Fusion Energy Sciences

Overview

The mission of the Fusion Energy Sciences (FES) program is to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundation needed to develop a fusion energy source. This is accomplished through the study of plasma, the fourth state of matter, and how it interacts with its surroundings.

Plasma science is wide-ranging, since 99% of the visible universe is composed of plasmas of various types. High-temperature fusion plasmas at hundreds of millions of degrees occur in national security applications, albeit for very short times. The same fusion plasmas could be exploited in the laboratory in a controlled fashion to become the basis for a future clean nuclear power source, which will provide domestic energy independence and security. This is a large driver for the FES subprograms focused on the scientific study of "burning plasma." In the burning plasma state of matter, the nuclear fusion process itself provides the dominant heat source for sustaining the plasma temperature. Such a self-heated plasma can continue to undergo fusion reactions that produce energy, without requiring the input of heating power from the outside, and thus resulting in large net energy yield.

In the FES program, foundational science for burning plasmas is obtained by investigating the behavior of laboratory fusion plasmas confined with strong magnetic fields. The DIII-D National Fusion Facility and the National Spherical Torus Experiment-Upgrade (NSTX-U) are world-leading Office of Science (SC) user facilities for experimental research available to and used by scientists from national laboratories, universities, and industry research groups. Complementing these experimental activities is a significant effort in fusion theory and simulation to predict and interpret the complex behavior of plasmas as self-organized systems. As part of this effort, FES supports several Scientific Discovery through Advanced Computing (SciDAC) centers in partnership with the Advanced Scientific Computing Research (ASCR) program office.

FES also investigates the behavior of plasmas that are confined near steady state. U.S. scientists take advantage of international partnerships to conduct research on superconducting tokamaks and stellarators with long-duration capabilities. In addition, the development of novel materials, a research area of high interest to many scientific fields, is especially important for fusion energy sciences since fusion plasmas create an environment of high-energy neutrons and huge heat fluxes that impinge on and damage the material structures containing the plasmas.

The frontier scientific area of the actual creation of strongly self-heated fusion burning plasmas will allow the discovery and study of new scientific phenomena relevant to fusion as a future energy source.

The FES program also supports discovery plasma science in research areas such as plasma astrophysics, high energy density laboratory plasmas (HEDLP), and low temperature plasmas. Some of this research is carried out through partnerships with the National Science Foundation (NSF) and the National Nuclear Security Administration (NNSA). Also, U.S. scientists are world leaders in the invention and development of new high-resolution plasma measurement techniques. A recent report[a] from the Fusion Energy Sciences Advisory Committee (FESAC) describes how plasma science advances have led to many spinoff applications and enabling technologies with considerable economic and societal impact for the American quality of life.

The FES program addresses several of the Administration's research and development budget priorities. Research in fusion has the potential to contribute to American energy dominance by making available to the American people a robust base-load electricity clean energy technology that relies on widely available and virtually inexhaustible fuel sources. Research in plasma science, within and beyond fusion, will contribute to American prosperity through the tremendous potential for spinoff applications as well as targeted investments in early-stage low temperature plasma research that can lead to the development of transformative technologies. Investments in our major fusion facilities and smaller-scale experiments will help maintain and modernize our research infrastructure for continuing to conduct world-leading research. Established partnerships within and outside DOE maximize leverage and increase the cost effectiveness of FES research activities. Finally, the unique scientific challenges and rigor of fusion and plasma physics research lead to the development of a well-

[a] https://science.energy.gov/~/media/fes/fesac/pdf/2015/2101507/FINAL_FES_NonFusionAppReport_090215.pdf

trained STEM-focused workforce, which will contribute to maintaining and advancing U.S. competitiveness and world-leadership in key areas of future technological and economic importance, as well as national security.

Highlights of the FY 2019 Request

Strategic choices in this Request are informed by the priorities described in "The Office of Science's Fusion Energy Sciences Program: A Ten-Year Perspective" (submitted to Congress in 2015), the research opportunities identified in a series of community engagement workshops held in 2015[a], and the FY 2017 FESAC investigation on the potential for transformative developments in fusion science and technology. Priorities include keeping SC fusion user facilities world-leading, investing in high performance computing and preparing for Exascale, supporting high-impact research in fusion materials, strengthening partnerships for access to international facilities with unique capabilities, learning how to predict and control transient events in fusion plasmas, and continuing stewardship of discovery plasma science (e.g., via intermediate-scale basic facilities). Furthermore, research priorities for burning plasma science in FY 2019 are to be informed by the FY 2018 report of the National Academy of Sciences (NAS) burning plasma study commissioned by FES.

Key points in the FY 2019 Request include:

<u>Modernizing and Managing Research Infrastructure</u>

- *DIII-D facility enhancements*—DIII-D will focus on completion of facility modifications and enhancements that began in FY 2018, which will maintain the world-leading status of the DIII-D tokamak. The time required for the facility enhancements will allow 12 weeks of research operation.
- *Continued support for NSTX-U program research and recovery activities*—The NSTX-U facility is down for recovery and repair, which will continue in FY 2019. The FY 2019 NSTX-U Operations budget will support high-priority activities to implement repairs and corrective actions required to obtain robust, reliable research operations. The Request for NSTX-U Research will fund the continued analysis of high-impact data, a focused effort on physics topics that directly support the recovery of robust NSTX-U plasma operations, and enhanced collaborative research at other facilities to support NSTX-U research program priorities.
- *Major Item of Equipment (MIE) project for world-leading fusion materials research*—Following the approval of the Linear Divertor Simulator Mission Need (CD-0) and down-selection of alternatives in FY 2018, FES will pursue the Materials Plasma Exposure eXperiment (MPEX) as an MIE project. MPEX will be able to address critical fusion materials science questions on the path toward proving the scientific viability of fusion power. It will provide a world-leading, highly cost-effective experimental device with superior capability, high throughput, and versatility.
- *Fusion nuclear science*—FES will initiate a study to evaluate options for a neutron source that will test materials in fusion-relevant environments.
- *High energy density laboratory plasmas*—FES will initiate a study to evaluate options for an upgrade to the Matter in Extreme Conditions (MEC) instrument on the Linac Coherent Light Source (LCLS) facility at SLAC National Accelerator Laboratory.
- *Continued U.S. hardware development and delivery to ITER*—The U.S. Contributions to ITER (U.S. ITER) First Plasma subproject will continue in the design, fabrication, and delivery of U.S. hardware contributions in support of the multi-billion-dollar international ITER project. The primary focus will be on the continued design and fabrication of the highest priority, in-kind contributions

<u>Innovative Research Partnership Models</u>

- *Scientific Discovery through Advanced Computing*—SciDAC will address high-priority research on tokamak disruptions and large-scale fusion data analysis challenges, and continue development of an integrated whole-device modeling capability in partnership with the ASCR program.
- *Long-pulse tokamak and stellarator research*—Long-pulse tokamak research will provide research opportunities for U.S. scientists on superconducting tokamaks with world-leading capabilities. In addition, there will be research opportunities for U.S. collaborations in the deuterium–tritium (DT) experimental campaign on the Joint European

[a] https://science.energy.gov/fes/community-resources/workshop-reports/

Torus (JET). Long-pulse stellarator research will enable U.S. teams to take full advantage of U.S. hardware investments on Wendelstein 7-X (W7-X) and enhance the scientific output on this device.

- *Discovery plasma science*—Basic plasma research is partially carried out in partnership with NSF and NNSA. Research and operations will be focused on the intermediate-scale plasma science facilities selected in FY 2017 and on HEDLP research on the MEC instrument, an end station at LCLS, stewarded by the SC Basic Energy Sciences (BES) program.

American Prosperity

- *Discovery plasma science*—Activities will continue in low temperature plasma research and HEDLP research, with connections and spinoffs to U.S. industry.

Fusion Energy Sciences
Funding ($K)

	FY 2017 Enacted[a]	FY 2018 Annualized CR[b]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Fusion Energy Sciences				
Burning Plasma Science: Foundations				
Advanced Tokamak	90,238	—	90,350	+112
Spherical Tokamak	76,789	—	63,000	-13,789
Theory & Simulation	40,000	—	36,000	-4,000
GPE/GPP/Infrastructure	5,000	—	1,000	-4,000
Total, Burning Plasma Science: Foundations	**212,027**	**—**	**190,350**	**-21,677**
Burning Plasma Science: Long Pulse				
Long Pulse: Tokamak	10,000	—	9,000	-1,000
Long Pulse: Stellarators	7,569	—	7,000	-569
Materials & Fusion Nuclear Science	24,000	—	22,500	-1,500
Total, Burning Plasma Science: Long Pulse	**41,569**	**—**	**38,500**	**-3,069**
Discovery Plasma Science				
Plasma Science Frontiers	52,409	—	24,500	-27,909
Measurement Innovation	10,255	—	0	-10,255
SBIR/STTR & Other	13,740	—	11,650	-2,090
Total, Discovery Plasma Science	**76,404**	**—**	**36,150**	**-40,254**
Subtotal, Fusion Energy Sciences	**330,000**	**327,759**	**265,000**	**-65,000**
Construction				
14-SC-60 U.S. Contributions to ITER	50,000	49,660	75,000	+25,000
Total, Fusion Energy Sciences	**380,000**	**377,419**	**340,000**	**-40,000**

SBIR/STTR:

- FY 2017 Enacted: SBIR: $8,814,000; STTR: $1,239,000
- FY 2019 Request: SBIR $8,323,000; and STTR $1,170,000

[a] The FY 2017 Enacted level includes SBIR and STTR.

[b] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

Fusion Energy Sciences
Explanation of Major Changes ($K)

	FY 2019 Request vs FY 2017 Enacted
Burning Plasma Science: Foundations: DIII-D will emphasize completion of facility improvements that began in FY 2018, followed by 12 weeks of research operation. Funding for the NSTX-U program will support continued repair activities for the facility and enhanced collaborative research at other facilities to support NSTX-U research program priorities. SciDAC continues to make progress toward whole-device modeling, strengthening research on plasma disruptions and addressing large-scale data analysis challenges. Funding is provided for General Plant Projects/General Purpose Equipment (GPP/GPE), which supports Princeton Plasma Physics Laboratory (PPPL) infrastructure improvements, repair, and maintenance.	-21,677
Burning Plasma Science: Long Pulse: Efforts are focused on highest-priority international collaboration activities, both for tokamaks and stellarators. Materials research and fusion nuclear science research programs are focused on highest priorities. Funding will be initiated for the Materials Plasma Exposure eXperiment (MPEX) Major Item of Equipment (MIE) project, which was identified as a priority in the community workshop on Plasma Materials Interactions.	-3,069
Discovery Plasma Science: Research and operations of intermediate-scale scientific user facilities in General Plasma Science are emphasized. For High Energy Density Laboratory Plasmas, the focus remains on supporting research utilizing the Matter in Extreme Conditions instrument of the LCLS user facility at SLAC. No funding is requested for Exploratory Magnetized Plasma research and Measurement Innovation.	-40,254
Construction: The U.S. Contributions to ITER project will continue design, fabrication, and delivery of key First Plasma hardware components.	+25,000
Total Funding Change, Fusion Energy Sciences	**-40,000**

Basic and Applied R&D Coordination
FES participates in coordinated intra- and inter-agency initiatives within DOE and with other federal agencies on science and technology issues related to fusion and plasma science. Within SC, FES operates the MEC instrument at the SLAC LCLS user facility operated by BES, and supports high-performance computing research with ASCR. Within DOE, FES operates a joint program with NNSA in HEDLP physics. FESAC provides technical and programmatic advice to FES and NNSA for the joint HEDLP program. Outside DOE, FES carries out a discovery-driven plasma science research program in partnership with NSF, with research extending to a wide range of natural phenomena, including the origin of magnetic fields in the universe and the nature of plasma turbulence. The joint programs with NNSA and NSF involve coordination of solicitations, peer reviews, and workshops.

Program Accomplishments
Heating the core of fusion reactors leads to sheared rotation that can improve plasma performance – New measurements and simulations of plasma rotation at the DIII-D tokamak facility at General Atomics (GA) show that self-organized "intrinsic rotation" in tokamaks is generated by turbulence. Such self-organized flow can be beneficial for fusion reactor performance because it suppresses turbulent energy loss and magnetohydrodynamic instabilities. The experimental measurements show that simply heating the plasma core can cause it to generate a sheared flow. The computer modeling provides a quantitative understanding of the amount of sheared flow that can be generated with the use of this self-generated intrinsic torque.

Plasma instabilities can be eliminated when the heating power is increased – Alpha particles born from fusion reactions drive plasma instabilities that can cause reactors to lose heat, reducing their efficiency. Results from the NSTX-U facility at PPPL show for the first time that additional neutral beam heating can suppress plasma instabilities known as global Alfvén eigenmodes (GAE). Eliminating the GAE instabilities may be a key first step toward achieving high plasma performance in a compact spherical tokamak. The ability to predict and control these instabilities is also important for burning plasmas and future fusion reactors, which are heated by a large population of fusion-generated alpha particles and neutral beam ions.

Massively parallel simulations shed light on long-standing magnetic confinement challenge – Efficient operation of tokamak magnetic confinement fusion devices relies on attainment of the high-confinement mode (H-mode), which reduces the energy leakage from the confinement region by at least a factor of two through suppression of turbulence at the plasma edge. While the transition to H-mode has been known for at least 35 years and has been reproduced on all the world's tokamaks, a predictive understanding of this phenomenon has proved elusive. Recently, massively parallel simulations performed by scientists in the SciDAC Edge Physics Simulation Center (a partnership with ASCR) have, for the first time, modeled this transition with the use of a first-principles plasma turbulence simulation code and SC leadership computing resources. The simulations took three days and used 90% of the capacity of the Titan supercomputer at the Oak Ridge Leadership Computing Facility.

Proto-MPEX points the way to world-leading capability for plasma-material interactions research – The Prototype Material Plasma Exposure eXperiment (Proto-MPEX) at Oak Ridge National Laboratory (ORNL) successfully demonstrated a novel plasma generator aimed at enabling new experimental capabilities that are needed for plasma-material interaction research. Proto-MPEX allows the study of materials exposed to the extreme plasma conditions expected in future fusion devices. Its versatile design, based on a high-density radio frequency helicon plasma source coupled with separate ion and electron heating schemes, allows for independent control of vital plasma parameters such as density, electron temperature, and ion temperature. Although currently limited to low power and short pulse, Proto-MPEX has demonstrated the feasibility of the source concept and led to high confidence in the construction of a new world-leading experimental capability.

New approach could solve a significant challenge in the design of stellarator coils – New research has shown that the mathematical optimization methods used to compute the three-dimensional electromagnetic coil shapes for stellarators can be modified to increase the space between the coils and smooth their sharp bends, while preserving the speed and reliability of the optimization. This new method will enable stellarator designs that have smoother coil shapes and increased inter-coil spacing, which could be more feasible to construct and maintain.

U.S. international collaboration makes excellent start in optimizing the use of lithium to control fusion plasmas – For fusion to generate substantial energy, the ultra-hot plasma that fuels fusion reactions must remain stable and be kept from cooling. U.S. researchers have recently shown that lithium is effective in both respects in experiments on the Experimental Advanced Superconducting Tokamak (EAST) in Hefei, China. The recent scientific effort deployed three different lithium delivery systems in EAST. Each lithium delivery technology performed as designed and enabled improved modes of operation, including tokamak operation with external control of periodic edge instabilities, as well as control over the elemental composition of the surrounding edge plasma. These results motivate continued effort to develop sophisticated boundary control solutions that use lithium.

Laboratory experiments explain the kink behavior of the Crab Nebula Jet – Using the high-power Omega laser at the University of Rochester's Laboratory for Laser Energetics, U.S. scientists conducted experiments to understand the dynamics of the Crab Nebula jet evolution. Fusion protons from deuterium/helium-3 implosion were used to obtain spatial visualization and detailed measurements of the electromagnetic fields. The data shows that the toroidal magnetic field, embedded in the supersonic jet, triggers plasma instabilities and results in considerable deflections throughout the jet propagation, mimicking the kinks in the Crab Nebula jet.

First-ever measurement of the optical spectrum of anti-hydrogen – The study of anti-hydrogen is important because any measurable difference between its spectra and that of normal hydrogen will break basic principles of physics and help explain the puzzling matter-antimatter imbalance in the universe. However, anti-hydrogen atoms have to be synthesized from non-neutral anti-proton and positron plasmas, which is extremely challenging. Using techniques from plasma physics research, U.S. scientists in the international ALPHA team have successfully trapped nearly 500 antihydrogen atoms at the Large Hadron Collider of the European Organization for Nuclear Research (CERN). By illuminating these trapped anti-hydrogen atoms with two different wavelengths of laser light, the physicists were able to measure the optical spectrum of anti-hydrogen for the first time ever. Their results, which showed that the anti-atoms interact with light at nearly the same wavelength as for normal-matter hydrogen, received attention in the popular media.

Description

The Burning Plasma Science: Foundations subprogram advances the predictive understanding of plasma confinement, dynamics, and interactions with surrounding materials. Among the activities supported by this subprogram are:

- Research at major experimental facilities aimed at resolving fundamental advanced tokamak and spherical tokamak science issues.
- Research on small-scale magnetic confinement experiments to elucidate physics principles underlying toroidal confinement and to validate theoretical models and simulation codes.
- Theoretical work on the fundamental description of magnetically confined plasmas and the development of advanced simulation codes on current and emerging high-performance computers.
- Research on technologies needed to support the continued improvement of the experimental program and facilities.
- Support for infrastructure improvements at PPPL.

Research in the Burning Plasma Science: Foundations area in FY 2019 will focus on high-priority challenges and opportunities in the areas of transients in tokamaks, plasma-material interactions, and integrated modeling, as identified by recent research needs workshops and other community-led studies.

Advanced Tokamak

The DIII-D user facility at General Atomics in San Diego, California, is the largest magnetic fusion research experiment in the U.S. and can magnetically confine plasmas at temperatures relevant to burning plasma conditions. Its extensive set of diagnostic systems, many unique in the world, and its extraordinary flexibility to explore various operating regimes make it a world-leading tokamak research facility. Researchers from the U.S. and abroad perform experiments on DIII-D for studying stability, confinement, and other properties of fusion-grade plasmas under a wide variety of conditions. The DIII-D research goal is to establish the broad scientific basis to optimize the tokamak approach to magnetic confinement fusion. Much of this research concentrates on developing the advanced tokamak concept, in which active control techniques are used to manipulate and optimize the plasma to obtain conditions scalable to robust operating points and high fusion gain for future energy-producing fusion reactors.

The Enabling Research and Development (R&D) element develops the technology to enhance the capabilities for existing and next-generation fusion research facilities, enabling these facilities to achieve higher levels of performance and flexibility needed to explore new science regimes.

Research on versatile university-led small-scale advanced tokamak projects is complementary to the efforts at the major user facilities, providing cost-effective development of new techniques and exploration of new concepts. Recent efforts are focused on improving fusion plasma control physics for advanced tokamaks through application of modern digital tokamak control theory and validation of fundamental plasma stability theory.

Spherical Tokamak

The NSTX-U user facility at PPPL has been designed to explore the physics of plasmas confined in a spherical tokamak (ST) configuration, characterized by a compact (apple-like) shape. If the predicted ST energy confinement improvements were to be experimentally realized in NSTX-U, then the ST might provide a more compact fusion reactor than other geometries. Following an extensive series of reviews (e.g., design validation and verification, extent of condition) in FY 2017 and FY 2018, NSTX-U activities will focus high-priority activities to implement repairs and corrective actions required to obtain robust, reliable research operations.

Small-scale ST plasma research involves focused experiments to provide data in regimes of relevance to the ST magnetic confinement program. This effort can help confirm theoretical models and simulation codes in support of the FES goal to develop an experimentally validated predictive capability for magnetically confined fusion plasmas. This activity also involves high-risk, but high-payoff, experimental efforts useful to advancing ST science.

Theory and Simulation

The Theory and Simulation activity is a key component of the FES program's strategy to develop the predictive capability needed for a sustainable fusion energy source. It also represents a world-leading U.S. strength and competitive advantage in fusion research. Its long-term goal is to enable a transformation in predictive power based on fundamental science and high-performance computing to minimize risk in future development steps and shorten the path toward the realization of fusion energy. This activity includes two main interrelated but distinct elements: Theory and SciDAC.

The Theory element is focused on advancing the scientific understanding of the fundamental physical processes governing the behavior of magnetically confined plasmas. The research supported ranges from foundational analytic theory to mid- and large-scale computational work using high-performance computing resources. In addition to its scientific discovery mission, the Theory activity provides the scientific grounding for the physics models implemented in the advanced simulation codes developed under the SciDAC activity described below and also supports validation efforts at major experiments.

The FES SciDAC element, a component of the SC-wide SciDAC program, is aimed at accelerating scientific discovery in fusion plasma science by capitalizing on SC investments in leadership-class computing systems and associated advances in computational science. The portfolio that emerged from the FY 2017 SC-wide SciDAC-4 re-competition consists of eight multi-institutional interdisciplinary partnerships, with seven jointly supported by FES and ASCR, and addresses the high-priority research directions identified in recent community workshops. The new portfolio emphasizes increased integration and whole-device modeling, as well as synergy with the fusion-relevant projects of the SC Exascale Computing Project (SC-ECP) to increase the readiness of the fusion community for the upcoming Exascale era.

Additional objectives of this element include the evaluation of the potential of emerging computational approaches, such as machine learning, to advance its mission and address the growing large-scale fusion data analysis challenges.

GPE/GPP/Infrastructure

This activity supports repairs of critical general infrastructure (e.g., utilities, roofs, roads, facilities) at the PPPL site.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Advanced Tokamak $90,238,000	**$90,350,000**	**+$112,000**
DIII-D Research $40,500,000	*$40,500,000*	*$0*
DIII-D Operations $46,600,000	*$47,000,000*	*+$400,000*
Operations funding supported 17.6 weeks of research operations at the DIII-D facility. Research was conducted to prepare for burning plasmas in ITER, determine the optimal path to steady-state tokamak plasmas, and develop the plasma material interaction boundary solutions necessary for future devices. Specific research goals involved testing the predictive models of fast ion transport by multiple Alfvén eigenmodes, studying the physical processes that determine the edge pedestal density structure, and examining the impurity generation and transport from the high-Z coated tiles. Targeted enhancements to the facility involved completion and commissioning of an additional high-power microwave heating system, as well as continued work on improving the neutral beam heating control system and designing the modifications necessary for a second off-axis, co- and counter-directed neutral beam.	Operations funding will support 12 weeks of research at the DIII-D facility and the completion of a neutral beam modification to add bi-directional off-axis injection capability. Research will continue to determine the optimal path to steady-state tokamak plasmas, explore techniques to avoid and mitigate transients in tokamaks, and develop the plasma-material interaction boundary solutions necessary for future devices. Experiments will exploit additional heating and current drive systems added in FY 2018. The new neutral beam capability will be utilized to examine the physics of self-driven tokamak plasmas. Specific research goals will be aimed at further integrating the core and edge conditions in high-performance plasmas and studying the role of neutral fueling and transport in determining the edge pedestal structure.	Priority and balance of effort will be shifted from research operations toward completion of the facility improvements begun in FY 2018.
Enabling R&D $2,165,000	*$2,000,000*	*-$165,000*
Support continued to be provided for research in superconducting magnet technology and plasma fueling and heating technologies required to enhance the performance for existing and future magnetic confinement fusion devices.	Research will continue in superconducting magnet technology and plasma fueling and heating technologies required to enhance the performance for existing and future magnetic confinement fusion devices.	Research efforts in heating, fueling, and magnet technology will be focused on the highest priorities.

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Small-scale Experimental Research $973,000	*$850,000*	*-$123,000*
Research continued to provide experimental data in regimes relevant to mainline tokamak confinement and experimental validation of models and codes.	Versatile university-led experiments will be focused on improving fusion plasma control physics for advanced tokamaks.	After the completion of diagnostic and control system enhancements in FY 2018, the emphasis will be on research operations.
Spherical Tokamak $76,789,000	**$63,000,000**	**-$13,789,000**
NSTX-U Research $32,000,000	*$27,000,000*	*-$5,000,000*
NSTX-U Operations $42,090,000	*$34,000,000*	*-$8,090,000*
Operations funding supported the recovery activities for the NSTX-U facility. Research focused on the study of ST confinement improvements observed during the FY 2016 experimental run campaign. Modeling and measurement data allowed elucidation of the detailed physical mechanisms responsible for these confinement improvements. In the absence of plasma operations at the NSTX-U facility, researchers carried out experiments on domestic and international spherical tokamaks, and continued analysis and publication of data obtained in FY 2016.	The NSTX-U Operations budget will support high-priority activities to implement repairs and corrective actions required to obtain robust, reliable research operations. The NSTX-U Research budget will fund the continued analysis of high-impact data, a focused effort on physics topics that directly support the recovery of robust NSTX-U plasma operations, and enhanced collaborative research at other facilities to support NSTX-U research program priorities.	Priority and balance of effort will be shifted from research operations toward repair and recovery of the facility.
Small-scale Experimental Research $2,699,000	*$2,000,000*	*-$699,000*
Research continued to provide experimental data in regimes relevant to mainline spherical torus confinement and experimental validation of models and codes.	Experimental studies of plasmas surrounded by liquid lithium material surfaces, which was identified as a priority research direction in the recent plasma-materials interactions workshop, will continue. Also, techniques to operate spherical tokamaks without the use of a central solenoid will continue to be experimentally tested.	After the completion of minor facility enhancements in FY 2018, activities in this category will focus on research operations.
Theory & Simulation $40,000,000	**$36,000,000**	**-$4,000,000**
Theory $22,000,000	*$18,000,000*	*-$4,000,000*
Theory continued to support theoretical and computational research addressing fundamental questions of magnetic confinement science. Emphasis was placed on projects maximizing synergy with the FES SciDAC portfolio and addressing the recommendations from the 2015 community workshops.	Theory will continue to focus on providing the scientific grounding for the physical models implemented in the large-scale simulation codes developed under SciDAC and addressing foundational problems in the science of magnetic confinement, as identified in recent community workshops.	Priority will be given to addressing the needs of the advanced simulation efforts.

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
SciDAC $18,000,000	*$18,000,000*	*$0*
The entire FES SciDAC portfolio was recompeted as part of the SC-wide SciDAC-4 review. The selected partnerships continued to focus on integrated simulations and whole device modeling, addressing the leading-priority research directions identified in the 2015 community workshops.	The SciDAC portfolio will continue to emphasize high-priority areas such as plasma disruptions, boundary physics, and plasma-materials interactions. The activities of all the partnerships will be coordinated to accelerate progress toward whole-device modeling. Synergy with whole-device modeling activities supported by the DOE Exascale Computing Project will be strengthened.	Studies will continue on highest-priority issues. In addition, research will address large-scale fusion data challenges.
GPE/GPP/Infrastructure $5,000,000	**$1,000,000**	**-$4,000,000**
Funding provided support for general infrastructure improvements for the PPPL site consistent with the PPPL Campus Modernization Plan, based upon an analysis of safety requirements, equipment reliability, and research-related infrastructure needs.	Funding will support Princeton Plasma Physics Laboratory (PPPL) infrastructure improvements, repair, and maintenance.	The focus will be on highest-priority infrastructure needs.

Fusion Energy Sciences
Burning Plasma Science: Long Pulse

Description

The Burning Plasma Science: Long Pulse subprogram explores new and unique scientific regimes that can be achieved primarily with long-duration superconducting international machines, and addresses the development of the materials and technologies required to withstand and sustain a burning plasma. The key objectives of this area are to utilize these new capabilities to accelerate our scientific understanding of how to control and operate a burning plasma, as well as to develop the basis for a future fusion nuclear science facility. This subprogram includes long-pulse international tokamak and stellarator research and fusion nuclear science and materials research.

Long Pulse: Tokamak

Multi-institutional U.S. research teams will continue their successful work on advancing the physics and technology basis for long-pulse burning plasma operation via bilateral research on U.S. and international fusion facilities. Research on overseas superconducting tokamaks, conducted onsite and also via fully remote facility operation, leverages progress made in domestic devices and allows the U.S. fusion program to gain the knowledge needed to operate long-duration plasma discharges in future fusion energy devices. These efforts will be augmented by research on overseas non-superconducting tokamaks and spherical tokamaks with unique capabilities.

Long Pulse: Stellarator

Stellarators offer the promise of steady-state confinement regimes without transient events such as harmful disruptions. The three-dimensional (3-D) shaping of the plasma in a stellarator provides for a broader range in design flexibility than is achievable in a 2-D system. The participation of U.S. researchers on W7-X in Germany provides an opportunity to develop and assess 3-D divertor configurations for long-pulse, high-performance stellarators. The U.S. plans to develop control schemes to maintain plasmas with stable operational boundaries, including the challenges of control with superconducting coils and issues of the diagnosis-control cycle in long-pulse conditions. U.S. researchers will play key roles in developing the operational scenarios and hardware configuration for high-power, steady-state operation, an accomplishment that will advance the performance/pulse length frontier for fusion. The strong U.S. contributions during the W7-X construction phase have earned the U.S. formal partnership status. Accordingly, the U.S. is participating fully in W7-X research and access to data.

U.S. domestic compact stellarator research is focused on optimization of the stellarator concept through quasi-symmetric shaping of the toroidal magnetic field. A conventional stellarator lacks axial symmetry, resulting in reduced confinement of energetic ions, which are needed to heat the plasma. Quasi-symmetric shaping, invented in the U.S., offers an improved solution for stable, well confined, steady-state stellarator plasma confinement.

Materials and Fusion Nuclear Science

The Materials and Fusion Nuclear Science activity seeks to address the large scientific and technical gaps that exist between current-generation fusion experiments and future fusion reactors. Traditional materials used in present-day experiments will not be acceptable in an intense fusion nuclear environment, and the development of components for fusion power plants must be significantly improved in order to adequately provide the multiple functions of heat extraction, tritium breeding, and particle control. The scientific challenge is understanding the complex fusion environment, which combines extremely strong nuclear heating and damage, high temperatures, fluid-solid interactions, high tritium concentrations, and high magnetic fields, as well as large variations of these parameters from the first wall to the vacuum vessel, and the impact on materials and component performance. To help develop solutions for this complex scientific challenge, new experimental capabilities along with game-changing types of research will be required. Facilities with these experimental capabilities will need to duplicate or effectively simulate various aspects of the harsh fusion environment. These experimental capabilities should also lead to the development of new materials, which could be used in other applications besides fusion.

A high-priority objective for the fusion materials science effort is to continue pursuing the design and fabrication of the new world-leading experimental device, the Materials Plasma Exposure eXperiment (MPEX) at ORNL, which will allow for dedicated studies of reactor-relevant heat and particle loads on neutron-irradiated materials. The overall motivation is to gain entry into a new class of fusion materials science wherein the combined effects of fusion-relevant heat, particle, and neutron fluxes can be studied for the first time anywhere in the world.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Long Pulse: Tokamak $10,000,000	**$9,000,000**	**-$1,000,000**
Multi-institutional U.S. research teams continued to conduct high-impact research on the international superconducting long-pulse tokamaks, taking advantage of their upgraded capabilities.	Research on the EAST and KSTAR superconducting tokamaks will continue to establish the physics bases and control tools for steady-state plasma scenarios, disruption avoidance and mitigation, and control of plasma-material interfaces. Also, a multi-institutional U.S. team will continue to develop diagnostics for the new Japanese superconducting tokamak JT-60SA. On the Joint European Torus, U.S. scientists will finish testing their shattered pellet disruption mitigation system and then collaborate on optimization of burning plasma scenarios with deuterium and tritium fuels.	Sustained funding enables continued exploitation of unique international capabilities by multi-institutional teams from the U.S.
Long Pulse: Stellarators $7,569,000	**$7,000,000**	**-$569,000**
Superconducting Stellarator Research $5,000,000	*$4,500,000*	*-$500,000*
U.S. scientists participated in W7-X research on topics important for understanding the physics of long-pulse plasma confinement in 3-D magnetic configurations. Topics included error fields, magnetic island physics, energetic-particle transport, impurity studies, plasma-material interactions, core plasma transport, and plasma control. The U.S. team collaborated in the preparation of equipment and plasma scenarios for long-pulse operation.	U.S. scientists will use data from the first major experimental campaign on W7-X to strengthen the basis for long-pulse operation with pellet fueling, test the innovative island divertor concept, investigate impurity recycling, study the effect of the U.S.-provided trim coils on fast-ion confinement and on modulation of divertor heat loads, and determine the effect of the radial electric field on impurity transport.	Sustained funding enables continued exploitation of the unique capabilities of the W7-X facility by a multi-institutional team from the U.S.
Compact Stellarator Research $2,569,000	*$2,500,000*	*-$69,000*
Research continued on experiments that are providing data in regimes relevant to mainline stellarator confinement and experimental validation of models and codes.	Research will provide experimental data in regimes of relevance to the mainline stellarator magnetic confinement efforts and help confirm theoretical models and simulation codes in support of the goal to develop an experimentally-validated predictive capability for magnetically confined fusion plasmas.	Research efforts are continued on highest-priority activities.

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Materials & Fusion Nuclear Science $24,000,000	**$22,500,000**	**-$1,500,000**
Fusion Nuclear Science $10,252,000	*$8,500,000*	*-$1,752,000*
Utilization of existing experimental capabilities and development of new ones to conduct research in the areas of plasma-facing materials and plasma-material interactions were a key emphasis. In addition, research on understanding tritium retention, permeation and processing, neutronics, and material-corrosion issues for blankets and scoping studies on future fusion facilities continued.	Research will continue to focus on the priority areas of plasma-facing components, safety, tritium fuel cycle, and breeder blanket technologies. Opportunities will be considered for high-priority research on liquid metal plasma-facing components in response to the outcome of the systems-level study conducted during the previous two years. In addition, a study will be initiated to evaluate options for a neutron source to test materials in fusion-relevant environments.	Research efforts are focused on highest-priority activities.
Materials Research $13,748,000	*$12,000,000*	*-$1,748,000*
The program emphasized the utilization of existing experimental capabilities and development of new ones to conduct research in the area of material response to simulated fusion neutron irradiation. There was a continued focus on research toward structural materials that can withstand high levels of damage, increasing the ductility of tungsten, and modeling of helium damage in numerous materials.	Research efforts will continue to focus on the development of materials that can withstand the extreme fusion environment expected in future fusion reactors.	Research efforts are focused on supporting the initiation of design and fabrication activities for MPEX.
Projects $0	*$2,000,000*	*+$2,000,000*
	A new MIE project, the Materials Plasma Exposure eXperiment (MPEX) at ORNL will develop a world-leading capability for reactor-relevant plasma exposures of neutron irradiated materials. Detailed project engineering and design efforts and some long-lead procurements will be performed.	The Request initiates funding for the MPEX MIE.

Description

The Discovery Plasma Science subprogram supports research that explores the fundamental properties and complex behavior of matter in the plasma state to improve the understanding required to control and manipulate plasmas for a broad range of applications. Plasma science is not only fundamental to understanding the nature of visible matter throughout the universe, but also to achieving the eventual production and control of fusion energy. Discoveries in plasma science are leading to an ever-increasing array of practical applications, such as nanomaterials and artificial diamond synthesis, micro- and opto-electronics fabrication, energy efficient lighting, plasma-enabled sterilization and tissue healing, combustion enhancement, and satellite communication.

The Discovery Plasma Science subprogram is organized into two principal activities: Plasma Science Frontiers and Measurement Innovation.

<u>Plasma Science Frontiers</u>

The Plasma Science Frontiers (PSF) activities involve research in largely unexplored areas of plasma science, with a combination of theory, computer modeling, and experimentation. These frontiers encompass extremes of the plasma state, ranging from the very small (several atom systems) to the extremely large (plasma structure spanning light years in length), from the very fast (attosecond processes) to the very slow (hours), from the diffuse (interstellar medium) to the extremely dense (diamond compressed to tens of gigabar pressures), and from the ultra-cold (tens of micro-kelvin degrees) to the extremely hot (stellar core). Advancing the science of these unexplored areas creates opportunities for new and unexpected discoveries with potential to be translated into practical applications. These activities are carried out on small- and mid-scale experimental collaborative research facilities.

The PSF portfolio includes coordinated research activities in the following three areas:

- *General Plasma Science* – Research in frontier areas of basic and low temperature plasma science and engineering, including advancing our understanding of the behavior of non-neutral and single-component plasmas, ultra-cold plasmas, dusty plasmas, and micro-plasmas, as well as the study of dynamical processes in classical plasmas including turbulence, thermal, radiative and particle transport, waves, structures, flows and their interactions.
- *High Energy Density Laboratory Plasmas* – Research directed at exploring the behavior of matter at extreme conditions of temperature, density, and pressure, including laboratory astrophysics and planetary science, structure and dynamic of matter at the atomic scale, laser-plasma interactions and relativistic optics, magnetohydrodynamics and magnetized plasmas, and plasma atomic physics and radiation transport.
- *Exploratory Magnetized Plasma* – Basic research involving the creation, control, and manipulation of magnetically confined plasmas to increase our understanding of terrestrial, space, and astrophysical phenomena or applications.

The PSF activity stewards world-class plasma science experiments and user facilities at small and intermediate scales. These platforms not only facilitate addressing frontier plasma science questions but also provide critical data for the verification and validation of plasma science simulation codes. This effort maintains strong partnerships with NSF and NNSA.

<u>Measurement Innovation</u>

The Measurement Innovation activity supports the development of world-leading innovative diagnostic techniques and their application to new, unexplored, or unfamiliar plasma regimes or scenarios. The challenge is to develop diagnostics with the high spatial, spectral, and temporal resolution necessary to validate plasma physics models used to predict the behavior of fusion plasmas. Advanced diagnostic capabilities successfully developed through this activity are migrated to domestic and international facilities as part of the Burning Plasma Science: Foundations and Burning Plasma: Long Pulse subprograms. The utilization of mature diagnostics systems is then supported via the research programs at major fusion facilities.

SBIR/STTR & Other

Funding for SBIR/STTR is included in this activity. Other items that are supported include research at Historically Black Colleges and Universities (HBCUs); the U.S. Burning Plasma Organization (USBPO), a national organization that coordinates research in burning plasma science; peer reviews for solicitations across the program; and FESAC.

Fusion Energy Sciences
Discovery Plasma Science

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Plasma Science Frontiers $52,409,000	**$24,500,000**	**-$27,909,000**
General Plasma Science $24,000,000	*$14,000,000*	*-$10,000,000*
Core research areas of this activity continued, with a program focus on intermediate-scale plasma science user facilities, as well as research in areas identified in the 2015 Frontiers of Plasma Science Workshops Report.	Core research areas of this activity will continue, with focus on intermediate-scale plasma science collaborative user facilities that address questions related to plasma dynamo, magnetic reconnection, particle acceleration, turbulence, and magnetic self-organization.	Basic plasma science research on the intermediate-scale plasma science collaborative user facilities will be emphasized.
High Energy Density Laboratory Plasmas $18,000,000	*$10,500,000*	*-$7,500,000*
Research emphasized utilizing the MEC at LCLS, including continued support for the MEC beam-line science team, the experimental and theoretical HEDLP research groups at SLAC, and enhanced support of external HED science users of the MEC instrument.	Research will emphasize utilizing the MEC at LCLS for warm dense matter studies. Support will continue for the MEC beam-line science team and the experimental HEDLP research groups at SLAC. A study will be initiated to evaluate options for a MEC upgrade. Modest support is provided to make medium-scale HEDLP facilities accessible to university researchers.	Support will be focused on research and operations for the MEC.
Exploratory Magnetized Plasma $10,409,000	*$0*	*-$10,409,000*
Research efforts focused on discovery at the frontier of laboratory magnetized-plasma physics, emphasizing high-priority research as identified by the plasma science frontiers workshops held in FY 2015.	No funding is requested.	Due to higher priority activities, no funding is requested.

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Measurement Innovation $10,255,000	**$0**	**-$10,255,000**
Measurement Innovation research activities continued with special emphasis on diagnostics for plasma transient instabilities, plasma-materials interactions, modeling validation, and basic plasma science identified in the 2015 community workshops.	No funding is requested.	Due to higher priority activities, no funding is requested.
SBIR/STTR & Other $13,740,000	**$11,650,000**	**-$2,090,000**
Funding continued to support USBPO activities, HBCUs, peer reviews for solicitations, and FESAC. SBIR/STTR funding is statutorily set at 3.65 percent of noncapital funding in FY 2017.	Support will continue for USBPO activities, HBCUs, peer reviews for solicitations, and FESAC. SBIR/STTR funding is statutorily set at 3.65 percent of noncapital funding in FY 2019.	The SBIR/STTR funding will be consistent with the FES total budget.

Description

The ITER facility, currently under construction in St. Paul-lez-Durance, France, aims to provide access to burning plasmas with fusion power output approaching reactor levels of hundreds of megawatts, for hundreds of seconds. Construction of ITER is a collaboration among the United States, European Union, Russia, Japan, India, Republic of Korea, and China, governed by an international agreement (the "ITER Joint Implementing Agreement"), through which the U.S. contributes in-kind-hardware components, personnel, and direct monetary funding to the ITER Organization (IO).

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
U.S. Contributions to ITER $50,000,000	**$75,000,000**	**+$25,000,000**
Funding was provided for the U.S. Contributions to ITER project to support continued progress on critical in-kind hardware contributions, including central solenoid superconducting magnet modules and structures, toroidal field magnet conductor, steady-state electrical network components, diagnostics development, tokamak cooling water system, and vacuum system.	The primary focus will be on First Plasma hardware including continued design and fabrication of the highest priority, in kind deliverables.	Funding will sustain progress on highest-priority First Plasma hardware contributions.

In accordance with the GPRA Modernization Act of 2010, the Department sets targets for, and tracks progress toward, achieving performance goals for each program.

	FY 2017	FY 2018	FY 2019
Performance Goal (Measure)	**FES Facility Based Experiments - Experiments conducted on major fusion facilities [DIII-D National Fusion Facility (DIII-D) and National Spherical Torus Experiment Upgrade (NSTX)-U] leading toward predictive capability for burning plasmas and configuration optimization**		
Target	Conduct research to examine the effect of configuration on operating space for dissipative divertors. Handling plasma power and particle exhaust in the divertor region is a critical issue for future burning plasma devices. The very narrow edge power exhaust channel projected for tokamak devices that operate at high poloidal magnetic field is of particular concern. Increased and controlled divertor radiation, coupled with optimization of the divertor configuration, are envisioned as the leading approaches to reducing peak heat flux on the divertor targets and increasing the operating window for dissipative divertors. Data obtained from DIII-D and NSTX-U and archived from Alcator C-Mod will be used to assess the impact of edge magnetic configurations and divertor geometries on dissipative regimes, as well as their effect on the width of the power exhaust channel, thus providing essential data to test and validate leading boundary plasma models.	Conduct research to test predictive models of fast ion transport by multiple Alfvén eigenmodes. Fusion alphas and injected energetic neutral particle beams provide an important source of heating and current drive in advanced tokamak operating scenarios and burning plasma regimes. Alfven eigenmode instabilities can cause the redistribution or loss of fast ions and driven currents, as well as potentially decreasing fusion performance and leading to localized losses. Measured fast ion fluxes in DIII-D and NSTX-U plasmas with different levels of Alfven eigenmode activity will be used to determine the threshold for significant fast ion transport, assess mechanisms and models for such transport, and quantify the impact on beam power deposition and current drive. Measurements will be compared with theoretical predictions, including quantitative fluctuation data and fast ion density, in order to validate models and improve understanding of underlying mechanisms. Model predictions will	Conduct research to understand the role of neutral fueling and transport in determining the pedestal structure. The edge pedestal is a key component in achieving overall high confinement in a magnetic fusion device. Therefore, obtaining a physics understanding and predictive capability for the pedestal height and structure is a major goal of fusion research and requires advances in the understanding of the separate structure of density and temperature profiles in the pedestal region. A key challenge is to understand the importance of particle sources in determining the density pedestal and project to burning plasma scenarios. Experiments on DIII-D and archived data from C-Mod, DIII-D, and NSTX will be used to test how fueling, reduced recycling, and transport affect the density pedestal structure. The role of divertor geometry and its effect upon the pedestal structure will also be investigated. U.S. researchers involved in collaborative activities on other relevant

	FY 2017	FY 2018	FY 2019
		guide the development of attractive operating regimes.	experiments may also contribute to this effort.
Result	Met	TBD	TBD
Endpoint Target	Magnetic fields are the principal means of confining the hot ionized gas of a plasma long enough to make practical fusion energy. The detailed shape of these magnetic containers leads to many variations in how the plasma pressure is sustained within the magnetic bottle and the degree of control that experimenters can exercise over the plasma stability. These factors, in turn, influence the functional and economic credibility of the eventual realization of a fusion power reactor. The key to their success is a detailed physics understanding of the confinement characteristics of the plasmas in these magnetic configurations. The major fusion facilities can produce plasmas that provide a wide range of magnetic fields, plasma currents, and plasma shapes. By using a variety of plasma control tools, appropriate materials, and having the diagnostics needed to measure critical physics parameters, scientists will be able to develop optimum scenarios for achieving high performance plasmas in future burning plasma devices and, ultimately, in power plants.		
Performance Goal (Measure)	**FES Facility Operations - Average achieved operation time of FES user facilities as a percentage of total scheduled annual operation time**		
Target	≥ 90 %	≥ 90 %	≥ 90 %
Result	Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the Office of Science's scientific user facilities take a great deal of time, money, and effort to prepare and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		
Performance Goal (Measure)	**FES Theory and Simulation - Performance of simulations with high physics fidelity codes to address and resolve critical challenges in the plasma science of magnetic confinement**		
Target	Lower hybrid current drive (LHCD) will be indispensable for driving off-axis current during long-pulse operation of future burning plasma experiments, since it offers important leverage for controlling damaging transients caused by magnetohydrodynamic instabilities. However, the experimentally	The interaction of the boundary plasma with the material surfaces in magnetically confined plasmas is among the most critical problems in fusion energy science. In FY 2018, perform high-performance computational simulations with coupled boundary plasma physics and materials surface models to predict the fuel	Understanding the relevant turbulent transport mechanisms at the edge of a high-performance tokamak is essential for predicting and optimizing the H-mode pedestal structure in future burning plasma devices. Global electromagnetic gyrokinetic simulations will be performed based on representative experimental

	FY 2017	FY 2018	FY 2019
	demonstrated high efficiency of LHCD is incompletely understood. In FY 2017, massively parallel, high-resolution simulations with 480 radial elements and 4095 poloidal modes will be performed using full-wave radiofrequency field solvers and particle Fokker-Planck codes to elucidate the roles of toroidicity and full-wave effects. The simulation predictions will be compared with experimental data from the superconducting EAST tokamak.	recycling and tritium retention of the divertor for deuterium-tritium burning plasma conditions, accounting for erosion, re-deposition and impurity transport in the plasma boundary, and an initial evaluation of the influence of material deposition on the recycling and retention.	pedestal scenarios in order to clarify which instabilities are most important for each of the particle and heat transport channels. Edge transport modeling will be performed in order to estimate and bound the particle and heat sources—e.g., the ionization density source and the atomic energy loss channels due to ionization, charge exchange, and radiation. Comparisons will be made with data from the DIII-D, JET, C-Mod and NSTX or MAST experiments.
Result	Met	TBD	TBD
Endpoint Target	Advanced simulations based on high physics fidelity models offer the promise of advancing scientific discovery in the plasma science of magnetic fusion by exploiting the Office of Science high performance computing resources and associated advances in computational science. These simulations are able to address the multiphysics and multiscale challenges of the burning plasma state and contribute to the FES goal of advancing the fundamental science of magnetically confined plasmas to develop the predictive capability needed for a sustainable fusion energy source.		

Fusion Energy Sciences
Capital Summary ($K)

	Total	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Capital Operating Expenses Summary						
Capital equipment	n/a	n/a	971	—	4,600	+3,629
General plant projects (GPP)	n/a	n/a	3,535	—	321	-3,214
Total, Capital Operating Expenses	**n/a**	**n/a**	**4,506**	**—**	**4,921**	**+415**
Capital Equipment						
Major items of equipment[b]						
Materials Plasma Exposure eXperiment (MPEX)	40,000–60,000	0	0	—	2,000	+2,000
Total Non-MIE Capital Equipment	n/a	n/a	971	—	2,600	+1,629
Total, Capital equipment	**n/a**	**n/a**	**971**	**—**	**4,600**	**+3,629**
General Plant Projects						
General Plant Projects under $5 million TEC	n/a	n/a	3,535	—	321	-3,214

Major Items of Equipment Descriptions

Materials Plasma Exposure eXperiment (MPEX): FES has conducted substantial research and development over the past five years to identify and develop an innovative linear, high intensity plasma source capable of producing the extreme plasma parameters required to simulate a burning plasma environment. FES is now building on this research to develop a first of a kind, world-leading, experimental capability which will be used to explore materials solutions to the daunting plasma materials interactions challenge. MPEX, which will be located at ORNL, will allow dedicated studies of reactor-relevant heat and particle loads on neutron-irradiated materials. The overall motivation is to gain entry into a new class of fusion materials science wherein the combined effects of fusion-relevant heat, particle, and neutron fluxes can be studied for the first time anywhere in the world. The preliminary total project cost range is estimated to be $40–60M.

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] Each MIE located at a DOE facility Total Estimated Cost (TEC) >$5M and each MIE not located at a DOE facility TEC > $2M.

Construction Projects Summary ($K)

	Total	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
14-SC-60, U.S. Contributions to ITER						
Total Estimated Cost (TEC)	TBD	1,057,244	50,000	49,660	75,000	+25,000
Other Project Cost (OPC)	TBD	80,641	0	—	0	0
Total, Project Cost (TPC), 14-SC-60	**TBD**	**1,137,885**	**50,000**	**49,660**	**75,000**	**+25,000**

Funding Summary ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Research	236,310	—	181,000	-55,310
Scientific user facility operations	88,690	—	81,000	-7,690
Major Item of Equipment	0	—	2,000	+2,000
Other (GPP, GPE, and Infrastructure)	5,000	—	1,000	-4,000
Construction	50,000	49,660	75,000	+25,000
Total, Fusion Energy Sciences	**380,000**	**377,419**	**340,000**	**-40,000**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

Scientific User Facility Operations and Research ($K)

The treatment of user facilities is distinguished between two types: TYPE A facilities that offer users resources dependent on a single, large-scale machine; TYPE B facilities that offer users a suite of resources that is not dependent on a single, large-scale machine.

Definitions:

Achieved Operating Hours – The amount of time (in hours) the facility was available for users.

Planned Operating Hours –

- For Past Fiscal Year (PY), the amount of time (in hours) the facility was planned to be available for users.
- For Current Fiscal Year (CY), the amount of time (in hours) the facility is planned to be available for users.
- For the Budget Fiscal Year (BY), based on the proposed budget request the amount of time (in hours) the facility is anticipated to be available for users.

Optimal Hours – The amount of time (in hours) a facility will be available to satisfy the needs of the user community if unconstrained by funding levels.

Percent of Optimal Hours – An indication of utilization effectiveness in the context of available funding; it is not a direct indication of scientific or facility productivity.

- For BY and CY, Planned Operating Hours divided by Optimal Hours expressed as a percentage.
- For PY, Achieved Operating Hours divided by Optimal Hours.

Unscheduled Downtime Hours – The amount of time (in hours) the facility was unavailable to users due to unscheduled events. NOTE: For type "A" facilities, zero Unscheduled Downtime Hours indicates Achieved Operating Hours equals Planned Operating Hours.

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
TYPE A FACILITIES				
DIII-D National Fusion Facility	**$87,100**	**—**	**$87,500**	**+$400**
Number of Users	603	—	640	+37
Achieved operating hours	704	—	N/A	N/A
Planned operating hours	680	—	480	-200
Optimal hours	1,000[b]	—	480[b]	-520
Percent optimal hours	70.4%	—	100.0%	+29.6%
Unscheduled downtime hours	N/A	—	N/A	N/A

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] Optimal hours in FY 2017 and FY 2019 are less than the standard 1,000 hours due to a planned outage for facility modifications and enhancements.

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
National Spherical Torus Experiment—Upgrade	**$74,090**	**—**	**$61,000**	**-$13,090**
Number of Users	292	—	307	+15
Achieved operating hours	N/A	—	N/A	N/A
Planned operating hours	0	—	0	0
Optimal hours	0	—	0	0
Percent optimal hours	N/A	—	N/A	N/A
Unscheduled downtime hours	N/A	—	N/A	N/A
Total Facilities	**$161,190**	**—**	**$148,500**	**-$12,690**
Number of Users	895	—	947	+52
Achieved operating hours	704	—	N/A	N/A
Planned operating hours	680	—	480	-200
Optimal hours	1,000	—	480	-520
Percent of optimal hours[b]	70.4%	—	100.0%	0.0%
Unscheduled downtime hours	N/A	—	N/A	N/A

Scientific Employment

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Number of permanent Ph.D.'s (FTEs)	765	—	597	-168
Number of postdoctoral associates (FTEs)	96	—	76	-20
Number of graduate students (FTEs)	239	—	197	-42
Other[c]	1,161	—	895	-266

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] For total facilities only, this is a "funding weighted" calculation FOR ONLY TYPE A facilities: $\frac{\sum_1^n[(\%OH\ for\ facility\ n)\times(funding\ for\ facility\ n\ operations)]}{Total\ funding\ for\ all\ facility\ operations}$

[c] Includes technicians, engineers, computer professionals, and other support staff.

14-SC-60, U.S. Contributions to ITER

1. Significant Changes and Summary

Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2018 CPDS and does not include a new start for FY 2019.

The DOE Order 413.3B approved Critical Decision (CD) CD-1, "Approve Alternative Selection and Cost Range," was approved on January 25, 2008, with a preliminary cost range of $1.45–$2.2 billion. Since 2008, the estimated cost range for the project increased such that the upper bound of the approved CD-1 cost range increased by more than 50%, triggering the need for a reassessment of the project cost range and re-approval by the Project Management Executive (PME). The PME for the U.S. ITER project is the Deputy Secretary of Energy. The cost range reassessment was completed in November 2016 and it was then subsequently approved by the PME on January 13, 2017. The CD-1 Revised cost range is now $4.7B to $6.5B.

As outlined in the May 2016 Secretary of Energy's Report to Congress, DOE was to baseline the "First Plasma" portion of the U.S. ITER project. As such, DOE has divided the U.S. ITER project hardware scope into two distinct subprojects, which represent the two phases of the project; First Plasma (FP) subproject (SP-1) and Post-First Plasma subproject (SP-2). The FP subproject scope consists of: 1) completing the design for all twelve systems the U.S. is contributing to ITER; 2) complete fabrication and delivery of the Toroidal Field (TF) superconductor; the Steady-State Electrical Network (SSEN), and the Central Solenoid (CS) superconducting magnet modules, assembly tooling, and associated structures; and 3) partial fabrication and delivery of seven other subsystems: Tokamak Cooling Water, Roughing Pumps, Vacuum Auxiliary, Pellet Injection, Ion Cyclotron Heating, Electron Cyclotron Heating, and two of seven Diagnostics. A review of CD-2, "Approve Performance Baseline" for the SP-1 was completed in November 2016 and then subsequently approved by the PME on January 13, 2017, with a total project cost of $2.5B, and a CD-4, "Project Completion" date of December 2027. In addition, the PME also approved CD-3, "Approve the Start of Construction" for the SP-1 on January 13, 2017. This CPDS focuses on the First Plasma subproject activities. Funding for the SP-2 will not be requested until FY 2020.

Establishment of an approved baseline for SP-2 will follow once the Administration has made a determination as to whether the U.S. will continue its participation in ITER. No procurements for SP-2 scope are anticipated until at the earliest FY 2021. Outyear numbers for this datasheet are shown as TBD. In addition to SP-1 and SP-2, and U.S. monetary resources (i.e., cash contributions) to support the ITER Organization (IO) construction-phase activities comprise the third and final element of the U.S. ITER project scope. The source of funds for all three project elements is the annual U.S. Contributions to ITER Congressional Line-Item appropriations.

Summary

SP-1 is more than 50% complete, as are the fabrication and delivery of two of the twelve subsystems the U.S. is to provide to ITER, specifically the Toroidal Field coil superconductor, and the Steady-State Electrical Network. The FY 2019 Request will focus on the continued design and fabrication of the highest priority, in kind deliverables. ITER is a major fusion research facility being constructed in St. Paul-lez-Durance, France by an international partnership of seven governments. Since it will not result in a facility owned by the U.S. or located in the U.S., the U.S. Contributions to ITER (U.S. ITER) project is not classified as a Capital Asset project, but is classified as a Major System Project. The U.S. ITER project is a U.S. Department of Energy project to provide the U.S. share of ITER construction (in-kind hardware i.e., subsystems, equipment, and components, as well as monetary resources to support the IO in France). Sections of this CPDS have been tailored accordingly to reflect the nature of this project.

The U.S. ITER project is managed as a DOE Office of Science (SC) project through the U.S. ITER Project Office (USIPO). The USIPO is managed by Oak Ridge National Laboratory, in partnership with Princeton Plasma Physics Laboratory and the Savannah River National Laboratory. The project began as a Major Item of Equipment (MIE) in FY 2006, and was changed to a Congressional control point Line-Item beginning in FY 2014. As with all SC projects, the principles of DOE Order 413.3B are applied in the effective management of the project, including critical decision milestones and their supporting prerequisite activities. Requirements for project documentation, monitoring and reporting, change control, and regular independent project reviews (IPRs) are being applied with the same degree of rigor as other SC line-item projects. Progress and performance are reported regularly in monthly performance metrics and project status reports.

Fabrication is underway in three of the U.S. hardware systems (CS magnet modules, structures, and assembly tooling) Tokamak Cooling Water System [TCWS] and Vacuum Auxiliary Systems [VAS]). The U.S. ITER project has subcontracted with General Atomics (GA) for the fabrication of the world's largest pulsed superconducting magnets for the ITER CS magnet system. CS magnet module fabrication includes six production and one spare. From 2006 through 2017, the U.S. ITER project has awarded and obligated over $957 million to U.S. industry, universities, and DOE laboratories.

The U.S ITER Federal Project Director with certification level 3 has been assigned to this Project and has approved this CPDS.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2006	7/5/2005		TBD	TBD		TBD	N/A	TBD
FY 2007	7/5/2005		TBD	TBD		TBD	N/A	2017
FY 2008	7/5/2005		1/25/2008	4Q FY 2008		TBD	N/A	2017
FY 2009	7/5/2005	09/30/2009[a]	1/25/2008	4Q FY 2010		TBD	N/A	2018
FY 2010	7/5/2005	07/27/2010[b]	1/25/2008	4Q FY 2011		TBD	N/A	2019
FY 2011	7/5/2005	05/30/2011[c]	1/25/2008	4Q FY 2011	04/12/2011[d]	TBD	N/A	2024
FY 2012	7/5/2005	07/10/2012[e]	1/25/2008	3Q FY 2012	05/02/2012[f]	TBD	N/A	2028
FY 2013	7/5/2005	12/11/2012[g]	1/25/2008	TBD[h]	04/10/2013[i]	TBD	N/A	2033

[a] Electron Cyclotron Heating (ECH) Transmission lines (TL) (06/22/2009); Tokamak Cooling Water System (07/21/2009); CS Modules, Structures, and Assembly Tooling (AT) (09/30/2009).
[b] Ion Cyclotron Heating Transmission Lines (ICH) (10/14/2009); Tokamak Exhaust Processing (TEP) (05/17/2010); Diagnostics: Residual Gas Analyzer (RGA) (07/14/2010), Upper Visible Infrared Cameras (VIR) (07/27/2010).
[c] Vacuum Auxiliary System (VAS) – Main Piping (12/13/2010); Diagnostics Low-Field-Side Reflectometer (LFS) (05/30/2011).
[d] Cooling Water Drain Tanks (04/12/2011).
[e] Diagnostics: Upper Port (10/03/2011), Electron Cyclotron Emission (ECE) (12/06/2011), Equatorial Port E-9 and Toroidal Interferometer Polarimeter (TIP) (01/02/2012), Equatorial Port E-3 (07/10/2012).
[f] Steady State Electrical Network (05/02/2012).
[g] VAS Supply (11/13/2012); Disruption Mitigation (12/11/2012); Pellet Injection (04/29/2013); Diagnostics: Motional Stark Effect Polarimeter (MSE) (05/29/2013), Core Imaging X-ray Spectrometer (CIXS) (06/01/2013).
[h] The CD-2 date will be determined upon acceptable resolution of issues related to development of a high-confidence ITER Project Schedule and establishment of an approved funding profile.
[i] RGA Divertor Sampling Tube (07/28/14); CS AT, Early Items (09/17/14).

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2014	7/5/2005		1/25/2008	TBD	12/10/2013[a]	TBD	N/A	2034
FY 2015	7/5/2005		1/25/2008	TBD		TBD	N/A	2036
FY 2016[b]	7/5/2005		1/25/2008	TBD		TBD	N/A	TBD
FY 2017[c]	7/5/2005		1/25/2008	TBD		TBD	N/A	TBD

CD-0 – Approve Mission Need

CD-1 – Approve Alternative Selection, Cost Range, and Start of Long-lead Procurements

CD-2 – Approve Performance Baseline

CD-3 – Approve Start of Fabrication

CD-4 – Approve Project Completion

		CD-1 Cost Range Update	CD-2/3		CD-4	
			SP-1	SP-2	SP-1	SP-2
FY 2018[d]	7/5/2005	1/13/17	1/13/17	2019	1Q2027	2034-2038
FY 2019	7/5/2005	1/13/17	1/13/17	TBD	1Q2027	2034-2038

3. Project Cost History

At the time of CD-1 approval in January 2008, the preliminary cost range was $1.45–$2.2 billion. Until recently, however, it has not been possible to confidently baseline the project due to past delays in the international ITER construction schedule. Various factors (e.g., schedule delays, design and scope changes, funding constraints, regulatory requirements, risk mitigations, and project management and leadership issues in the ITER Organization) have affected the project cost. In response to a 2013 Congressional request, a DOE Office of Science IPR Committee assessed the project and determined that the existing cost range estimate of $4.0 to $6.5B would likely encompass the final TPC. This range, recommended in 2013, was included in subsequent Presidents Budget Requests and in the May 2016 DOE "Report on the Continued U.S. Participation in the ITER Project" to Congress. In preparation for baselining SP-1, based on the results of the IPR, a decision was made to update the lower end of this range to reflect updated cost estimates resulting in the current approved CD-1R range of $4.7 to $6.5B. This updated CD-1R range incorporates increases in the projects hardware estimate that have occurred since August 2013. The SP-1 TPC has been baselined at $2.5B.

4. Project Scope and Justification

Introduction

ITER is an international partnership among seven Member governments (China, the European Union, India, Japan, the Republic of Korea, the Russian Federation, and the United States) aimed at demonstrating the scientific and technological feasibility of fusion energy for peaceful purposes. The *Agreement on the Establishment of the ITER International Fusion Energy Organization for the Joint Implementation of the ITER Project* (ITER Agreement), signed on November 21, 2006, provides the legal framework for the four phases of the program: construction, operation, deactivation, and

[a] CS Modules and Structures (11/18/2013); VAS Main Piping B-2, L-1, L-2 (12/10/2013).

[b] CS AT Remaining Items (12/02/2015).

[c] Roughing Pumps (03/2017); VAS 03 Supply (06/2017); Roughing Pumps I&C (06/2017); VAS 03 Supply I&C (04/2017); CS AT Bus Bar Alignment and Coaxial Heater (04/2017); VAS Main Piping L3/L4 (03/2017); VAS 02 CGVS (&C Part 1 (06/2017).

[d] VAS 02 Supply Part 1 (05/2018); ICH RF Building and I&C (11/2017); TCWS Captive Piping and First Plasma (10/2017); ICH RF components supporting INDA/IO testing (01/2018).

decommissioning. Through participation in the agreement, the European Union, as the host, will bear five-elevenths (45.45%) of the ITER facility's construction cost, while the other six Members, including the U.S., will each support one-eleventh (9.09%) of the ITER facilities cost. Operation, deactivation, and decommissioning of the facility are to be funded through a different cost-sharing formula in which the U.S. will contribute a 13% share, which is not a part of the U.S. ITER project funding. Responsibility for ITER integration, management, design, licensing, installation, and operation rests with the IO, which is an international legal entity located in France.

Scope

U.S. Contributions to ITER – Construction Project Scope

The overall U.S. ITER project includes three major elements:

- Hardware components, built under the responsibility of the U.S., then shipped to the ITER site for IO assembly, installation, and operation.
- Funding to the IO to support common expenses, including ITER research and development (R&D), IO staff and infrastructure, IO-provided hardware, on-site assembly/installation/testing of all ITER components, and IO Central Reserve.
- Other project costs, including R&D and conceptual design related activities.

The U.S. is to contribute the following hardware to ITER:

- Tokamak Cooling Water System (TCWS): manages the thermal energy generated during the operation of the tokamak.
- 15% of ITER Diagnostics: provides the measurements necessary to control, evaluate, and optimize plasma performance and to further the understanding of plasma physics.
- Disruption Mitigation (DM) Systems: limits the impact of plasma disruptions to the tokamak vacuum vessel, blankets, and other components.
- Electron Cyclotron Heating (ECH) Transmission Lines: brings additional power to the plasma and deposits power in specific areas of the plasma to minimize instabilities and optimize performance.
- Tokamak Exhaust Processing (TEP) System: separates hydrogen isotopes from tokamak exhaust.
- Tokamak Fueling System (Pellet Injection): injects fusion fuels in the form of deuterium-tritium ice pellets into the vacuum chamber.
- Ion Cyclotron Heating (ICH) Transmission Lines: bring additional power to the plasma.
- Central Solenoid (CS) Magnet System: confines, shapes and controls the plasma inside the vacuum vessel. All CS workscope is SP-1.
- 8% of Toroidal Field (TF) Conductor: component of the TF magnet that confines, shapes, and controls the plasma. All TF work scope was completed in FY 2017.
- 75% of the Steady-State Electrical Network (SSEN): supplies the electricity needed to operate the entire plant, including offices and the operational facilities. All SSEN work scope was completed in FY 2017.
- Vacuum Auxiliary System (VAS): creates and maintains low gas densities in the vacuum vessel and connected vacuum components.
- Roughing Pumps: evacuate the tokamak, cryostat, and auxiliary vacuum chambers prior to and during operations.

Justification

The purpose of ITER is to investigate and conduct research in the so-called "burning plasma" regime—a performance region that exists beyond the current experimental state of the art. Creating a self-sustaining burning plasma will provide essential scientific knowledge necessary for practical fusion power. There are two parts of this need that will be achieved by ITER. The first part is to investigate the fusion process in the form of a "burning plasma," in which the heat generated by the fusion process exceeds that supplied from external sources (i.e., self-heating). The second part of this need is to sustain the burning plasma for a long duration (e.g., several hundred to a few thousand seconds), during which time equilibrium conditions can be achieved within the plasma and adjacent structures. ITER is the necessary next step to establish the confidence in proceeding with development of a demonstration fusion power plant.

Although not classified as a Capital Asset, the U.S. ITER project is being conducted in accordance with the project management principles of DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets.

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Hardware			
FY 2006	13,754	13,754	6,169
FY 2007	34,588	34,588	24,238
FY 2008	25,500	25,500	24,122
FY 2009	85,401	85,401	26,278
FY 2010	85,266	85,266	46,052
FY 2011	63,875	63,875	84,321
FY 2012[b]	91,441	91,407	99,215
FY 2013	107,635	107,669	110,074
FY 2014[c]	161,605	161,605	153,368
FY 2015	128,682	128,682	105,908
FY 2016[d]	115,000	115,000	106,519
FY 2017	50,000	50,000	123,117
FY 2018	63,000	63,000	116,366
FY 2019	75,000	75,000	75,000
Subtotal	1,100,747	1,100,747	1,100,747
Total, Hardware	TBD	TBD	TBD
Cash Contributions[e]			
FY 2006	2,112	2,112	2,112
FY 2007	7,412	7,412	7,412
FY 2008	2,644	2,644	2,644
FY 2009	23,599	23,599	23,599
FY 2010	29,734	29,734	29,734
FY 2011	3,125	3,125	3,125
FY 2012	13,214	13,214	13,214
FY 2013	13,805	13,805	13,805
FY 2014[b]	32,895	32,895	32,895
FY 2015	15,957	15,957	15,957
FY 2016[f]	0	0	0
FY 2017	0	0	0
FY 2018	0	0	0
FY 2019	0	0	0
Subtotal	144,497	144,497	144,497
Total, Cash Contributions	TBD	TBD	TBD
Total, TEC	TBD	TBD	TBD

[a] Costs through FY 2017 reflect actual costs; costs for FY 2018 and the outyears are estimates.
[b] Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.
[c] Appropriations prior to FY 2014 reflect major item of equipment funding. Starting in FY 2014, this project is funded as a Congressional control point.
[d] FY 2016 funding for taxes and tax support is included in the FY 2017 Hardware funding amount.
[e] Includes cash payments, secondees, taxes and tax support.
[f] No FY 2016 funding is provided to support the ITER organization.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Other project costs (OPC)			
FY 2006	3,449	3,449	1,110
FY 2007	18,000	18,000	7,607
FY 2008	-2,074	-2,074	7,513
FY 2009	15,000	15,000	5,072
FY 2010	20,000	20,000	7,754
FY 2011	13,000	13,000	10,032
FY 2012[a]	345	345	22,336
FY 2013	2,560	2,560	5,984
FY 2014[b]	5,000	5,000	2,717
FY 2015	5,361	5,361	5,500
FY 2016	0	0	3,958
FY 2017	0	0	1,058
FY 2018	0	0	0
FY 2019	0	0	0
Subtotal	80,641	80,641	80,641
Total, OPC	TBD	TBD	TBD
Total Project Costs (TPC)			
FY 2006	19,315	19,315	9,391
FY 2007	60,000	60,000	39,257
FY 2008	26,070	26,070	34,279
FY 2009	124,000	124,000	54,949
FY 2010	135,000	135,000	83,540
FY 2011	80,000	80,000	97,478
FY 2012[a]	105,000	104,966	134,765
FY 2013	124,000	124,034	129,863
FY 2014[b]	199,500	199,500	188,980
FY 2015	150,000	150,000	127,365
FY 2016	115,000	115,000	110,477
FY 2017	50,000	50,000	124,175
FY 2018	63,000	63,000	116,366
FY 2019	75,000	75,000	75,000
Subtotal	1,325,885	1,325,885	1,325,885
Total, TPC	TBD	TBD	TBD

6. Details of the 2018 Project Cost Estimate

The project has an approved updated Critical Decision-1 Cost Range and DOE has chosen to divide the project hardware scope into two distinct subprojects (First Plasm subproject (SP-1) and Post- First Plasma subproject SP-2). The baseline for SP-1 was approved in January 2017. Baselining of SP-2 will follow Administration has made a decision on whether the U.S. will continue its participation in ITER. No procurements for SP-2 scope are anticipated until FY 2021 at the earliest. An IPR of U.S. ITER was conducted on November 14-17, 2016, to consider the project's readiness for CD-2 (Performance Baseline) and CD-3 (Begin/Continue Fabrication) for SP-1 as well as the proposed updated CD-1 Cost Range. Outcomes from the IPR indicated that the project was ready for approval of SP-1 CD-2/3 following a reassessment of contingency to account for risk

[a] Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.
[b] Appropriations prior to FY 2014 reflect major item of equipment funding. Starting in FY 2014, this project is funded as a Congressional control point.

in the areas of escalation and currency exchange. This recommendation has been addressed. In addition, the IPR committee found no compelling reason to deviate from the cost range identified in the May 2016 Report to Congress ($4.0B to $6.5B) and recommended that this range be adopted and approved as the Updated CD-1 cost range. However, as noted above, in preparation for baselining SP-1 and based on the outcome of the IPR, a decision was made to update the lower end of this range to reflect updated cost estimates resulting in the current approved CD-1R range of $4.7 to 6.5B.

7. Schedule of Appropriation Requests

		Prior Years	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Outyears	Total
FY 2006	TEC	1,038,000	0	0	0	0	0	0	0	1,038,000
	OPC	84,000	0	0	0	0	0	0	0	84,000
	TPC	1,122,000	0	0	0	0	0	0	0	1,122,000
FT 2007	TEC	1,047,051	30,000	0	0	0	0	0	0	1,077,051
	OPC	44,949	0	0	0	0	0	0	0	44,949
	TPC	1,092,000	30,000	0	0	0	0	0	0	1,122,000
FY 2008	TEC	1,048,230	30,000	0	0	0	0	0	0	1,078,230
	OPC	43,770	0	0	0	0	0	0	0	43,770
	TPC	1,092,000	30,000	0	0	0	0	0	0	1,122,000
FY 2009[a]	TEC	266,366	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	38,075	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	304,441	0	0	TBD	TBD	TBD	TBD	TBD	TBD
FY 2010	TEC	294,366	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	70,019	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	364,385	0	0	TBD	TBD	TBD	TBD	TBD	TBD
FY 2011	TEC	379,366	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	65,019	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	444,385	0	0	TBD	TBD	TBD	TBD	TBD	TBD
FY 2012[b]	TEC	394,566	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	75,019	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	469,585	0	0	TBD	TBD	TBD	TBD	TBD	TBD
FY 2013[c]	TEC	617,261	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	82,124	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	699,385	0	0	TBD	TBD	TBD	TBD	TBD	TBD
FY 2014[d]	TEC	581,868	225,000	0	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	73,159	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	655,027	225,000	0	TBD	TBD	TBD	TBD	TBD	TBD
FY 2015	TEC	603,105	194,500	144,639	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	70,280	5,000	5,361	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	673,385	199,500	150,000	TBD	TBD	TBD	TBD	TBD	TBD

[a] The Prior Years column for FY 2009 through FY 2012 reflects the total of appropriations and funding requests only through the year of that row. Thus, for example, in the FY 2010 row, it reflects only funding from FY 2006 to FY 2012.

[b] The FY 2012 request was submitted before a full-year appropriation for FY 2011 was in place, and so FY 2011 was TBD at that time. Hence, the Prior Years column for FY 2012 reflects appropriations for FY 2006 through FY 2010 plus the FY 2012 request.

[c] The FY 2013 amount shown in the FY 2014 request reflected a short-term continuing resolution level annualized to a full year and based on the FY 2012 funding level for ITER.

[d] Prior to FY 2015, the requests were for a major item of equipment broken out by TEC, OPC, and TPC.

		Prior Years	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Outyears	Total
FY 2016	TEC	603,105	194,500	144,639	150,000	TBD	TBD	TBD	TBD	TBD
	OPC	70,280	5,000	5,361	0	TBD	TBD	TBD	TBD	TBD
	TPC	673,385	199,500	150,000	150,000	TBD	TBD	TBD	TBD	TBD
FY 2017	TEC	603,105	194,500	144,639	115,000	125,000	TBD	TBD	TBD	TBD
	OPC	70,280	5,000	5,361	0	0	TBD	TBD	TBD	TBD
	TPC	673,385	199,500	150,000	115,000	125,000	TBD	TBD	TBD	TBD
FY 2018	TEC	603,105	194,500	144,639	115,000	50,000	63,000	TBD	TBD	TBD
	OPC	70,280	5,000	5,361	0	0	0	TBD	TBD	TBD
	TPC	673,385	199,500	150,000	115,000	50,000	63,000	TBD	TBD	TBD
FY 2019	TEC	603,105	194,500	144,639	115,000	50,000	63,000	75,000	TBD	TBD
	OPC	70,280	5,000	5,361	0	0	0	0	TBD	TBD
	TPC	673,385	199,500	150,000	115,000	50,000	63,000	75,000	TBD	TBD

8. Related Operations and Maintenance Funding Requirements

The U.S. Contributions to ITER operations is assumed to begin with initial integrated commissioning activities and continue for a period of 15 to 25 years. The fiscal year in which commissioning activities begin depends on the international ITER project schedule which currently indicates 2025.

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	12/2025
Expected Useful Life (number of years)	15–25
Expected Future start of D&D for new construction (fiscal quarter)	TBD

9. D&D Funding Requirements

Since ITER is being constructed in France by a coalition of countries and will not be a DOE asset, the “one-for-one” requirement is not applicable to this project.

The U.S. Contributions to ITER Decommissioning are assumed to begin when operations commence and continue for a period of 20 years. The U.S. is responsible for 13 percent of the total decommissioning cost.

The U.S. Contributions to ITER Deactivation are assumed to begin 20 years after commissioning and continue for a period of 5 years. The U.S. is responsible for 13 percent of the total deactivation cost.

10. Acquisition Approach for U.S. Hardware Contributions

The U.S. ITER Project Office (USIPO) at Oak Ridge National Laboratory, with its two partner laboratories (Princeton Plasma Physics Laboratory and Savannah River National Laboratory), will procure and deliver in-kind hardware in accordance with the Procurement Arrangements established with the international IO. The USIPO will subcontract with a variety of research and industry sources for design and fabrication of its ITER components, ensuring that designs are developed that permit fabrication, to the maximum extent possible, under fixed-price subcontracts (or fixed-price arrangement documents with the IO) based on performance specifications, or more rarely, on build-to-print designs. USIPO will use cost-reimbursement type subcontracts only when the work scope precludes accurate and reasonable cost contingencies being gauged and established beforehand. USIPO will utilize best value, competitive source selection procedures to the maximum extent possible, including foreign firms on the tender/bid list where appropriate. Such procedures shall allow for cost and technical trade-offs during source selection. For the large-dollar-value subcontracts (and critical path subcontracts as appropriate), USIPO will utilize unique subcontract provisions to incentivize cost control and schedule performance. In addition, where it is cost effective and it reduces risk, the USIPO will participate in common procurements led by the IO, or request the IO to perform activities that are the responsibility of the U.S.