

- 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.

The committee stresses that peer-review evaluations of U.S. participation in the ITER project could provide the most reliable measure of robustness. Until the ITER Organization is fully staffed and the international research plan is set in motion on an operational ITER, numerical metrics may not be sufficient to judge the robustness of U.S. participation and the project's effect on the domestic program. Similarly, to properly gauge organizational progress in establishing an effective participatory relationship with the ITER Organization's management structure and the project it runs, independent advisory assessments will be needed. These assessments will give U.S. decision-makers early and independent insight into the vitality of U.S. involvement.

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[4] International Atomic Energy Agency, "Progress in the ITER Physics Basis," *Nuclear Fusion*, Vol. 47, No. 6, June 2007, IOP Publishing, Vienna, Austria.
[5] American Nuclear Society, *Fusion Science and Technology*, No. 2, February 2008.

- Balance in the fraction of U.S. published research conducted on ITER according to author's institutional affiliation (university, national laboratory, and industry).

The DOE plan's metrics are concentrated on measuring the level of activity of the U.S. program, but do not characterize that activity. Strong U.S. participation in ITER will require the involvement and coordination of researchers from universities, national laboratories, and the industrial sector. Ensuring that a healthy balance is struck will be critical. This balance will need to be determined by an advisory committee.

- 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.

While the metrics given in the above section indicate the level of involvement of U.S. researchers in the ITER project itself, they do not provide insight on the unique synergistic effect that ITER research "coming home" will have on the U.S. base program. The fusion community and DOE expects that research conducted for ITER will provide a tremendous intellectual boost to the base program, and having a tool to measure this invigoration will be valuable to policymakers.

- The achievement of predictive capability will offer another effective measure of the success of the U.S. ITER program.

If the U.S.' predictive capability achieves a viable ability to predict ITER operating parameters, as well as other important measures such as component lifetime or suitability in a commercial fusion device, it will be a good indication that the U.S. is participating robustly in the ITER research program. Such questions must necessarily be addressed by expert panels in a peer review process due to their technical complexity.

Recommendation: 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 author's institutional affiliation (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.

Appendixes

Appendix A

Letter of Request from the U.S. Department of Energy

DEPARTMENT OF ENERGY UNITED STATES OF AMERICA

Under Secretary for Science
Washington, DC 20585

August 10, 2006

Dr. Ralph Cicerone
President
National Academy of Sciences
Mail Stop 822
500 Fifth Street
Washington, D.C. 20001

Dear Dr. Cicerone:

The Energy Policy Act of 2005 (EPAct), Section 972, authorizes U.S. participation in ITER, and directs the Department, in consultation with the Fusion Energy Sciences Advisory Committee (FESAC), to develop a plan for the participation of U.S. scientists in ITER. Additionally, Section 972 (c)(4)(B) of EPAct specifically directs the Department of Energy to request a review of the plan by the National Academy of Sciences.

On behalf of the Secretary of the Energy, I have enclosed a plan titled "Planning for U.S. Community Participation in the ITER Program" prepared by the U.S. Burning Plasma Organization under the guidance of the Office of Fusion Energy Sciences. This plan was discussed by the FESAC at its meeting on June 1, 2006. The FESAC review and endorsement of the plan is enclosed.

If you have any questions, please contact me directly at (202) 586-0505 or Dr. James F. Decker at (202) 586-5434.

Sincerely,

Raymond L. Orbach

Raymond L. Orbach
Under Secretary for Science

Enclosures:
Plan
FESAC Comments

cc:
D. Shapero, NAS ✓

Printed with soy ink on recycled paper

Appendix B

Meeting Agenda

National Academy of Sciences Building
Washington, DC

Friday, December 14, 2007

CLOSED SESSION

7:30 am	Breakfast available	
8:00 am	Committee discussion	
10:00 am	Break	

OPEN SESSION

10:15 am	DOE perspectives and plans for engagement of ITER	E. Oktay, DOE/OFES
10:50 am	Discussion	Committee and Guests
11:00 am	Perspectives from OSTP	K. Beers, OSTP
11:25 am	Discussion	Committee and Guests
11:30 am	ITER Organization engagement of member states and research agenda	*D. Campbell, ITER Organization, Fusion Science and Technology Department
12:20 pm	Discussion	Committee and Guests
12:30 pm	Working lunch	
1:30 pm	EU participation in ITER and research plans	J. Pamela, EFDA
2:05 pm	Discussion	Committee and Guests
2:15 pm	Japanese participation in ITER and research plans	S. Matsuda, Japan Atomic Energy Agency
2:50 pm	Discussion	Committee and Guests
3:00 pm	Break	
3:15 pm	Plans for U.S. engagement with ITER Organization	N. Sauthoff, ORNL
3:50 pm	Discussion	Committee and Guests
4:00 pm	Engagement of U.S. plasma science community in ITER research and reflections on USBPO plan	J. Van Dam, U.S. BPO
4:35 pm	Discussion	Committee and Guests
4:45 pm	Activities of the U.S. BPO long-range burning plasma program strategy subcommittee	E. Marmar, MIT
4:55 pm	Discussion	Committee and Guests
5:00 pm	U.S. engagement in ITER technology research	S. Milora, ORNL
5:35 pm	Discussion	Committee and Guests
5:45 pm	General discussion	Committee and Guests
6:00 pm	Break and depart for dinner	Committee and Speakers
6:30 pm	Working dinner	
8:00 pm	Adjourn	

Saturday, December 15, 2007

CLOSED SESSION

7:30 am	Breakfast available	
8:00 am	Committee discussion	
10:00 am	Break	

10:15 am	Continued discussion
11:30 am	Working lunch
12:30 pm	Continued discussion
2:30 pm	Break
2:45 pm	Continued discussion
4:30 pm	Adjourn full meeting

* by phone