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Ned R. Sauthoff

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Ned R. Sauthoff

U.S. ITER Project Office, Princeton Plasma Physics Laboratory, Princeton, NJ, 08543 USA

Abstract

The United States participates in the ITER project and program to enable the study of the science and technology of burning plasmas, a key programmatic element missing from the world fusion program. The 2003 U.S. decision to enter the ITER negotiations followed an extensive series of community and governmental reviews of the benefits, readiness, and approaches to the study of burning plasmas. This paper describes both the technical and the organizational preparations and plans for U.S. participation in the ITER construction activity: in-kind contributions, staff contributions, and cash contributions as well as supporting physics and technology research. Near-term technical activities focus on the completion of R&D and design and mitigation of risks in the areas of the central solenoid magnet, shield/blanket, diagnostics, ion cyclotron system, electron cyclotron system, pellet fuelling system, vacuum system, tritium processing system, and conventional systems. Outside the project, the U.S. is engaged in preparations for the test blanket module program. Organizational activities focus on preparations of the project management arrangements to maximize the overall success of the ITER Project; elements include refinement of U.S. directions on the international arrangements, the establishment of the U.S. Domestic Agency, progress along the path of the U.S. Department of Energy's Project Management Order, and overall preparations for commencement of the fabrication of major items of equipment and for provision of staff and cash as specified in the upcoming ITER agreement.

Tele: 609-243-3207
Fax: 609-243-3266
nsauthoff@pppl.gov

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1. Background

The U.S. has long pursued the study of the science and technology of burning plasmas. In the late 1980's, the U.S. was engaged in both the conceptual design of ITER and the design of CIT and BPX. The Engineering Design Activities provided an opportunity for the U.S. to work with the other three ITER parties to advance both the physics and the technology of reactor-scale plasmas, leading to the completion of the 1998 design for ITER. Following the Congressionally-mandated withdrawal, the U.S. continued to recognize the importance of studies of burning plasma, due to the essential scientific questions related to energetic particles, self-heating and associated self-organization, and the disparate size-scalings of essential physics phenomena. As a result, in 2001, the Fusion Energy Sciences Advisory Committee conducted a study of readiness for burning plasma studies, which concluded that it was time for a more extensive analysis which could enable a decision on U.S. strategies. In the Summer of 2002, following more than six months of supporting work by a large number of scientists and engineers, over 230 fusion scientists and engineers gathered in Snowmass, Colorado for the performance of a uniform technical assessment of approaches to the study of burning plasmas; the group assessed the potential scientific and technological benefits of the study of burning plasmas, the readiness for such pursuits, and the strengths of a range of approaches to the study of burning plasmas. The output of the Snowmass study served as the technical basis for the development of a strategy proposed by the Fusion Energy Sciences Advisory Committee in September of 2003, which was subsequently reviewed by the National Research Council, an arm of the National Academies of Science and Engineering. The National Research Council concluded that the U.S. should participate in the negotiations for the construction of ITER, which (when coupled with a cost study by the Department of Energy's Office of Science) led to the president's decision in January 2003 that the U.S. should participate in negotiations over the construction of ITER. Throughout 2003, the U.S. participated with the other five ITER parties in the activities of the Negotiators' Standing Sub Group (NSSG), addressing the arrangements related to the ITER agreement and project management procedures and processes and structures for staffing, management, procurement allocations, procurement methods and systems, resource man–agement, and decommissioning. Particularly encouraging and productive was the work of the procurement allocations group, which demon–strated that technical experts motivated toward project success can indeed achieve complex decision-processes such as the assignment of the ITER components to the parties for fabrication. Following the December 2003 Negotiators' meeting, the U.S. participated in meetings to address both characterization of the offered ITER sites and exploration of a broader approach.

In July 2004, the Department of Energy announced the completion of their competitive selection of national laboratories to host the U.S. Domestic Agency, with a partnership of Princeton Plasma Physics Laboratory and Oak Ridge National Laboratory being selected. The integrated project team, consisting of both government and project office personnel, commenced the preparation of U.S. project arrangements and the conduct of the disciplined project management order of the Department of Energy, complete with its sequence of critical decisions starting with Mission Need. In March 2004, the project presented its acquisition strategy, preliminary project execution plan and cost-range estimates to an independent review committee which provided advice to the Office of the Deputy Secretary of Energy regarding the cost baseline range as well as the project arrangements.

2. Technical Activities

The U.S. has conducting activities focused on completing research and development and design of the provisionally assigned U.S. in-kind contributions, on mitigating the risks for those components, and on performing estimates of the cost range including sufficient contingency, escalation and resources for risk mitigation.

2.1 Central Solenoid Magnet

During the Engineering Design Activities, the United States in collaboration with other parties performed the R&D, design and fabrication of a Central Solenoid Model Coil using Niobium-3 Tin superconductor in a layer-wound configuration. Following the completion of the 1998 design and resulting from design optimizations aimed at increasing the flexibility of the plasma shaping, the baseline design of the ITER central solenoid was revised to consist of a stack of six modules, independently powered to enable flexible control of plasma shape. Each module of the central solenoid coil differs from that of the Central Solenoid Model Coil in that it is pancake-wound, which leads to different issues and merits continued additional R&D and design.

The U.S. magnet activities include the qualification of vendors of superconducting strand at the higher performance level of 1000 amperes per square millimeter, the further characterization of potential jacket materials for the cable-in- conduit conductor, and design of the modified configuration. The U.S. has contracted with three vendors of superconducting strand, who are each scheduled to deliver 100 kilogram lots of the higher performance superconducting strand in 2005. Studies of the jacket material for the superconducting coils' cable-in-conduit conductor have focused on both JK2LB steel (which is the baseline design) as well as Incoloy-908, the material used in the jacket of the Central Solenoid Model Coil. The materials scientists have reported on studies of the structures, grain shapes, precipitates, and other internal characteristics in an effort to understand macroscopic behavior, in particular crack propagation and fracture toughness. The results of these studies are being finalized and will be discussed with the international team as well as the other parties in an effort to optimize the design of the central solenoid coil.

2.2 *Shield/Blanket*

The shield modules consist of a plasma-facing surface of beryllium, bonded to a copper heat sink, bonded to a stainless steel block with water cooling. The U.S. experience during the Engineering Design Activities was more focused on the divertor structure which had a carbon plasma-facing surface in contrast to beryllium.

U.S. activities have focused not only on studies and prototypes for the bonding of beryllium to copper and copper to stainless steel, but also on affordable manufacturing methods including casting of the shield block.

2.3 *Diagnostics*

Instrumentation for the measurement of plasma behavior is key to the understanding of burning plasmas, the primary motivation for U.S. involvement in ITER. The diagnostics on ITER differ considerably from those of conventional fusion devices because of the need for neutron shielding and of the radiation environment. The diagnostic allocations were modified to be structured by ports because of the complexity of the integration of the diagnostics into the nuclear shielding and cooling structures of the port plugs.

U.S. activities on diagnostics have focused both on a specific set of provisionally allocated U.S. diagnostic instruments and on generic issues of the design of the port plugs for diagnostics, which share significantly in structure and functions with port plugs for heating and current drive systems and somewhat for shield/blankets. The U.S. has provided members to the Diagnostic Working Group which devised the restructured assignments of diagnostics by port plugs; the U.S. also participated in the Diagnostic Engineering Port Plug Task Force which is working to devise generic solutions for the mechanical, thermo–mechanical, and nuclear-shielding functions of the diagnostic port plugs.

2.4 *Ion Cyclotron System*

The ion cyclotron system consists of the antenna, embedded in a port plug, connected to transmission lines that lead to the power tubes and the associated power supplies. U.S. responsibility consists of half of the antenna (shared with Europe), and all of the transmission lines, power tubes, and power supplies. The U.S. and Europe are in partnership for a high power prototype of the ITER antenna which will be tested on JET in order to qualify it for ITER, with particular focus on matching throughout a range of plasma scenarios including ELMy-H-mode.

U.S. design activities include not only the work on the antenna which is related to the high power prototype, but also studies of transmission line, power tubes, and power supplies.

2.5 *Electron Cyclotron System*

The electron cyclotron system provides not only electron heating but also current drive not only for modification of the current profile within the plasma but also for the stabilization of neoclassical tearing modes, which could limit the plasma pressure. The electron cyclotron system consists of two subsystems, one being the start-up gyrotrons of 120 gigahertz frequency and the bulk system which consists of 170 gigahertz gyrotrons for the current drive and stabilization systems.

U.S. activity in the electron cyclotron system consists primarily of development of 120 gigahertz tubes, and conceptual designs and costings for the bulk of the system.

2.6 *Pellet Injector*

The baseline pellet injector system is a centrifuge system with a pellet speed of 300 meters per second. The unique challenge of ITER is the duration of the discharge and correspondingly the number of pellets which must be launched reliably.

U.S. activities in this area build upon a strength of the United States in the research and development of pellet fuelling systems, for both centrifuges and gas guns. Recently the U.S. activity has focused on prototyping the performance of pellets launched at a range of velocities through guide tubes of various radii of curvature, with the aim being to determine the maximum pellet speed which can be reliably launched through a guide-tube system that can be installed within the ITER vacuum vessel.

2.7 *Vacuum System Components*

Another provisionally allocated component for the United States is a set of vacuum components which are nearly standard parts, for which no research and development is required.

2.8 Tritium Processing System

The U.S. works with Europe and Korea on the integrated design and fabrication of the tritium processing system, which consists of an exhaust processing system which separates the hydrogen from non-hydrogen, the isotope separation system which separates the hydrogen isotopes into protium, deuterium and tritium, and the gas storage and delivery system. U.S. responsibility is for the tokamak exhaust processing system.

The U.S. has provided members for the Tritium Processing Integration Group, which is performing an integrated design of the entire tritium processing system to optimize its reliability and performance.

2.9 Conventional Systems

The U.S. is also assigned responsibility for seventy percent of the steady-state electrical system as well as a portion of the cooling water system. The electric power system provides construction site power early in the schedule as well as bulk power for the operations phase; as such, there are early requirements as well as late requirements. The cooling water system has components which must be installed early in the construction of the tokamak building, such as tanks in the basement. As such, the cooling water system also has early and late components leading to early involvement of the U.S. in the design and fabrication.

2.10 Test Blanket Module

While outside the core ITER project, an integral function of ITER is the testing of tritium breeding blanket modules. The U.S. is an active participant in the conceptualization and design of test blanket modules, which will be installed in three ports, perhaps configured as 6 half-ports to enable the study of a range of possible configurations and technologies.

U.S. participation has focused on the Test Blanket Working Group, in which the U.S. has three official members.

3. Organizational Activities

Throughout 2003, the United States worked with the other five ITER parties to explore a range of arrangements for critical functions such as staffing, procurement, management, resource management, etc. These discussions were not completed when they were suspended at the end of 2003, and will need to be resumed following the site selection in preparation of the draft ITER Agreement. The U.S. feels that project management arrangements are key to the success of the project and that effective project management must include strong central control of specifications and strong centralized coordination of the activities of the ITER parties, particularly in the performance of the parties' in-kind contributions.

In late 2003, the U.S. Department of Energy issued a request for proposals for national labs to host the U.S. Domestic Agency, to be known as the U.S. ITER Project Office. Following a competition begun in late 2003, in July 2004 the Department selected a partnership of the Princeton Plasma Physics Laboratory and the Oak Ridge National Laboratory to perform the hosting function. The project office will perform projects-specific work for the ITER design, prototyping, vendor qualification, manufacturing design, fabrication, testing, and delivery.

Project activities within the Department of Energy are conducted in compliance with the D.O.E. Project Management Order 413.3 which consists of a series of specific activities punctuated by critical decisions on mission need, analysis of alternatives and cost baseline range, setting the baseline, start of construction, and project completion. In October 2004, the Department with support by the project office prepared the Mission Need documentation for Critical Decision-0, the first step in the sequence of critical decisions; it was signed by the Director of the DOE Office of Science, Raymond Orbach, in October 2004 and is presently under review within the Department for signature by the Deputy Secretary. In parallel with the Department's processing of the CD-0 package, the project office and the integrated project team have been preparing the materials necessary for the sequence of reviews leading to Critical Decision-1, analysis of alternatives and establishment of the cost baseline range. The Acquisition Strategy, the Preliminary Project Execution Plan, and the Cost Baseline Range package were reviewed by a DOE Office of Science Review Team in March 2005. This package is being updated to accommodate the recommendations from the review and will be submitted to the Department for its action.

4. The Future

The U.S. fusion research community is anxious to commence work on burning plasma studies. As such, the U.S. community awaits the selection of the site for ITER, which is the precursor decision for the international agreement. The U.S. recognizes that there are significant issues yet to be addressed regarding the arrangements for the project (management structure, key staff, procurement arrangements, finalization of procurement allocations, resource management, and particularly the clarification of the roles for the Central Team and the Domestic Agencies) and expects to work with the full set of six parties in the finalization of the ITER Agreement and annexes to that agreement.

In addition to the in-kind contributions, the parties are responsible for providing staff for the ITER organization as well as cash to cover common expenses such as assembly and installation as well as contractor personnel for the ITER Organization. As part of the DOE Office of Science review of the U.S. contributions to ITER project, the project team prepared cost estimates for not only the in-kind contributions but also the provision of staff and cash.

In February 2005, the President of United States submitted his budget request for fiscal 2006 which included the total budget and budget profiles for the "U.S. Contributions to ITER" project, with a total of $1.122 billion. This budget request is based on an estimate that includes not only fabrication costs but also remaining R&D and design, full personnel costs, contingency and escalation; as such, this estimate may have limited applicability in other parties. This presidential request is being considered by the Congress.

Finally, U.S. participation in ITER is targeted at the study of burning plasmas. As such, the U.S. ITER program consists of more than the mere construction of the facility. The U.S. is in the process of establishing a U.S. Burning Plasma Program which will coordinate U.S. activities on topics relevant to burning plasmas and will position the U.S. for its research role on ITER following the completion of construction. In that regard, the U.S. participation in the International Tokamak Physics Activity plays a strong role in the identification of key R&D needs and the IEA Tokamak Agreements enable planning of joint experiments to address key questions.

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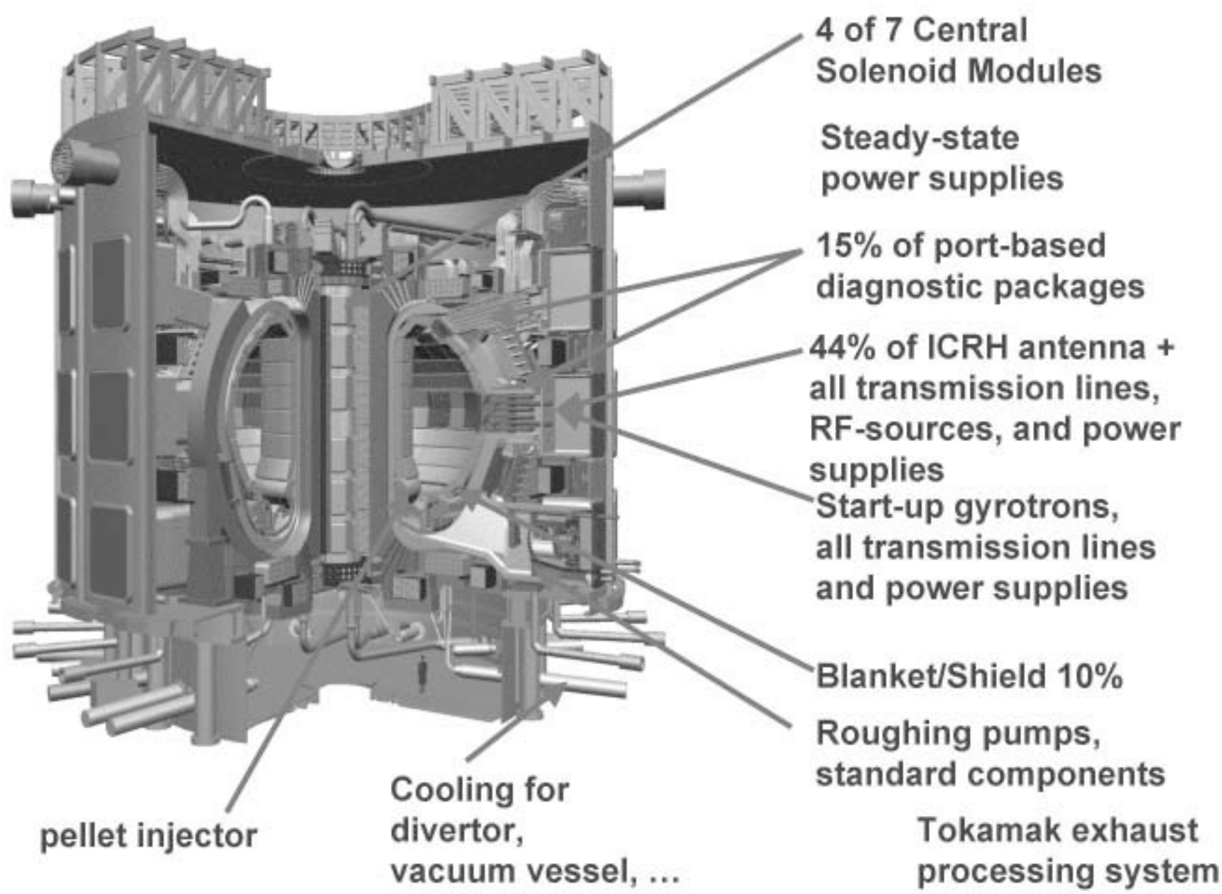

Fig. 1: In-kind contributions provisionally allocated to the United States.

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P.O. Box 451
Princeton, NJ 08543

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