U.S. Department of
ENERGY

U.S. Participation in the ITER Project

May 2016

United States Department of Energy
Washington, DC 20585

Message from the Secretary

ITER remains the best candidate today to demonstrate sustained burning plasma, which is a necessary precursor to demonstrating fusion energy power. Having fully assessed the facts regarding the U.S. contributions to the ITER project, I recommend that the U.S. remain a partner in the ITER project through FY 2018 and focus on efforts related to First Plasma. The U.S. along with all ITER Members across the world have witnessed and acknowledged the significant progress made at ITER by the new leadership, but there is still much that remains to be done. Prior to the FY 2019 budget submittal (late in calendar year 2017 to early 2018), I recommend that the U.S. re-evaluate its participation in the ITER project to assess if it remains in our best interests to continue our participation. My recommendation to support First Plasma cash and in-kind contributions is predicated on continued and sustained progress on the project, increased transparency of the ITER project risk management process, as well as a suite of management reforms proposed in this report that we expect will be agreed upon by the ITER Council. At this time, our continued participation in the fashion recommended is consistent with DOE's science mission and is in the best interest of the nation. The report discusses the critical issues that factored in this recommendation.

Sincerely,

Ernest J. Moniz

Executive Summary

This report discusses the critical issues that factored in the recommendation that the U.S. remain a partner in the ITER project through FY 2018, at which time the U.S. will reassess the project. ITER remains the best candidate today to demonstrate sustained burning plasma, a necessary precursor to demonstrating fusion energy power, which holds the possibility of providing abundant and carbon free energy. The project appears to be technically achievable, although significant technical and management risks remain. Since the beginning of the ITER project, there have been management problems, cost overruns, schedule delays and budget increases. Under the current Director General (DG), [1] Bernard Bigot, the management of the ITER Organization (IO) and the performance of the project have improved substantially, as confirmed recently by two independent groups: the 2015 Management Assessment (MA) and the independent review of the new schedule presented to the ITER Council in November 2015.

The international ITER project Members and the IO continue to make progress on construction, delivery and fabrication. The design for First Plasma (FP) is 79% complete through manufacturing design, while the overall design to Deuterium-Tritium (DT) is 61% complete. The U.S. remains concerned about the ITER Members encountering problems in meeting the schedule needs of the ITER project, in particular due to past delays and anticipated funding constraints. The U.S. ITER in-kind contributions have been designed, constructed and delivered consistent with the key milestones. Four of the twelve U.S. hardware systems are currently in final fabrication.

That said, the improvements and performance, while promising, still require additional time to determine if they will be sustained and lead to the long-term success of the project. The improvements must be balanced against several years of inadequate performance prior to DG Bigot's tenure, as well as the technical, cost and schedule risks that exist. Until a resource loaded baseline is accepted by all Members (expected to be approved by the ITER Council in June 2016 and given final, Ministerial approval in the Spring of 2017), and unless IO transparency and management continues to improve, uncertainty remains in the ability of the project to complete construction within a reasonable schedule and cost. Even with an approved baseline, technical risks remain due to the size, uniqueness and tolerances of individual components as well as assembly of the components. As a result, DOE recommends continuing the reforms already underway, implementing additional measures as described in this report, and revisiting this recommendation as part of the FY 2019 budget process (end of 2017 to early 2018).

This report updates estimates of the full cost, by fiscal year, of all future Federal funding requirements for construction, operation, and maintenance associated with remaining a Member in the ITER project. The estimated out-year budget increases for ITER could be

[1] A list of Acronyms is provided in the back of this report.

accommodated with increases in future budgets for the DOE Office of Science (SC) that provide for growth at rates greater than inflation, but could not be accommodated within out-year budgets that have little or no growth without significant tradeoffs in other programs. The President's FY 2017 Budget provides sufficient budget flexibility, as part of Mission Innovation, to accommodate the funding requirements for proceeding with ITER.

DOE has identified additional measures to improve project management discipline for both the U.S. in-kind contributions and the international collaboration.

- For the U.S. in-kind effort going forward, DOE will: 1) manage it as a construction project under DOE Order 413.3b, "Program and Project Management for the Acquisition of Capital Assets," with the Deputy Secretary as Project Management Executive and subject to the Energy Systems Acquisition Advisory Board (ESAAB); 2) work with OMB and Congress to establish a separate budget line item for the U.S. ITER Project, separate from the Fusion Energy Sciences budget line; 3) establish a CD-2 performance baseline in FY 2017; and 4) integrate funding needs into the long-range plans for SC.
- For the management of the IO going forward, we will through our role in the ITER Council, insist on: 1) efforts to provide transparency into the management of the overall project; 2) the use of the standing risk committee of the IO to identify and help overcome risks that threaten the success of the ITER project; and 3) ensuring that cash contributions are limited to those levels absolutely required for the project's success and that process improvements will prevent future, unmitigated growth.

Recommendation on U.S. Participation in the ITER Project

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1 Introduction

This report discusses the critical issues that factored in the recommendation that the U.S. remain a partner in the ITER project through FY 2018 and focus on efforts related to First Plasma (FP). As part of the FY 2019 budget process, the U.S. will re-evaluate its participation in the ITER project to assess if it remains in our best interest to continue. In addition, this report provides an estimate of the full cost of all Federal funding requirements for construction, operation, and maintenance associated with this recommendation to remain a partner in the ITER project.

When completed, ITER will enable study of burning plasma and demonstration of net fusion power. ITER is a complex project scientifically, technically, organizationally, and politically. The project is planned around achieving two distinct milestones: FP and Deuterium-Tritium (DT). In FP operations, ITER will demonstrate the integrated operations of all systems required and then allow for experiments to be conducted on hydrogen plasmas. In DT operations, ITER will move into nuclear operations and experiments on deuterium initially, followed by DT plasmas.

The U.S. became a Member of ITER when the Agreement on the Establishment of the ITER Fusion Energy Organization for the Joint Implementation of the ITER Project (JIA), a binding international agreement, entered into force in 2007. The other Members are China, the European Union (EU), India, Japan, the Republic of Korea (ROK) and Russia. As host, the EU committed to covering 45.46% of the construction costs, while the other Members each committed to 9.09% of the construction costs. For the U.S. and Members other than the EU, the costs rise to 13% during operations. As a Member, the U.S. gains full access to all research data from ITER. Each Member has a Domestic Agency (DA) that provides components and systems in-kind (80% of their share) and funds to run the central ITER Organization (IO). The IO is managed by DG Bernard Bigot; the DG reports to the ITER Council (IC), which comprises representatives from each Member. The DG is the ITER Project Manager, but the DAs report to their respective Member countries, not to the DG.

In developing this report's recommendation, DOE considered the effects on the fusion program; scientific and technical viability of the facility; diplomatic and national security effects; and anticipated budgetary resources at DOE. DOE also considered the international commitment the U.S. made in the JIA. ITER performance was evaluated on 1) the management performance improvements at the IO; 2) the recent project performance of the IO and the Members; 3) the results of the 2015 Management Assessment; and 4) the results of the independent review of the schedule that the IO presented to the IC in November 2015. The recommendation is predicated on future progress in the ITER project, which includes that a resource-loaded baseline to FP be approved by the IC in June 2016 and at a Ministerial meeting in the spring 2017, that the baseline includes a realistic contingency level commensurate with the complexity of ITER, and that IO transparency and management continues to improve.

The U.S. remains concerned about whether the construction progress seen in the past six months will continue, and thus we will push to implement improved oversight mechanisms and monitoring. By the time the FY 2019 budget is developed, there is expected to be an approved ITER baseline to FP, a completed Ministerial meeting where the Members confirm support for ITER, the EU budget proposal for the seven years starting in 2020, and sufficient operating experience under DG Bigot's leadership to determine whether the recent improvements are being sustained.

This report is organized as follows. A summary of the recent reviews, starting with the 2013 Management Assessment (MA) and including the most recent Independent Review of the Updated Long-Term Schedule (ULTS), is provided in Section 2. A summary of factors influencing the U.S. recommendation, including the importance of ITER to fusion development, the opportunity costs, and the foreign policy implications is provided in Section 3. Cost estimates for staying in the ITER project under different assumptions for completion dates and potential costs associated with withdrawal from the ITER project are provided in Section 4. Section 5 outlines U.S. plans to ensure continued improvement in ITER project performance, including an emphasis on regular reviews of the project and ensuring transparency through the monitoring of key milestones, and also outlines the U.S. path forward toward baselining the U.S. ITER Project and seeking advice from the National Academies regarding the future direction and emphases of the U.S. fusion energy sciences program.

2 Results of Recent Reviews

ITER is a complex project scientifically, technically, organizationally and politically. The costs have continued to increase and the schedule has continued to slip over the years. The estimated costs for the IO scope have increased 5-fold since 2003, while the estimated U.S. costs have risen from $1.1B to a range between $4 and $6.5B. The schedule to achieve FP has slipped from November 2020 in the most recently approved baseline to no sooner than December 2025, and that date does not include any schedule contingency as noted below. December 2025 is an early finish date and based on U.S. experience in large projects, it is likely that the actual date will be a year or more later. The DT operations milestone is estimated to be no sooner than 2032, again with no schedule contingency. Slippage in the FP date will impact the DT date, and risks that materialize in the DT scope will also delay the DT date.

Until recent management improvements, including the appointment of DG Bernard Bigot, the ITER project had not been well managed, and some of the DAs – the EU's in particular - had not been meeting critical commitments in completing civil and Tokamak building construction. The poor performance directly led to schedule delays and cost increases for other DAs by extending the length of the project.

To evaluate the management of the IO, the IC meets semiannually to discuss the budgets, schedule, project performance, and other management issues. In addition, the IC charges an

independent MA every two years. Finally, the IC can charge independent reviews, such as the recently completed IC Review Group (ICRG) for the ULTS. The results of the last two MAs and the independent review of the ULTS are discussed below.

2.1 2013 Management Assessment

Each MA is given a charge by the IC. The assessment is conducted by an independent team selected from one of the Members. MA-2013 was conducted by a team from the U.S. (led by William Madia) and charged with a thorough examination of the root causes of the schedule delays. The assessment made the following eleven recommendations:

- Create a Project Culture
- Accelerate the DG Transition
- Hold the DG Accountable for Resolving Conflicts
- Reduce the Number of Senior Managers in the IO
- Strengthen Systems Engineering
- Instill a Nuclear Safety Culture
- Develop a Realistic ITER Project Schedule
- Align IO and DA Interests
- Simplify and Reduce the IO Bureaucracy
- Use Human Resources Systems Tools as a Strategic Asset
- Improve Advisory Assessment Responsiveness

At the urging of the U.S. through the ITER Council, significant management improvements have been made in the two and a half years since MA-2013 was accepted by the IC. Of the recommendations, nine were to be implemented by the IO and two by the IC, including MA-2013 Recommendation 2 to "Accelerate the DG Transition," with an understanding that the new DG would implement the nine recommendations for the IO.

The new DG, Bernard Bigot, was appointed on March 5, 2015. The DG accepted the appointment based on an understanding that he would

- Have a year to begin to turn around the project,
- Be given full authority to make all technical decisions in the best interest of the project,
- Produce an updated schedule that he (and the Members) could commit to implement,
- Have freedom to revamp the management structure and align personnel more closely to project need,
- Establish an Executive Project Board to include the DAs and that can take the needed decisions in due time for effective global project management,
- Modify the staff regulations for improved efficiency and cost effectiveness, and
- Establish a reserve fund that could be used to fund IO-driven project changes.

DG Bigot created an "action plan" to resolve the nine MA-2013 recommendations and has reported on progress in completing the action plan regularly.

2.2 Results of the 2015 Management Assessment

The MA-2015 Preliminary Report was provided early in April 2016, and the official presentation will be made to the IC in June 2016. MA-2015 was asked to assess the progress made in the implementation of recommendations from both the prior MA-2013 and from an IO-charged Overall Management Performance Evaluation (OMPE) Working Group.

The report states that the "ITER Organization (IO) has made and is making a great effort in improving the effectiveness and efficiency of both the design and construction of the project in the year 2015, based on the recommendations of the prior MA-2013 and the Overall Management Performance Evaluation (OMPE) Working Group under the leadership of the new Director General (DG), Mr. Bernard Bigot." The MA-2015 Preliminary Report concluded the following:

- The creation of an engineering project culture has been instituted and is improving.
- Re-structuring and re-organizing efforts have taken place and are ongoing.
- Specific measures for improving management systems for both project and staff have been taken and are in the process of being implemented.
- Recommendations from the OMPE Working Group have been integrated with MA-2013.
- The new DG is effective as the leader of the IO.
- The global efficiency of the decision-making process of the project has been improved although it has only been in place for a short period of time.
- The IO and DA cooperation has been emphasized but has not been improved significantly.
- Improved performance of the management of both the IO and the project is observable.
- Communications between leadership of the IO and DAs has been dramatically improved.
- Human resource management is improving but still needs significant transformation.

The MA-2015 Preliminary Report also includes a set of observations based on staff polling in the earlier days of the DG's tenure. These may be reflective of either staff uncertainty over the new DG or the actions of the prior DG. A new staff survey is a recommended step to determine the views of the staff now that the new DG has been in charge for over one year.

The MA-2015 Preliminary Report made the following recommendations:

- Institutionalize collaborations and partnership between IO and DAs and within IO.
- Improve management and leadership structure for a more efficient organization.
- Highlight core values and enhance organizational culture.
- Improve communication and management process.
- Optimize human resource management practices.

2.3 Results of the Independent Review of the Schedule Presented in November 2015

In November 2015, the DG presented the ULTS, which includes an assessment of the resources required to staff the IO, manage the project, and complete the IO's assembly and installation. Two versions of the ULTS were presented: a "fastest technically-achievable schedule" that assumes hardware delivery to FP is not constrained by DA budgets, and a schedule that integrates the IO assembly schedule with budget-constrained schedules of the DAs. The two schedules showed similar dates for FP; however, they differed on the date for start of DT operations. None of the schedules include any schedule contingency, and as a result based on U.S. experience in large projects, the dates for FP and DT are not realistically achievable. The December 2025 for FP and the 2032 for DT are early finish dates, and slippage in both schedules is likely due to risks that could materialize. In addition, both schedules also showed a significant increase in the planned IO costs that had not been incorporated in the Members' budget plans and could impact Member performance of in-kind hardware fabrication.

The IC approved a two-year set of milestones derived from the ULTS and requested bimonthly updates on the milestones, which include both IO and Member milestones. In addition, the Council established the ITER Council Review Group (ICRG) to perform an independent review of the ULTS working under the leadership of a Chair designated by the IC.

The ICRG's report to the IC, completed in April 2016, states that "…Dr. Bernard Bigot… has restructured the ITER Organization's (IO) senior management in a major way, with highly experienced senior managers leading the ITER Organization Central Team. This has led to a substantial improvement in project performance, a high degree of motivation, and considerable progress during the past 12 months." Regarding the updated schedule, the ICRG found that, "the resource estimate is generally complete, including scope that was previously missing, and provides a credible estimate of cost and human resources." As of the end of April 2016, DG Bigot stated that the IO overall value weighted estimate for construction project completion for FP systems is reported to be approximately 40% complete. And he stated that the design for FP systems is estimated at around 79% complete through detail design.

Regarding the proposed FP date of December 2025, the ICRG recognized that this is the earliest possible technically achievable date, and that this date did not have any schedule contingency associated with it. Therefore, the ICRG recommended that the IO determine a "target date" for FP "that includes a reasonable contingency once an initial quantitative risk analysis is performed." The current U.S. estimates for schedule contingency are between two and three years, based on input from two independent project management experts involved with the development of the ULTS and review of it. As a result, until the IO analysis has been completed, the U.S. estimates a late finish date for FP of December 2028.

The ICRG found that the IO request for 4B Euros (additional resources for construction through DT, already reflected in U.S. funding tables in this report) were credible. The ICRG performed "drill-down" detailed reviews of a sample (seven major elements) of the ULTS resource estimate into project work areas. The drill-downs confirmed that the resource-loading was done in a detailed and systematic manner. In general and based on the drill-down samples, the ICRG concluded that the resource estimates were reasonable for this stage of the project. The ICRG recommended that the IO continue to iterate based on the post-FP input from Members.

The ICRG made 20 recommendations overall and six related to the Human Resource function at the IO. These include generally restricting assignments to not more than two terms for staff and "making changes within the Human Resources Department and to human resources policies and procedures to ensure that the organization is more flexible and supportive."

At the April 27 meeting, the ITER Council requested that all recommendations be acted upon to produce an updated schedule to FP be presented to the IC in June 2016, with a comprehensive schedule to DT operations to be provided in November 2016. Developing a reliable DT schedule requires a reliable FP schedule, which means that schedule contingency to FP must be included. The IC also requested that an Action Plan be developed for recommendations that involve longer-term improvements.

3 Factors Influencing the U.S. Recommendation

In coming to the recommendation, DOE considered the fusion program strategy; project management; foreign policy and international relations; and anticipated budget conditions at DOE. These perspectives are discussed below.

3.1 Importance to U.S. Fusion

The purpose of ITER is to demonstrate that magnetically confined plasmas can achieve the "burning" state and produce more fusion power than the power needed to operate the experiment. The U.S. joined the ITER negotiations, in part, based on positive statements about the need for a burning plasma experiment by the National Academies of Science[2], and from the fusion community, as expressed by the Fusion Energy Sciences Advisory Committee (FESAC). ITER, and the U.S. domestic research program, is harnessing many of the world's fusion scientists to this goal. A burning plasma experiment is a necessary step toward building a demonstration fusion plant, which would be the next major step towards the ultimate realization of fusion as an abundant and environmentally benign, carbon-free energy source capable of delivering energy at the base load levels. ITER is still regarded as the fastest path for the study of high gain burning plasmas and to develop supporting technologies, despite the

[2] http://www.nap.edu/catalog/10816/burning-plasma-bringing-a-star-to-earth . The letter report, delivered in December 2002 begins on page 156.

project delays, and it remains the only path being pursued for a facility to study sustained, magnetically confined burning plasmas. A complete ITER project will demonstrate burning plasma at fusion reactor scale. The National Academies embraced the view that burning plasma science learned from ITER would be extensible to a wide range of magnetic configurations.

ITER is designed to allow for world-leading research on the burning plasma state and is the cornerstone of DOE's Fusion Energy Sciences (FES) strategic plan to achieve its mission. Most of the FES program is structured to support the development of scientific foundations in support of burning plasma science that ITER is designed to enable. The impact of U.S. research is found in many basic aspects of the ITER design, its required flexibility, planned measurements and operating scenarios, and research plans. A U.S. value placed on the ITER project and research program is that ITER shall be a flexible, well-diagnosed scientific instrument and will allow scientists to explore the physics of burning plasma at energy densities close to that of a commercial power plant. This is a critical step towards producing and delivering electricity from fusion to the grid. Based on the current fleet of fusion facilities coupled with known scaling relationships, with successful integration and assembly, there is high degree of confidence that the ITER design is credible and will produce net fusion power when operating in the nuclear phase. The proposed schedule for construction will, in the nearer term, allow for achievement of FP and experiments on hydrogen and deuterium plasmas, which will inform the research plans for other experiments at operating plasma facilities around the world and eventually in ITER during the DT phase.

3.2 Project Management

Project management has greatly improved since DG Bigot began in March of 2015, and the project is now being well run. The indicators include the IO management improvement, the results from the MA-2015 Preliminary Report, the performance of the ITER project to the new schedule and the ability to achieve the defined milestones, and the results from independent review of schedule. DG Bigot has hired new, highly qualified individuals into his senior management team and has reorganized to a structure that is consistent with running a large, complex project. The MA-2015 Preliminary Report results support the actions to date and provide recommendations for continued improvement.

The pace of construction has accelerated under the leadership of DG Bigot, and the IO is meeting all milestones, which compares to less than 50% of milestones met prior to his arrival. The IO is responsible for much of the design, as well as the assembly and installation of components at the site. As of the date of this report, the design for FP is 79% complete through manufacturing design, while the overall project through DT is 61% complete. Three ITER Members remain on or ahead of schedule on meeting commitments; they did not deviate from the 2010 baseline and are set to deliver their in-kind commitment well within the current 2025 FP baseline estimate dates. U.S. ITER has continued to meet its deliveries and key schedule milestones. The U.S. is on track to complete its milestones in 2016. The U.S. ITER Project Office (USIPO) is delivering according to plan and according to the two-years of milestones established by the IC in November 2015.

With regards to the schedule, the ICRG has determined that the ULTS is credible and forms a solid basis for approval, once final iterations through DT are completed. IC approval of the ULTS will allow the DG to 1) present the ULTS to Ministers for approval, 2) operate under a set cost and schedule baseline, and 3) permit the IO to begin benchmarking milestones beyond the current two-year window. This will enable further confidence once all parties commit to the financial contributions necessary to meet the approved schedule.

An IC meeting was held on April 27, 2016. Members discussed the ICRG results, pledged to improve transparency, and endorsed actions by DG Bigot to improve project management. The ULTS will be submitted at the IC in June 2016.

The performance data seen and the results of the MA-2015 Preliminary Report are positive indicators; however, the duration of improvements is simply not yet long enough to conclude that the strength seen will continue and the project will continue to be well managed. Strong management by the DG and ongoing engagement by the U.S. (through, for example, the IC, advisory committees, and the executive project board) will be needed to ensure that all of the Members maintain commitments. As a result, the U.S. will aggressively pursue oversight mechanisms to ensure that the positive trends in improvement project performance and management are sustained. The U.S. will evaluate the project performance indicators of the overall ITER project in November 2017 to determine if the improvements seen to date have continued and can be expected to be sustainable throughout the project.

For the ITER project and the IO, key project and management performance indicators to be monitored will include: continued improvement in the management of the ITER project (e.g., results of the MA-2017 report); effective risk analysis and management, transparency of progress performance by all the DAs and the IO (e.g., monthly Cost Performance Index status); and continued success in completing major milestones (listed in Section 5) that are indicators of overall ITER performance. Risk management is a particular focus because of the lack of transparency into the individual Member's risks in the past, and because of the interdependencies inherent in the ITER project. Finally, independent project reviews every six months will be pursued through the IC to inform DOE leadership on the overall ITER project performance. Such reviews are similar to those performed by the Office of Science (SC) throughout the project lifecycle of major SC projects to validate project progress and identify recommendations for project performance improvement.

3.3 Foreign Policy/International Implications

The Agreement on the Establishment of the ITER Fusion Energy Organization for the Joint Implementation of the ITER Project (JIA) is a binding international agreement that was entered into domestically as a congressional-executive agreement. It is an agreement among most of the leading world science powers. As seen in other successful multilateral partnerships, there is an increasing dependence on close cooperation among many countries to work together to

build and operate large-scale science projects given their high costs and uncertainties. Because the JIA's withdrawal provision provides that withdrawal shall not affect the withdrawing party's contribution to construction costs, if the U.S. were to withdraw, the expectation from other Members would likely be that the U.S. would still provide for the hardware it is committed to deliver and its cash contribution commitment. The potential costs associated with withdrawal are provided in Section 4. If the U.S. were to withdraw and not meet its commitment (cash and in-kind), the U.S. would likely be criticized as an unreliable partner, our ability to enter into similar international partnerships could be undermined, and other ITER Members might take actions against the U.S. to try to compel us to meet our commitments.

As a Member in ITER, the U.S. has access to all intellectual property and research generated as part of this multilateral effort. With countries from France to China looking to take advantage of the commercial potential of fusion energy, the U.S. must ensure that our scientists and engineers are on an equal footing with their international counterparts and that our innovation ecosystem can take full advantage of the breakthroughs that may result from ITER.

3.4 Opportunity Costs in the U.S. and Effects on the Office of Science Budget

The budget profile for the U.S. ITER contributions is provided in Section 4, which gives preliminary estimates of annual funding profiles for FY 2016 through FY 2035. ITER will involve an additional commitment of approximately $3.5B of funding in out-year budgets. The FY 2017 Budget requests $125M for U.S. ITER. The $125M is carried forward in out-year planning exercises for SC, but meeting the U.S. commitments will require increasing this annual expenditure by a factor of two or more. Further refinement of the estimates and independent review would be required before the costs could be approved as a baseline.

The estimated out-year budget increases for ITER could be accommodated with increases in future budgets for SC that provide for growth at rates greater than inflation, but could not be accommodated within out-year budgets that have little or no growth. The President's FY 2017 Budget provides sufficient budget flexibility, as part of Mission Innovation, to accommodate the funding requirements for proceeding with ITER. Absent additional funds, the DOE funding needs for ITER will affect funding of other DOE priorities.

The DOE Office of Science is considering several other projects of $1B or more, including Exascale computing, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment, Proton Improvement Plan, the Advanced Photon Source Upgrade, and Spallation Neutron Source Second Target Station. Absent additional resources being made available, DOE would need to delay some of the projects listed above or identify additional resources for the ITER project. At this time, the specific projects and programs have not yet been determined, but DOE is committed to funding the resources needed for ITER in the budgets through FY 2018.

There are economic benefits from the investment in ITER as well. To date, U.S. ITER has awarded over 500 contracts in 43 states (59% of the major contracts to be awarded). The value

of contracts awarded exceeds $800 million. Major active contracts include General Atomics (CA) for central solenoid modules, New England Wire Technologies (NH) for toroidal field conductor cabling, and Major Tool & Machine, Inc. (IN) and Petersen, Inc. (UT) for central solenoid structures. Major completed contracts include Luvata Waterbury, Inc. (CT) and Oxford Superconducting Technologies (NJ) for toroidal field conductor strand, AREVA Federal Services (NC) for tokamak cooling water system design and components, and R&D contracts with universities and national laboratories.

4 Costs of U.S. Contributions to ITER Construction

The following is an estimate of the full cost, by fiscal year, of all future Federal funding requirements for construction, operation, and maintenance associated with a recommendation in FY 2017 to remain a partner in the ITER project. Through the JIA, the U.S. commitment during the construction phase is 9.09% and the U.S. commitment to operations, deactivation, and decommissioning phases is 13%. After FP, ITER will operate nominally for 20 years. The most recent total cost range of $4 – 6.5B was provided in 2013, and the cost estimates in this Section are still within that range.

At present, the U.S. ITER schedule and cost are preliminary estimates and have not been independently validated. The expectation is that the ULTS for ITER to FP will be approved in June 2016,[3] and the U.S. ITER Project to FP will be baselined in FY 2017. The ULTS does not have contingency, but as mentioned previously in this report, for planning purposes, the U.S. considers that a schedule contingency of three years for FP is a reasonable estimate for a project of this complexity.

Two estimates for the construction costs for U.S. contributions to ITER are provided below. Both are based on the schedule reviewed by the ICRG (see Section 2.3), and both include the cost increases requested by the IO (e.g., establishing the Reserve Fund). The 2025 FP cost estimate ensures that the U.S. provides its in-kind contributions and cash commitments consistent with achieving FP by December 2025, the technically achievable date in the ULTS (or early finish date). The 2028 FP cost estimate ensures that the U.S. provides its in-kind contributions and cash commitments so as not to delay FP any later than the late finish date of December 2028 (assuming three years of schedule contingency). In both cases, a DT date of 2035, which the IO noted as the resource-constrained date in the ULTS, is supported by the profiles provided. The ICRG Report noted that the schedule from FP to DT was not as developed as the schedule to FP. As a result, while the overall cost for the U.S. will remain within the range mentioned above, it is expected that the profiles for post-FP construction costs will change after the baseline is approved.

[3] It is expected that the complete ITER baseline through DT will be approved at a Ministerial meeting in 2017.

In addition, the costs potentially associated with a U.S. withdrawal are outlined under the assumption that the U.S. meets its commitments consistent with the JIA.

The total U.S. life-cycle cost consists of Construction and Operations, Deactivation, and Decommissioning. Construction comprises the in-kind hardware contributions of R&D and design (as needed), procurement/fabrication/testing, and shipping to ITER; and the cash contributions to the IO for ITER construction, ITER R&D, IO staff and infrastructure, IO-provided hardware, on-site assembly/installation/testing of all ITER components, and the IO Reserve fund (which serves as contingency funding for directed design changes and missing items). Operations/Deactivation/Decommissioning is a cash contribution only.

It is assumed that U.S. personnel support during hardware assembly/installation at ITER will be funded by the IO. The funding for the U.S. research program at the ITER facility will be funded through the DOE FES Program budget and is not included in this estimate.

4.1 2025 First Plasma Construction Cost Profile

The table below represents an annual construction funding profile for the U.S. costs, both in-kind hardware and cash, to support delivery of U.S. hardware in-line with the international target schedule for FP in 2025. The "Post-First-Plasma" profile supports a DT date of 2035.

First Plasma Construction Cost

($M)	Prior Years	FY16	FY17	FY18*	FY19*	FY20*	FY21	FY22	FY23	FY24	FY25	FY26	Total
Hardware	897	115	100	167	187	181	166	151	132	124	41	42	2,303
Cash**	126	-	25	108	77	82	85	88	98	105	54	-	848
Total First Plasma	**1,023**	**115**	**125**	**275**	**264**	**263**	**251**	**239**	**230**	**229**	**95**	**42**	**3,151**

Post-First-Plasma Construction Cost

($M)	Prior Years	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	FY35	Total
Hardware	-	11	12	24	36	45	46	180	210	249	235	217	95						1,360
Cash**	-								23	26	25	13	25	11	3	3	10	2	141
Total Post-First Plasma	-	**11**	**12**	**24**	**36**	**45**	**46**	**180**	**233**	**275**	**260**	**230**	**120**	**11**	**3**	**3**	**10**	**2**	**1,501**

*FY18-FY20 cash includes payment of 2016 cash commitments ($32.5M) and 2017 cash commitment ($35M)
** Assumes IO's current cash profile with transition from First Plasma to Post-First-Plasma in 2026

This U.S. ITER funding profile has a maximum single year budget of $275M. The estimated costs for FP hardware and cash through 2025 total $3.15B; and the estimated costs for Post-FP hardware and remaining cash total $1.50B. The overall estimated construction costs are

$4.65B,[4] of which approximately $1B has already been obligated. The cash represents the IO's construction phase contribution needs as of April 19, 2016.

At present, the cost profile above and that presented in the next section are preliminary estimates, have not been independently validated, and have not undergone the reviews associated with the rigorous CD-2 process that will approve a baseline.

4.2 2028 First Plasma Construction Cost Profile

The table below represents an annual construction funding profile to support a 2028 FP, three years after the early finish, best technically achievable date but within the late finish date that is consistent with a schedule contingency the U.S. would place on such a complex project. The profile still supports a DT operations date of 2035.

First Plasma Construction Cost

($M)	Prior Years	FY16	FY17	FY18*	FY19*	FY20*	FY21	FY22	FY23	FY24	FY25	FY26	FY27	Total
Hardware	897	115	100	122	163	168	157	148	139	109	100	83	45	2,346
Cash**	126	-	25	108	77	82	85	88	98	105	54	-		848
Total First Plasma	**1,023**	**115**	**125**	**230**	**240**	**250**	**242**	**236**	**237**	**214**	**154**	**83**	**45**	**3,194**

Post-First-Plasma Construction Cost

($M)	Prior Years	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	FY35	Total
Hardware	-	8	13	13	36	96	144	178	205	212	175	189	107	45			1,421
Cash**	-						23	26	25	13	25	11	3	3	10	2	141
Total Post- First Plasma	**-**	**8**	**13**	**13**	**36**	**96**	**167**	**204**	**230**	**225**	**200**	**200**	**110**	**48**	**10**	**2**	**1,562**

*FY18-FY20 cash includes payment of 2016 cash commitments ($32.5M) and 2017 cash commitment ($35M)
**Assumes IO's current cash profile with transition from First Plasma to Post-First-Plasma in 2026

This U.S. ITER funding profile has a peak single year maximum of $250M. The estimated costs for FP hardware and cash through 2027 total $3.20B; and the estimated costs for Post-FP hardware and remaining cash total $1.56B. The overall estimated construction costs are

[4] In addition to the construction costs, it is estimated that the U.S. would provide $1.2B in FY 2016 dollars for facility operations, decommissioning and deactivation.

$4.76B,[5] of which approximately $1B has already been obligated. The cash estimate represents the IO's construction estimate as of April 19, 2016.

4.3 Potential Costs Associated with U.S. Withdrawal

The JIA provides that withdrawal shall not affect the withdrawing party's contribution to construction costs. The U.S. would likely be expected to deliver or pay for its remaining share of the ITER construction costs, which could exceed $2B, excluding escalation and contingency. Excluding escalation is based on complete payment of all remaining U.S. commitments for the construction costs in FY 2016. Contingency would most likely be subject to negotiation during withdrawal.

In addition, as with the termination of any project, there are project shutdown costs, which are estimated to total $66M and comprise the following:

- 90-day notice period plus severance pay for the termination of U.S. ITER Project Lab (ORNL, PPPL, and SRNL) employees (143 personnel, $18M);
- Termination costs for U.S. personnel employed by the IO (35 personnel, $9M);
- Contract termination fees for all existing contracts (~$31M); and
- Project closeout activities ($8M).

The total project cost estimate for U.S. withdrawal, and assuming no assignment of U.S. contracts to the IO, could therefore potentially exceed $3B, including the ~$1B costed to date.

5 U.S. Requirements for ITER Project Improvements and Next Steps

DOE has identified additional measures that can improve project management discipline for both the international collaboration (how we want the IO to function to manage the entire effort) and the U.S. in-kind program (how we plan to manage our domestic project). This two-pronged strategy is described in the subsections below, where Sections 5.1 through 5.3 are focused on improvements to the international project and Sections 5.4 through 5.6 focus on improvements DOE will pursue domestically (both for the U.S. ITER Project and for the Fusion Energy Science program).

[5] In addition to the construction costs, it is estimated that the U.S. would provide $1.2B in FY 2016 dollars for facility operations, decommissioning and deactivation.

5.1 U.S. Requirement for Regular Independent Reviews

The successful conclusion of the ICRG points to a need for a more regular, independent review than that contained in the biennial MA report. It is recommended that the U.S. should only remain a Member in ITER beyond FY 2019 if the ITER project maintains its current momentum and continues to improve its performance. The U.S. will work to ensure that the IC conduct routine robust ITER project performance/risk management reviews every six months during the construction phase of the project. Such reviews would be similar to the ones conducted by SC on its projects, and can be implemented within the current IC and IO management frameworks. The scope would be approved by the IC, and the reviews would evaluate five areas critical to project success:

- Project Management – effectiveness of the overall organization and functions to include Senior Management, Human Resource, Procurement and Safety.
- Risk Management – approach to and utilization of risk management tools, planning and procedures across the entire project;
- Technical progress – major ITER technical systems, including design, complexity fabrication arrangements, systems engineering and integration, and the overall efficiency of technical decision making;
- Safety – approach, effectiveness and progress in planning and implementing the safety, particularly nuclear safety, aspects of the project; and
- Cost and Schedule – cost and schedule progress and monitoring.

5.2 Increased Transparency into DAs to Assess Risk

The U.S. will work to ensure through the IC close monitoring of and further enhancements to the risk management processes established by the IO. The risk management committee monitors IO and DA risks in a comprehensive risk register. A report and discussion will be included at each IC meeting, and a summary of the risk management activities will be provided by the DG in his interim status reports to the IC. These actions would help to ensure early notification of issues, particularly those that might impact achieving the milestones discussed in Section 5.3, and establish confidence that appropriate mitigation plans are being developed and implemented across all levels of the IO and DA's.

5.3 Key Performance Indicators/Milestones to Track Performance

Assurance of continued progress of the overall ITER project is critical to the U.S. in making an informed decision for remaining a partner in ITER. A table of critical performance indicator milestones for the next few years is provided below; neither the U.S., China nor Russia have items on or near the critical path in the next few years. The milestones are indicators of real, sustained IO progress towards completing construction and tangible movement towards equipment installation and assembly. The record of completing these milestones in the next

two years and evidence of progress on being able to meet the subsequent milestones will be a significant input to the decision on remaining a partner in ITER.

Milestone Description	Responsible Organization	Date (Calendar Year)
Signature of Construction Management Agent Contract	IO-Central Team	2016 Q3
First Sub Segment Assembly of Vacuum Vessel Sector 5 completed	IO-European Union	2016 Q4
Completion of Ready-For-Equipment 1A (Tokamak Assembly Hall)	IO-European Union	2017 Q1
Civil works and finishing performed in B2 level of Tokamak Building allowing TB04 installation to begin in tokamak building B2 level	IO-European Union	2017 Q4
First Vacuum Vessel sector 6 segment completed	IO-ROK	2017 Q4
First Toroidal Field coil delivery from Japan to ITER site	IO-Japan	2018 Q3
IO submittal to ASN for release of regulatory hold point, allowing start of machine assembly in pit	IO	2018 Q3
First Vacuum Vessel sector delivery to ITER site	IO-ROK	2018 Q4
First Toroidal Field Coil Delivery to ITER site from EU	IO-European Union	2019 Q3
Lower segment cryostat installation starts	IO-India	2019 Q3
Delivery of first EU Vacuum Vessel segment	European Union	2020

5.4 Next Steps for U.S. ITER Project

DOE will baseline the U.S. ITER Project (the in-kind contribution to the IO) to FP in FY 2017. Baselining of the U.S. ITER Project requires a credible international schedule, which was not available previously but which will be available this year and approved as a new baseline for the ITER Project at a Ministerial meeting in 2017. The CD-2 Performance Baseline Approval will be in accordance with DOE Order 413.3B,"Program and Project Management for the Acquisition of Capital Assets," requirements with the Deputy Secretary as Project Management Executive. The current plan is to manage the cash contribution outside of the U.S. ITER Project baseline. As a baselined project, independent project reviews will be conducted of the U.S. ITER project every six months. In addition, the status of the project will be included in the Energy Systems Acquisitions Advisory Board (ESAAB) process. This review process has been renewed in the past year to tighten up on the management of DOE projects.

Future budget planning for continued support for ITER needs to be considered within the context of the total budget for SC, and not merely within the FES program. Also, it is important to increase transparency in future budget planning for the ITER project. For these reasons, DOE

will work with OMB and Congress to seek to establish a separate budget line item for the U.S. ITER project, separate from the Fusion Energy Science budget line.

5.5 Limit on Cash Contributions

Budget profiles since 2013 have found that the cost range of U.S. in-kind components has not changed; however, the U.S. contribution to the ITER construction is still increasing as indicated by the recent request for additional IO funding. Until the overall ITER project is baselined and approved by the IC, there is uncertainty over the total IO costs (and thus the cash contribution needed from each Member), the fluctuation in the monetary exchange rate and the increases caused by future schedule delays. In addition, the IO and Members need to manage risks related to our understanding that it appears the EU will not have sufficient resources to meet both their in-kind commitments and the increased resources requested by the DG. This creates the potential for cost growth stemming from new delays caused by the EU choice as to whether they focus their resources on their in-kind contributions or provide the additional cash contribution needed by the IO. The U.S. will seek to negotiate a limit to the cash provided to the IO for assembly and construction to minimize our exposure to the liability of future cost growth. Such a limit could be pursued through the mechanisms available via the JIA and approved within the ITER Council.

5.6 National Academy of Sciences Study of the U.S. Fusion Program

The DOE will request that the National Academies perform a study of how to best advance the fusion energy sciences in the U.S., given the developments in the field since the last Academy studies in 2004, the specific international investments in fusion science and technology, and the priorities for the next ten years developed by the community and FES that were recently reported to Congress. This study will address the scientific justification and needs for strengthening the foundations for realizing fusion energy given a potential choice of U.S. participation or not in the ITER project, and will develop future scenarios in either case.

6 Conclusion

Based on the recent performance of ITER and the improved prospects for a successful science project, the recommendation is that the U.S. remain a partner in ITER through FY 2018 and focus on the FP construction in-kind hardware and cash contribution to ITER Organization. ITER remains the fastest path for the study of burning plasma. A recommendation to remain a partner past FY 2018 cannot be made until the U.S. has seen proof of continued and sustained project performance over the next two years.

Risks remain in the project. Prior to the FY 2019 budget submittal, we will be in a better position to assess the project as we will have 1) an updated IO project baseline through DT, 2) a baseline for the U.S. ITER Project through FP, and 3) two and a half years of results under the

new management. We will re-evaluate the progress of the project at that time and make a recommendation as to whether to continue or withdraw in order to inform the FY 2019 budget.

DOE has to complete an official baseline of the U.S. ITER project to provide a more accurate Total Project Cost (TPC) and annual funding profile for the U.S. to meet its commitments than what is estimated in this report. Once a project performance baseline and annual funding profile has been formulated, it will be independently reviewed and validated. The earliest date for completing the DOE baselining process, including independent validation, to FP would be in the first half of FY 2017.

Exceptional oversight and rigorous project management of ITER is essential for making the project successful. The U.S. will keep pressure on the other Members to continue to improve transparency and hold to the timeliness of their scheduled deliverables in order to reduce the potential for cost increases from further delays. We will also maintain close oversight over the operations of the IO through the IC and through ongoing, rigorous assessments.

Acronyms

DA	Domestic Agency
DG	Director General
DOE	U.S. Department of Energy
DT	Deuterium-Tritium
ESAAB	Energy Systems Acquisition Advisory Board
EU	European Union
FES	Fusion Energy Sciences
FESAC	Fusion Energy Sciences Advisory Committee
FP	First Plasma
IC	ITER Council
ICRG	ITER Council Review Group
IO	ITER Organization
JIA	Agreement on the Establishment of the ITER Fusion Energy Organization for the Joint Implementation of the ITER Project
MA	Management Assessment
MAC	Management Advisory Committee
OMPE	Overall Management Performance Evaluation
ROK	Republic of Korea
SC	DOE Office of Science
TPC	Total Project Cost
USIPO	U.S. ITER Project Office
ULTS	Updated Long-Term Schedule