Fusion Energy Sciences

Funding Profile by Subprogram

(dollars in thousands)

	FY 2005 Current Appropriation	FY 2006 Original Appropriation	FY 2006 Adjustments	FY 2006 Current Appropriation	FY 2007 Request
Fusion Energy Sciences					
Science	148,494	158,507	-1,585[a]	156,922	154,213
Facility Operations	89,733	104,582	-1,046[a]	103,536	121,555
Enabling R&D	28,720	27,461	-275[a]	27,186	43,182
Total, Fusion Energy Sciences	266,947[b]	290,550	-2,906	287,644	318,950

Public Law Authorizations:
Public Law 95-91, "Department of Energy Organization Act, 1977"
Public Law 103-62, "Government Performance and Results Act of 1993"
Public Law 109-58, "Energy Policy Act of 2005"

Mission

The Fusion Energy Sciences (FES) program is the national research effort to advance plasma science, fusion science, and fusion technology—the knowledge base needed for an economically and environmentally attractive fusion energy source. FES is pursuing this effort through collaborations among U.S. universities, industry, national research laboratories, and the international fusion community.

Benefits

Fusion is the energy source that powers the sun and stars. In the fusion process, forms of the lightest atom, hydrogen, fuse together to make helium in a very hot and highly charged gas or plasma. In the process, tremendous amounts of energy are produced. Fusion could play a key role in U.S. long-term energy plans and independence because it offers the potential for plentiful, safe and environmentally benign energy. The hydrogen isotopes deuterium and tritium, the fundamental fuel for a fusion reaction, are derived from sources as common and abundant as sea water and the earth's crust. Besides the advantages of an abundant fuel supply, the fusion process would produce little to no carbon emissions. A fusion power plant could be designed to shut down easily, have only short-lived radioactivity, and produce manageable radioactive waste. A science-based approach to fusion offers the most deliberate path to commercial fusion energy and is advancing our knowledge of plasma physics and associated technologies, yielding near-term benefits in a broad range of scientific disciplines. Examples include plasma processing of semiconductor chips for computers and other electronic devices, advanced video displays, innovative materials coatings, space propulsion, a neutron source for the detection of explosives and highly enriched uranium for homeland security, and the efficient destruction of chemical and radioactive wastes.

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[a] Reflects a rescission in accordance with P.L. 109-148, the Emergency Supplemental Appropriations Act to Address Hurricanes in the Gulf of Mexico and Pandemic Influenza, 2006.
[b] Total is reduced by $2,207,000 for a rescission in accordance with P.L. 108-447, the Consolidated Appropriations Act, 2005; $6,211,000, which was transferred to the SBIR program; and $745,000, which was transferred to the STTR program.

Strategic and Program Goals

The Department's Strategic Plan identifies four strategic goals (one each for defense, energy, science, and environmental aspects of the DOE mission) plus seven general goals that tie to the strategic goals.

The FES program supports the following goal:

Science Strategic Goal
General Goal 5, World-Class Scientific Research Capacity: Provide world-class scientific research capacity needed to: ensure the success of Department missions in national and energy security; advance the frontiers of knowledge in physical sciences and areas of biological, medical, environmental, and computational sciences; or provide world-class research facilities for the Nation's science enterprise.

The FES program has one program goal which contributes to General Goal 5 in the "goal cascade":

Program Goal 05.24.00.00: Bring the power of the Stars to Earth—Answer the key scientific questions and overcome enormous technical challenges to harness the power that fuels our sun.

Contribution to Program Goal 05.24.00.00 (World-Class Scientific Research Capacity)

The FES program contributes to this goal by managing a program of fundamental research into the nature of fusion plasmas and the means for confining plasma to yield energy. This program includes: (1) exploring basic issues in plasma science; (2) developing the scientific basis and computational tools to predict the behavior of magnetically confined plasmas; (3) using the advances in tokamak research to enable the initiation of the burning plasma physics phase of the Fusion Energy Sciences program; (4) exploring innovative confinement options that offer the potential to increase the scientific understanding and to improve the confinement of plasmas in various configurations, as well as to identify those configurations that are most suitable for a fusion reactor; (5) investigating non-neutral plasma physics and high energy density physics; and (6) developing the cutting edge technologies that enable fusion facilities to achieve their scientific goals.

These activities require operation of a set of unique and diversified experimental facilities, including smaller-scale university devices involving individual Principal Investigators, larger national facilities that require extensive collaboration among domestic institutions and an even larger, more costly experiment that requires international collaborative efforts to share the costs and gather the scientific and engineering talents needed to undertake such an experiment. These facilities provide scientists with the means to test and extend theoretical understanding and computer models—leading ultimately to an improved predictive capability for fusion science.

The following indicators establish specific long term (10 years) goals in scientific advancement to which the FES program is committed and against which progress can be measured.

- **Predictive Capability for Burning Plasmas:** Progress toward developing a predictive capability for key aspects of burning plasmas using advances in theory and simulation benchmarked against a comprehensive experimental database of stability, transport, wave-particle interaction, and edge effects.
- **Configuration Optimization:** Progress toward demonstrating enhanced fundamental understanding of magnetic confinement and improved basis for future burning plasma experiments through research on magnetic confinement configuration optimization.
- **High Energy Density Plasma Physics:** Progress toward developing the fundamental understanding and predictability of high energy density plasma physics.

Funding by General and Program Goal

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
General Goal 5, World-Class Scientific Research Capacity			
Program Goal 05.24.00.00, Bring the Power of the Stars to Earth (Fusion Energy Sciences)	266,947	287,644	318,950

Status of International ITER Negotiations and U.S. Policy and Budget Activities

The FES program is also pushing the boundaries in large scale international scientific collaboration. With the support of a Presidential negotiating mandate, FES is actively leading a U.S. effort to provide manpower and components as in-kind contributions in the support of ITER—an international project to build and operate the first fusion science facility capable of producing a sustained burning plasma. The mission for ITER is to demonstrate the scientific and technological feasibility of fusion energy. The site selection for the international ITER Project, Cadarache, France, in the European Union, was a major six-party decision on June 28, 2005, at a Ministerial-level meeting in Moscow, Russia. Negotiations continued throughout the Fall of 2005, which led to the ITER parties (a) approving and welcoming the designated Director General Nominee chosen to lead the ITER organization, (b) approving and welcoming India into the ITER negotiations as a full non-host ITER party, and (c) completing the text of the draft ITER Agreement. In completing the text of the ITER Agreement, it was determined that the international ITER Organization management structure will include the following critical positions: the Director General will provide overall leadership, the Principal Deputy Director General will provide the project management under the direction of the Director General, and multiple Deputy Directors-General will fulfill key management positions in construction, procurement, science, administration, regulatory, quality assurance, and other functional areas. It was agreed by the ITER parties that each participating party will hold at least one of these management positions. The Director General will propose his management structure to the ITER Council for its approval. It is anticipated that these positions will be filled by the time the United States completes the CD-1 cost and schedule range decision, planned for September 2006.

During the negotiations and following the acceptance of India as a full, non-host party, a revised allocation of hardware deliverables from each Party, including India, was agreed upon. Collectively, these two decisions enable all the ITER Parties to accomplish the originally planned ITER construction scope of work and, in addition, provide a contingency for the shared activities at the ITER site, such as design, system integration, provision of infrastructure and installation of hardware. The provision for such contingency is consistent with sound project management principles. Contingency resources are to be accessed at the request of the Director General and with subsequent approval by the ITER Council. The amount of funding required by each Party remains the same. For each of the 6 non-hosts, like the United States, what was previously a 10% share of a total, that excluded contingency for the site activities, now becomes about 9.1% of the ITER hardware, personnel and cash plus contingency for the site activities. The corresponding host share is about 45.4%.

Given the critical advances accomplished in 2005, it is the objective of the international ITER parties involved to obtain the negotiators' acceptance of the draft ITER Agreement by early 2006 indicating the end of the negotiations. The ITER Agreement, including various supporting documents, is key to the legal understanding and organization of the ITER Project. It is the collection of these documents that is hereafter referred to as the ITER Agreement. In accordance with the Energy Policy Act of 2005, and as determined during the Fall 2005 ITER negotiations, the ITER Agreement directly addresses the following EPAct requirements. Accordingly, the ITER Agreement:

(i) clearly defines the U.S. financial contribution to construction and operations (as well as deactivation and decommissioning), as well as any other project costs associated with a project,
(ii) ensures that the share of high-technology components of ITER that are manufactured in the United States is at least proportionate to the U.S. financial contribution to ITER,
(iii) ensures, by virtue of the in-kind contribution procurement approach, that the United States will not be financially responsible for cost overruns in components manufactured by other ITER parties,
(iv) guarantees the United States full access to all data generated by ITER,
(v) enables U.S. researchers to propose and carry out an equitable share of experiments on ITER,
(vi) provides the United States with a role in all collective decision-making related to ITER, and
(vii) describes and defines the process for discontinuing and decommissioning ITER and the U.S. role in that process.

Once the negotiators have initialed the final report of the negotiations, and the Agreement has been available to the Congress for 120 days, the next step, assuming no objection from the Congress, will be to obtain governmental signatures on the completed ITER Agreement around mid-2006, by all ITER parties, thereby leading to a multilateral commitment for ITER. The final step is the ratification or formal acceptance of the documents which then allows the ITER Agreement to enter into force and the ITER Organization to be established. The U.S. participation in ITER, as a non-host participant, is being accomplished through the "U.S. Contributions to ITER" Major Item of Equipment (MIE) project. In support of ITER and the U.S. Contributions to ITER MIE, FES is placing increased emphasis on its national burning plasma program—a critical underpinning to the fusion science in ITER. FES plans to enhance burning plasma research efforts across the U.S. domestic fusion program, including the following elements:

- Providing ITER R&D support both in physics and technology and exploring new modes of improved or extended ITER performance;
- Developing safe and environmentally attractive technologies necessary for ITER;
- Exploring fusion simulation efforts that examine the complex behavior of burning plasmas in tokamaks, which will impact the planning and conduct of experimental operations in ITER;
- Carrying out experiments on our national science facilities with diagnostics and plasma control that can be extrapolated to ITER; and
- Integrating all that is learned into a forward-looking approach to future fusion applications.

The U.S. Contributions to ITER project is being managed by the U.S. ITER Project Office (USIPO), established as a Princeton Plasma Physics Laboratory (PPPL)/Oak Ridge National Laboratory (ORNL) partnership. The management structure for the USIPO includes the Project Manager, managers for Planning Control and Project Engineering, Chief Scientist, Team Leaders in the areas of Design Integration, Magnets, Diagnostics, Heating and Fueling, Tritium, Plasma Facing Components, and dedicated cost and procurement personnel.

Since the establishment of the U.S. ITER Project Office in July 2004, preliminary cost and schedule ranges have been prepared, reviewed, and revised to reflect resolution of uncertainties associated with the international ITER Project. In July 2005, the Deputy Secretary of Energy approved DOE 413.3 Critical Decision 0, Mission Need for ITER. Project management documentation required by DOE Order 413.3 has been updated. The Project Office is preparing for approval of Critical Decision 1, Approve Alternative Selection and Cost Range, in September 2006 and Critical Decision 2, Approve

Performance Baseline, in September 2007. The FY 2006 Appropriation provided for a slower start for the U.S. Contributions to ITER project consistent with the delay in site selection. As a result of this slower start, the funding profile has been altered from the one provided with the FY 2006 Budget by shifting funds formerly intended for FY 2006 and FY 2007 into FY 2008 and beyond. This revised funding profile should still allow the U.S. to fulfill its non-host obligations to the international project, a minimum contribution of any ITER party during the phase of construction.

The FY 2007 request provides for the continuation of the U.S. Contributions to ITER MIE project. The Total Project Cost remains unchanged from FY 2006 and is summarized below in the Significant Program Shifts section, Total Estimated Costs (TEC) in the Facilities Operations subprogram, and Other Project Costs (OPC) in the Enabling R&D subprogram. There is a necessary shift indicated in the FY 2007 TEC and OPC categories to accommodate domestic and international project priorities under the revised funding profile.

The Energy Policy Act of 2005 Sec. 972(c)(5)(C) requires the Secretary of Energy to provide "a report describing how United States participation in the ITER will be funded without reducing funding for other programs in the Office of Science (including other fusion programs)…" The Department's FY 2007 budget provides for healthy increases for all programs within the Office of Science and supports the ITER request of $60,000,000 almost entirely from new funds in the Fusion Energy Sciences (FES) budget request.

The Director of the Office of Science has stated that the FES program in the Office of Science will reasonably bear at least some of the cost of building ITER from within its budget and that ITER will not unduly harm funding of other Office of Science research programs. The Department expects that the $1.122 billion ITER funding profile could have some effect on the overall allocation of funds, both within the FES program and within the Office of Science, in future budgets. This has been and will continue to be the standard practice for funding large, capital-intensive projects within DOE. Nevertheless, as demonstrated by this FY 2007 request, the Office of Science can fund ITER while maintaining healthy funding for other research programs.

During the ITER negotiations, the U.S. domestic program has continued to support the domestic technical preparations for the ITER project and has begun to plan for the operation of ITER. These activities are being promoted and coordinated through the community-based U.S. Burning Plasma Organization established in 2005 for this purpose.

The Energy Policy Act (EPAct), July 2005, requires development of a plan by DOE for the participation of U.S. scientists in ITER that includes a U.S. research agenda, methods to evaluate whether the ITER is promoting progress toward making fusion a reliable and affordable source of power, and a description of how work at the ITER will relate to other elements of U.S. fusion program. The EPAct requires that this plan be developed in consultation with FESAC, and reviewed by the National Academy of Sciences. In FY 2006, DOE has initiated steps to develop a plan for the participation of U.S. scientists in ITER.

As a first step, FES asked the U.S. fusion community to establish a Burning Plasma Organization (USBPO) to coordinate and facilitate a coherent burning plasma related work program and ITER supporting research. FES appointed the Director of USBPO in May 2005 to lead this effort. The USBPO organized a national workshop at ORNL on December 7–9, 2005 to review the developments in the U.S. program on burning plasma related topics since the Snowmass 2002 study that formulated the technical basis for the U.S. to join ITER. In addition, the workshop was also charged to identify what issues remain to be resolved for successful burning plasma experiments in ITER, what contributions can/should the U.S. fusion program make to resolve these issues, and how should the USBPO be structured to best help the community make these contributions.

The USBPO, working together with the Fusion Energy Sciences Advisory Committee (FESAC), will produce a ‘Plan for U.S. Scientific Participation in ITER’ with technical details in 2006. This Plan, which will be a dynamic tool, will guide the U.S. preparations for the ITER experiments in the ongoing U.S. fusion program, and will contribute to the detailed planning by all ITER Parties of the ITER experiments. The Plan will be reviewed by the National Academy of Sciences and updated every three years to account for new technical developments in fusion research.

Annual Performance Results and Targets

FY 2002 Results	FY 2003 Results	FY 2004 Results	FY 2005 Results	FY 2006 Targets	FY 2007 Targets
Program Goal 05.24.00.00 (World-Class Scientific Research Capacity)					
Science[a]					
N/A	N/A	N/A	Conduct experiments on the major fusion facilities (DIII-D, Alcator C-Mod and NSTX) leading toward the predictive capability for burning plasmas and configuration optimization. – In FY 2005, FES will measure plasma behavior in Alcator C-Mod with high-Z antenna guards and input power greater than 3.5 MW.[b] [met goal]	Conduct experiments on the major fusion facilities (DIII-D, Alcator C-Mod, and NSTX) leading toward the predictive capability for burning plasmas and configuration optimization. – In FY 2006, FES will inject 2 MW of neutral power in the counter direction on DIII-D and begin physics experiments.	Conduct experiments on major fusion facilities leading toward the predictive capability for burning plasmas and configuration optimization. – In FY 2007, FES will measure and identify magnetic modes on NSTX that are driven by energetic ions traveling faster than the speed of magnetic perturbations (Alfvén speed); such modes are expected in burning plasmas such as ITER.
N/A	N/A	N/A	Increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. – In FY 2005, FES will simulate nonlinear plasma edge phenomena using extended MHD codes with a resolution of 20 toroidal modes. [met goal]	Increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. – In FY 2006, FES will simulate nonlinear plasma edge phenomena using extended MHD codes with a resolution of 40 toroidal modes.	Increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. – In FY 2007, improve the simulation resolution of linear stability properties of Toroidal Alfvén Eigenmodes driven by energetic particles and neutral beams in ITER by increasing the number of toroidal modes used to 15.

[a] The performance metrics for Science are not PART measures.

[b] This target addresses issues related to first wall choices and the trade-offs between low-Z and high-Z materials. This choice can affect many important aspects of tokamak operation, including: impurity content and radiation losses from the plasma; hydrogen isotope content in the plasma and retention in the walls; and disruption hardiness of device components. All of these issues are significant when considering choices for next step devices to study burning plasma physics, especially ITER. Definitive experimental results have been compared to model predictions, and are documented in a *Target Completion Report* submitted in September 2005.

FY 2002 Results	FY 2003 Results	FY 2004 Results	FY 2005 Results	FY 2006 Targets	FY 2007 Targets
Facility Operations					
Kept deviations in weeks of operation for each major facility within 10% of the scheduled weeks. [met goal]	Kept deviations in weeks of operation for DIII-D and Alcator C-Mod within 10% of the approved plan. NSTX did not meet the target because of a coil joint failure. [Goal partially met.]	Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%.[met goal]	Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%. [met goal]	Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%.	Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%.
Kept deviations in cost and schedule for upgrades and construction of scientific user facilities within 10% of project baselines; successfully completed within cost and in a safe manner all TFTR decontamination and decommissioning activities. [met goal]	Kept deviations in cost and schedule for upgrades and construction of scientific user facilities within 10% of approved baselines. [met goal]	Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%. [met goal]	Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%. [met goal]	Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%.	Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%.

Means and Strategies

The Fusion Energy Sciences program will use various means and strategies to achieve its program goals. However, external factors may impact the ability to achieve these goals.

The science and the technology of fusion have progressed to the point that the next major research step is the exploration of the physics of a sustained plasma reaction in a burning plasma physics experiment. ITER is the focal point of sustained burning plasma fusion research around the world, and the Administration has joined the negotiations to conduct this experiment. In light of this action, many elements of the fusion program that are broadly applicable to burning plasmas are now being directed more specifically toward the needs of ITER. These elements represent areas of fusion research in which the United States has particular strengths relative to the rest of the world, such as theory, modeling, and experimental physics. Longer range technology activities have been redirected to support preparations for the realization of the burning plasma device and associated experiments.

Scientists from the United States participate in leading edge scientific experiments on fusion facilities abroad and conduct comparative studies to supplement the scientific understanding obtained from domestic facilities. These include the world's highest performance tokamaks (JET in England and JT-60 in Japan), a stellarator (the Large Helical Device in Japan), a superconducting tokamak (Tore Supra in France), and several smaller devices. In addition, the United States is collaborating with South Korea on the design of diagnostics for their long-pulse, superconducting, advanced tokamak (KSTAR). The strengthened relationships resulting from these international collaborations can foster scientific advancement and facilitate shared science worldwide. These collaborations provide a valuable link with the 80% of the world's fusion research that is conducted outside the United States. The United States is an active participant in the International Tokamak Physics Activity (ITPA), which facilitates identification of high priority research for burning plasmas in general, and for ITER specifically, through workshops and assigned tasks. ITPA further identifies coordinated experiments on the international tokamak programs and coordinates implementation of these experiments through the International Energy Agency Implementing Agreements on tokamaks. In FY 2004, the United States began participating in the ITER Transitional Arrangements activities, which is an international framework established during the earlier ITER Engineering Design Activities to prepare for the international project and the Parties' "in-kind" equipment fabrication for ITER during the period of negotiations for the ITER Agreement. In addition, we have established a community-based Burning Plasma Organization to stimulate and coordinate ITER-related research within the U.S. fusion program.

In FY 2007, funding for the U.S. Contributions to ITER MIE project is identified as Total Estimated Costs (TEC) in the Facility Operations subprogram, and Other Project Costs (OPC) in the Enabling R&D subprogram. The TEC funding provides for the U.S. "in-kind" equipment contributions, U.S. personnel to work at the ITER site, and cash for the U.S. share of common expenses such as infrastructure, hardware assembly, and installation. The OPC funding is provided for R&D and design in support of equipment—mainly heating, current drive and diagnostics—that will be provided by the U.S. to ITER. The results of this R&D and design are applicable to ITER and other burning plasma experiments. In addition, there is related support for both the ITER physics basis and the preparations for science and technology research to be conducted using ITER. This related support comes from a broad spectrum of science and technology activities within the FES program such as the experimental research from existing facilities, as well as the fusion plasma theory and computation activities, and is not part of the MIE project.

In the area of high energy density physics, OFES will continue to seek to leverage NNSA's program efforts and pursue non-defense high energy density physics experiments on their facilities. Through an interagency process, collaboration in this area will be extended to other agencies as well.

All research projects undergo regular peer review and merit evaluation based on SC-wide procedures and Federal regulations pertaining to extramural grant programs under 10 CFR 605. A similar and modified process is also followed for research proposals submitted by the laboratory programs and national collaborative facilities. All new projects are selected by peer review and merit evaluation. FES formally peer reviews the FES scientific facilities to assess the scientific output, collaborator satisfaction, the overall cost-effectiveness of each facility's operations, and the ability to deliver the most advanced scientific capability to the fusion community. Major facilities are reviewed by an independent peer process on a 5-year basis as part of the grant renewal process, or an analogous process for national laboratories. The three national fusion facilities (DIII-D at General Atomics, C-Mod at MIT, and NSTX at PPPL) had such peer reviews in the April-June 2003 time frame. Checkpoint reviews at the 3-year point provide interim assessment of program quality. These checkpoint reviews for the three facilities will be held in 2006. Program Advisory Committees for the major facilities provide annual or semi-annual feedback on assessments of the quality of research performed at the facility; the reliability and availability of the facility; user access policies and procedures; collaborator satisfaction; facility staffing levels; R&D activities to advance the facility; management of the facility; and long-range goals of the facility.

Facility upgrades and construction projects have a goal to stay within 10 percent, on average, of cost and schedule baselines for upgrades and fabrication of scientific facilities. In FES, fabrication of major research facilities has generally been on time and within budget. Major collaborative facilities have a goal to operate more than 90 percent, on average, of total planned annual operating time. FES's operation of major scientific facilities has ensured that a growing number of U.S. scientists have reliable access to those important facilities.

External factors that affect the level of performance include:

(1) changing mission needs as described by the DOE and SC mission statements and strategic plans;
(2) scientific opportunities as determined, in part, by proposal pressure and scientific workshops;
(3) results of external program reviews and international benchmarking activities of entire fields or sub fields, such as those performed by the National Academy of Sciences (NAS);
(4) unanticipated failures in critical components of scientific facilities that cannot be mitigated in a timely manner; and
(5) strategic and programmatic decisions made by non-SC funded domestic research activities and by major international research centers.

Validation and Verification

Progress against established plans is evaluated by periodic internal and external performance reviews. These reviews provide an opportunity to verify and validate performance. Monthly, quarterly, semiannual, and annual reviews consistent with specific program management plans are held to ensure technical progress, cost and schedule adherence, and responsiveness to program requirements.

Program Assessment Rating Tool (PART) Assessment

The Department implemented a tool, the PART Assessment, to evaluate selected programs. PART was developed by OMB to provide a standardized way to assess the effectiveness of the Federal Government's portfolio of programs. The structured framework of the PART provides a means through which programs can assess their activities differently than through traditional reviews. The Fusion Energy Sciences (FES) program has incorporated feedback from OMB into the FY 2007 budget request and has taken the necessary steps to continue to improve performance.

In the FY 2005 PART review, OMB gave the FES program a relatively high score of 82% overall which corresponds to a rating of "Moderately Effective." This score is attributable to the use of standard management practices in FES. The assessment found that FES has developed a limited number of adequate performance measures which are continued for FY 2006. These measures have been incorporated into this Budget Request, FES grant solicitations, and the performance plans of senior managers. As appropriate, they will be incorporated into the performance based contracts of M&O contractors. To explain these complex scientific measures better, the Office of Science has developed a website (http://www.sc.doe.gov/measures/) that answers questions such as "What does this measure mean?" and "Why is it important?" Roadmaps, developed in consultation with the Fusion Energy Sciences Advisory Committee (FESAC) and also available on the website, will guide reviews, every three years by FESAC, of progress toward achieving the long-term Performance Measures. The Annual Performance Targets are tracked through the Department's Joule system and reported in the Department's Annual Performance Report. In response to PART findings, FES established a Committee of Visitors (COV) process to provide outside expert validation of the program's merit-based review processes for impact on quality, relevance, and performance. The first COV report is available on the web (http://www.ofes.fusion.doe.gov/more_html/fesac/committeeofvisitors.pdf), as is the FES response to this report (http://www.ofes.fusion.doe.gov/more_html/fesac/covlettertohazeltine.pdf). The second COV report is also available on the web (http://www.ofes.fusion.doe.gov/more_html/fesac/cov_final.pdf), as is the FES response (http://www.ofes.fusion.doe.gov/more_html/fesac/ofesresponseto2ndcov.pdf).

OMB found that the FES budget was not sufficiently aligned with scientific program goals and that a science-based strategic plan for the future of U.S. fusion research within an international context needed to be developed. In response, FESAC was tasked to write a report that identified and prioritized scientific issues and respective campaign strategies. An interim report was completed in July 2004 and a final report was completed in April 2005. This report forms the basis of an FES strategic plan which also includes efforts in ITER, and was completed in September 2005.

For the FY 2007 Budget, OMB has developed PARTWeb—a new interface for PART that facilitates collaboration between agencies and OMB. PARTWeb will link to the http://ExpectMore.gov website and will improve public access to PART assessments and follow up actions. For 2006 there are three actions for Fusion Energy Sciences.

- Developing strategic and implementation plans in response to multiple Congressional requirements.
- Implementing the recommendations of expert review panels, especially two major National Academies studies, as appropriate.
- Re-engaging the advisory committee in a study of how the program could best evolve over the coming decade to take into account new and upgraded international facilities.

This budget request is the first important response to Congressional language regarding ITER and the domestic fusion energy program. FES is actively working to implement recommendations as appropriate. Improvements will be posted at http://www.sc.doe.gov/measures/FY06.html

Overview

Fusion science is a subfield of plasma science that deals primarily with the study of fundamental processes taking place in plasmas, or ionized gases, in which the temperature and density approach the conditions needed to allow the nuclei of two low-mass elements, e.g., hydrogen isotopes deuterium and tritium, to join together, or fuse. When these nuclei fuse, a large amount of energy is released. There are two leading methods of confining the fusion plasma—magnetic confinement, in which strong magnetic fields constrain the charged plasma particles, and inertial confinement, in which laser or particle beams or x-rays (drivers) compress and heat the plasma (target) during very short pulses. Most of the world's fusion energy research effort, the United States included, is focused on the magnetic confinement approach. However, the National Nuclear Security Administration (NNSA) supports a robust program in inertial fusion for stockpile stewardship. By leveraging this large NNSA investment, FES is able to access an important research base from which the physics of the target-driver interaction can be studied in the hopes of finding a promising path to practical fusion energy.

The Fusion Energy Sciences program activities are designed to address the scientific and technology issues facing both magnetic and inertial fusion. The FESAC Priorities Panel has identified six scientific campaigns, or topical areas, to organize these scientific and technical issues in both magnetic and inertial fusion research. Four of these topical areas are in magnetic fusion: Macroscopic Plasma Physics, Multi-scale Transport Physics, Plasma-boundary Interfaces, and Waves and Energetic Particles. One topical area covers High Energy Density Physics, closely related to inertial fusion, and one topical area covers Fusion Engineering Science applicable to critical technologies issues in both magnetic and inertial fusion. The panel has identified 15 fundamental scientific questions, 1-3 for each topical area, in order to guide the key scientific research to be carried out in fusion energy science over the next ten years.

These six topical issues or scientific campaigns have been codified into three thrusts that characterize the program activities:

- Burning Plasmas, that will include our efforts in support of ITER;
- Fundamental Understanding, that includes high performance plasma experiments, theory and modeling, as well as general plasma science;
- Configuration Optimization, that includes innovative experiments on advanced tokamaks, and alternate concepts;

Progress in all of these thrust areas, in an integrated fashion, is required to achieve ultimate success.

How We Work

The primary role of FES is management of resources and technical oversight of the program. FES has established an open process for obtaining scientific input for major decisions, such as the planning, funding, evaluating and, where necessary, terminating facilities, projects, and research efforts. There are also mechanisms in place for building fusion community consensus and orchestrating mutually beneficial international collaborations that are fully integrated with the domestic program. FES is likewise active in promoting effective outreach to and communication with related scientific and technical communities, industrial and government stakeholders, and the public.

Advisory and Consultative Activities

The Department of Energy uses a variety of external advisory entities to provide input that is used in making informed decisions on programmatic priorities and allocation of resources. The FESAC is a standing committee that provides independent advice to the Director of the Office of Science on complex scientific and technological issues that arise in the planning, implementation, and management of the fusion energy sciences program. The Committee members are drawn from universities, national laboratories, and private firms involved in fusion research or related fields. The Director of the Office of Science charges the Committee to provide advice and recommendations on various issues of concern to the fusion energy sciences program. The Committee conducts its business in public meetings, and submits reports with advice and recommendations to the Department.

A variety of other committees and groups provide input to program planning. Ad hoc activities by fusion researchers provide a forum for community debate and formation of consensus. The President's Council of Advisors on Science and Technology (PCAST) has also examined the fusion program on several occasions, as has the Secretary of Energy Advisory Board. The National Research Council, whose Plasma Physics Committee serves as a continuing connection to the general plasma physics community, recently carried out an assessment of the Department of Energy's Fusion Energy Sciences' strategy for addressing the physics of burning plasmas. In addition, the extensive international collaborations carried out by U.S. fusion researchers provide informal feedback regarding the U.S. program and its role in the international fusion effort. These sources of information and advice are integrated with peer reviews of research proposals and, when combined with high-level program reviews and assessments, provide the basis for prioritizing program directions and allocations of funding.

Program Advisory Committees (PACs) serve an extremely important role in providing guidance to facility directors in the form of program review and advice regarding allocation of facility run-time. These PACs are comprised primarily of researchers from outside the host facility, including non-U.S. members. They review proposals for research to be carried out on the facility and assess support requirements, and in conjunction with host research committees, provide peer recommendations regarding priority assignments of facility time. Because of the extensive involvement of researchers from outside the host institutions, PACs are also useful in assisting coordination of overall research programs. Interactions among PACs for major facilities assure that complementary experiments are appropriately scheduled and planned.

Facility Operations Reviews

FES program managers perform quarterly reviews of the progress in operating the major fusion facilities. In addition, a review of each of these major facilities occurs periodically by peers from the other facilities. Further, quarterly reviews of each major project are conducted by the Associate Director for Fusion Energy Sciences with the Federal Project Director in the field and other involved staff from both the Department and the performers.

Program Reviews

The peer review process is used as the primary mechanism for evaluating proposals, assessing progress and quality of work, and for initiating and terminating facilities, projects, and research programs. This policy applies to all university and industry programs funded through grants, national laboratory programs funded through Field Work Proposals (FWPs), and contracts from other performers. Peer review guidelines for FES derive from best practices of government organizations that fund science and technology research and development, such as those documented in the General Accounting Office report, "Federal Research: Peer Review Practices at Federal Science Agencies Vary" (GAO/RCED-99-99, March 1999), as well as more specifically from relevant peer review practices of other programs in the Office of Science.

Merit review in FES is based on peer evaluation of proposals and performance in a formal process using specific criteria and the review and advice of qualified peers. In addition to the review of the scientific quality of the programs provided by the peer review process, FES also reviews the proposals for their balance, relevance, and standing in the broader scientific community.

Universities and most industries submit grant proposals to receive funding from FES for their proposed work. Grants typically extend for a three- to five-year period. The grants review process is governed by the already established SC Merit Review System. DOE national laboratories submit annual FWPs for funding of both new and ongoing activities. These are subject to peer review according to procedures patterned after those in 10 CFR Part 605, which governs the SC grant program. For the major facilities that FES funds, these extensive reviews are conducted as part of a contract or cooperative agreement renewal, with nominal five-year renewal dates. External peer reviews of laboratory programs are carried out on a periodic basis.

Another review mechanism, motivated in response to PART findings, involves charging FESAC to establish a Committee of Visitors (COV) to review program management practices every three to four years on a rotating basis for the following program elements: (1) theory and computation, (2) innovative confinement concepts, high energy density physics, and general plasma science, and (3) tokamak research and enabling R&D. In April 2005, the second COV completed its review of the research portfolio and peer review process for the FES innovative confinement concepts, high energy density physics, and general plasma science programs. It concluded that these FES-supported research programs were of high quality and that the biggest concern was flat budgets for these programs. Further, the COV found that OFES program managers are serious, conscientious, and dedicated, and are doing a good job overall. Prior to their on-site review, the COV did a survey of the fusion community and found that this community agrees with these findings. With respect to recommendations, the COV suggested that OFES should (1) develop a uniform, clearly stated, rebuttal procedure, (2) implement several minor changes in the peer review process to improve the accuracy of the final funding decisions, and (3) improve the uniformity and consistency of the information contained in the proposal files. All of these recommendations are being adopted now for proposals requesting FY 2006 funds.

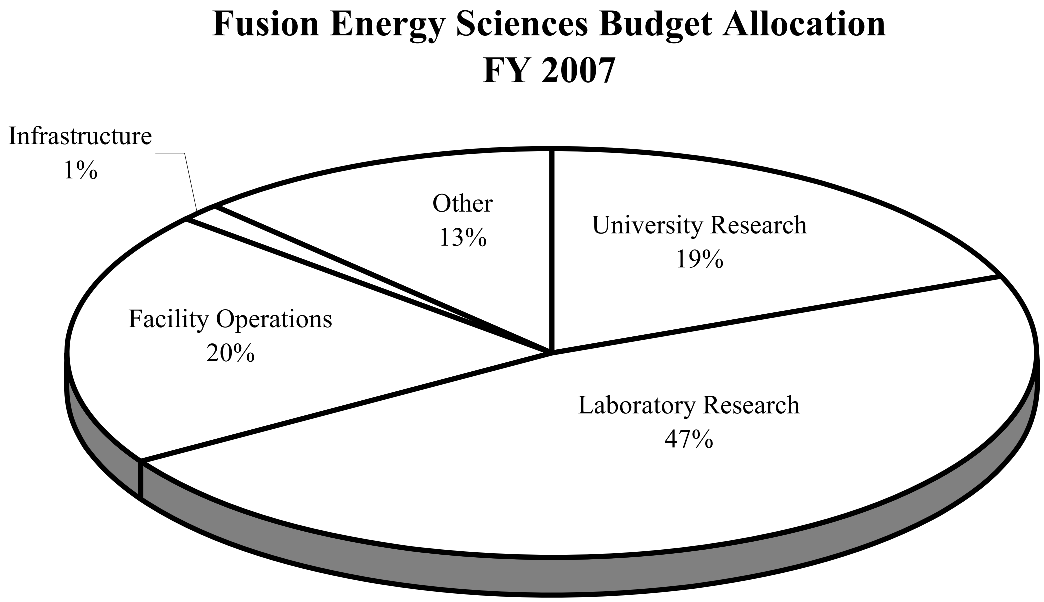
Planning and Priority Setting

The FESAC carries out an invaluable role in the fusion program by identifying critical scientific issues and providing advice on intermediate and long-term goals to address these issues. As described above, FESAC has recently assisted the Department and the fusion community in establishing priorities for the fusion program, including strategies to integrate U.S. activities in ITER into the overall U.S. domestic fusion program.

A variety of sources of information and advice, as noted above, are integrated with peer reviews of research proposals. These, combined with high-level program reviews and assessments, provide the basis for prioritizing program directions and allocations of funding.

How We Spend Our Budget

The FES budget has three components: Science, Facility Operations, and Enabling R&D. Research efforts are distributed across universities, laboratories, and private sector institutions. There are two major facilities, located at a national laboratory (Princeton Plasma Physics Laboratory), and a private sector institution (General Atomics [GA]). In addition to a major research facility at Massachusetts Institute of Technology (MIT), there are several smaller experimental facilities located at other universities and labs. Technology supports and improves the technical capabilities for ongoing experiments and provides limited long-term development for future fusion power requirements.



Research

The DOE Fusion Energy Sciences program funds research activities involving over 1,100 researchers and students at 65 academic and private sector institutions located in 30 states and at 11 DOE and Federal laboratories in 8 states. The three major facilities are operated by the hosting institutions but are configured with national research teams made up of local scientists and engineers, and researchers from other institutions and universities, as well as foreign collaborators.

- **University Research**

  University researchers continue to be a critically important component of the fusion research program and are responsible for training graduate students. University research is carried out on the full range of scientific and technical topics of importance to fusion. University researchers are active participants on the major fusion facilities and one of the major facilities is sited at a university (Alcator C-Mod at MIT). In addition, there are 16 smaller research and technology facilities located at universities, including a basic plasma science user facility at University of California, Los Angeles (UCLA) that is jointly funded by DOE and NSF. There are 5 universities with significant groups of theorists and modelers. About 40 Ph.D. degrees in fusion-related plasma science and engineering are awarded each year. Over the past three decades, many of these graduates have gone into the industrial sector and taken with them the technical basis for many of the plasma applications found in industry today, including the plasma processing on which today's semiconductor fabrication lines are based.

  The university grants program is proposal driven. External scientific peer review proposals submitted in response to announcements of opportunity and available funding are competitively awarded according to the guidelines published in 10 CFR Part 605. Support for basic plasma physics is carried out mostly through the NSF/DOE Partnership in Basic Plasma Science and Engineering.

  In addition, the FES Principal Young Investigator program supports tenure track university faculty on a competitive basis; research in fusion and plasma science is included in this program.

- **National Laboratory and Private Sector Research**

  FES supports national laboratory-based fusion research groups at the Princeton Plasma Physics Laboratory, Oak Ridge National Laboratory, Sandia National Laboratory, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Idaho National Laboratory, Argonne National Laboratory, Pacific Northwest National Laboratory, and Los Alamos National Laboratory. In addition, one of the major research facilities is located at and operated by General Atomics in San Diego, California. The laboratory programs are driven by the needs of the Department, and research and development carried out there is tailored to take specific advantage of the facilities and broadly based capabilities found at the laboratories.

  Laboratories submit Field Work Proposals for continuation of ongoing or new work. Selected parts of proposals for continuing work are reviewed on a periodic basis, and proposals for new work are peer reviewed. FES program managers review laboratory performance on a yearly basis to examine the quality of their research and to identify needed changes, corrective actions, or redirection of effort.

Significant Program Shifts

The FY 2007 request is $318,950,000, 10.9% over the FY 2006 Appropriation. The FY 2007 budget continues the redirection of the fusion program to prepare for and participate in the international ITER project. The redirection will require modest reductions in several program elements which are primarily not directly related to ITER.

Experimental research on tokamaks is continued, with increasing emphasis on physics issues of interest to the ITER project. The research and facility operations funding for the three major facilities will increase by $4,217,000 from the FY 2006 level. Operations at the largest facility, DIII-D, will increase from 7 weeks in FY 2006 to 12 weeks in FY 2007, while operations at C-Mod at MIT and NSTX at PPPL will each increase by one week over FY 2006, to 15 and 12 weeks respectively.

A new baseline was established in July 2005 for the National Compact Stellarator Experiment (NCSX), a joint ORNL/PPPL advanced stellarator experiment being built at PPPL. It results in a 14-month delay in the schedule with completion in July 2009 and a new TEC of $92,401,000. The FY 2007 request of $15,900,000 supports the new baseline.

An increase of $2,748,000 from the FY 2006 level in the Scientific Discovery through Advanced Computing (SciDAC) program will continue development of tools to facilitate international fusion collaborations and initiate development of an integrated software environment for multiphysics, multi-scale simulations of fusion systems. Within SciDAC, the Fusion Simulation Project is a major initiative involving plasma physicists, applied mathematicians, and computer scientists to create a comprehensive set of models of fusion systems, combined with the algorithms required to implement the models and the computational infrastructure to enable them to work together.

Other program shifts include: a reduction of $1,028,000 from the FY 2006 level in the Fusion Theory program and thereby the analytic theory capabilities of the program; a reduction of $3,907,000 from the FY 2006 level in the High Energy Density Physics program, resulting in a reduction in research in innovative approaches to high energy density physics (fast ignition and plasma jets), a reduction in research in heavy ion beam science, and the discontinuation of the Congressionally-directed, non-defense research at the Atlas pulsed power facility; a reduction of $3,616,000 from the FY 2006 level in the Plasma Technology and Materials Research programs in the Enabling R&D category, thereby eliminating research on a U.S. Test Blanket Module for use on ITER; and a reduction of $1,788,000 from the FY 2006 level in the Experimental Plasma Research program leading to reductions in all projects in the program.

ITER

International Accomplishments:

Multilateral ITER negotiations continued in FY 2005 and in early FY 2006. Significant advances during the negotiations include: the selection of Cadarache, France, as the host site for ITER, designation and approval of the Director General Nominee, and approval and invitation for India to join the ITER negotiations as a full non-host participant. Equally important, the ITER parties completed the comprehensive process to finalize the draft ITER Agreement and supporting documentation, the collection of which covers all phases of the ITER project. In accordance with the requirements contained within the Energy Policy Act of 2005, Section 972(c)(3)(B)(i-vii), the draft ITER Agreement will finalize the current provisional list of equipment to be provided by each ITER Party, including India, and will finalize the mode of operation among the ITER parties and central project team during the construction, operation, and decommissioning phases of the ITER program. The process for finalizing the ITER Agreement included incorporation of input by topical area experts from each negotiating party including government officials, legal representatives, and fusion scientists, clarification and discussion among the representatives of each party and resolution of differences by the negotiators. Given the progress of the Fall 2005 negotiations among the ITER parties in resolving key issues, it is the objective of the international ITER parties to obtain the negotiators' acceptance of the draft ITER Agreement by early 2006 indicating the end of the negotiations. The next step will be to obtain governmental signatures on the completed ITER Agreement later in FY 2006, by all ITER parties, thereby leading to a multilateral commitment for ITER. During this time, representatives of the parties will address critical implementation decisions on detailed arrangements including assignment of management personnel.

U.S. ITER Project Accomplishments:

The Project Office, serving as the U.S. domestic agency for the international ITER Project, is responsible for the management of the U.S. contributions including hardware, personnel, and cash. Since the establishment of the Project Office in July 2004, the following accomplishments have been made:

- preliminary cost and schedule ranges have been prepared, reviewed, and revised to reflect resolution of uncertainties associated with the international ITER Project
- the Deputy Secretary of Energy approved DOE 413.3 Critical Decision 0, Mission Need for ITER
- project management documentation required by DOE Order 413.3 has been updated for the U.S. Contributions to ITER MIE project.

In FY 2005 and FY 2006, the Project Office has been preparing for approval of Critical Decision 1, Approve Alternative Selection and Cost Range, in September 2006 and Critical Decision 2, Approve Performance Baseline, in September 2007. This preparation includes monitoring and responding to activities associated with the international ITER Project. The schedule for Critical Decision 2 is dependent on the ability of the international ITER Organization establishing an efficient mode of operation and on their assessment of the current design and schedule for the international ITER Project—both of which affect the establishment of the performance baseline of the U.S. Contributions to ITER project.

The FY 2006 Appropriation provided for a slower start for the U.S. Contributions to ITER project. As a result of this slower start, the funding profile has been altered from the profile provided with the

FY 2006 Budget by shifting funds formerly intended for FY 2006 and FY 2007 into FY 2008 and beyond. This revised funding profile will still allow the U.S. to fulfill its non-host obligations to the international project, a minimum contribution of any ITER party during the phase of construction.

The FY 2007 request for the U.S. Contributions to ITER MIE project includes Total Estimated Costs (TEC) funding of $37,000,000 in the Facilities Operations subprogram and Other Project Costs (OPC) funding of $23,000,000 in the Enabling R&D subprogram. The annual Total Project Cost (TPC) profile for FY 2006 through FY 2014 is provided below, and the funding cap of $1,122,000,000 is maintained. The profile shows a more modest first two years than was contained in the FY 2006 President's Budget. The near-term reductions reflect the longer site selection process and allow for the U.S. to be more consistent with the other ITER parties in the pace of starting the long lead procurements, providing increased numbers of personnel to the ITER Organization, and providing cash for common expenses. The reductions in FY 2006 ($30,185,000) and FY 2007 ($86,000,000) relative to the levels shown in the FY 2006 budget are re-distributed in the outyears to allow for completion of the U.S. commitment as a non-host ITER participant. The profile and funding cap could change in the future if increases in escalation and/or fluctuations in the currency exchange rates occur. The profile is preliminary until the Director General Nominee and ITER Organization have achieved a standard mode of operation, and the baseline scope, cost, and schedule for the MIE project (CD-2) are established.

U.S. Contributions to ITER MIE Project

Annual Profile[a]

(budget authority in thousands)

Fiscal Year	Total Estimated Costs	Other Project Costs	Total Project Costs
2006	15,866	3,449	19,315
2007	37,000	23,000	60,000
2008	149,500	10,500	160,000
2009	208,500	6,000	214,500
2010	208,500	1,500	210,000
2011	180,785	500	181,285
2012	130,000	—	130,000
2013	116,900	—	116,900
2014	30,000	—	30,000
Total	1,077,051	44,949	1,122,000

Estimated TEC, OPC, and TPC Costs

The Current Estimate in the table below is the same as the FY 2006 estimate and does not yet reflect the results of the December 2005 negotiations. The estimate is now being revised to incorporate the key results of the negotiations; i.e., India was accepted as a non-host partner, cost sharing was agreed upon, a revised allocation of hardware contributions was agreed upon, and a new contingency was agreed upon

[a] The funding profile is a preliminary estimate incorporating the key results of the December 2005 negotiations. In addition, shifts between OPC and TEC funding have been made consistent with the intentions of DOE 413.3 to provide for R&D and design in support of the MIE project. During FY 2006, several U.S. reviews are scheduled to validate the preliminary cost and schedule profile for the U.S. Contributions to ITER MIE project. In addition, international ITER Project activities in FY 2006 will also validate the international cost and schedule which can have an affect on the U.S. Contributions to ITER project. The performance baseline, including the funding profile, will be established at CD-2 planned for September 2007.

for the international ITER Organization. Based on the results of the negotiations, the fabrication and other project costs in the table will be reduced and the contingencies will be increased; however, the Total Project Cost will remain unchanged. After these revisions are reviewed in accordance with DOE project management procedures, the details will be available for the FY 2008 budget request.

	(dollars in thousands)	
	Current Estimate	Previous Estimate
Fabrication Costs		
Procurement of U.S. in-kind equipment (non-host contribution to ITER)	573,800	573,800
Installation of U.S. in-kind equipment	71,900	71,900
Assignment of U.S. scientists and engineers to ITER Org (non-host contribution to ITER)	87,300	87,300
Contribution of funds for support personnel at ITER Org (non-host contribution to ITER)	36,200	36,200
Operation of U.S. ITER Project Office including management, QA, procurement, etc.	123,600	123,600
Subtotal	892,800	892,800
Contingencies at approximately 16% of above costs	145,200	145,200
Total Estimated Costs (TEC)	1,038,000	1,038,000
Other Project Costs - Base Program R&D and Design Support for above tasks	68,000	68,000
Contingencies at approximately 24% of OPC costs	16,000	16,000
Total Other Project Costs (OPC)	84,000	84,000
Total Project Costs (TPC)	1,122,000	1,122,000

Related Annual Funding Requirements

The Current Estimate in the table below has been revised based upon the results of the December 2005 negotiations (i.e., agreement was reached on cost sharing during operations, deactivation and decommissioning), on the procedure for converting currencies into Euros, and on the 20 year period of annual contributions to the decommissioning fund in conjunction with ITER operations. It has been possible to make these revisions now because the changes are straightforward.

	(dollars in thousands)	
	Current Estimate	Previous Estimate
FY 2014–FY 2033		
U.S. share of annual facility operating costs including commissioning, maintenance, repair, utilities, power, fuel, improvements, and annual contribution to decommissioning fund for period 2014 to 2033. Estimate is in year 2014 dollars.	55,700	58,300
FY 2034–FY 2038		
U.S. share of the annual cost of deactivation of ITER facility for period 2034–2038. Estimate is in year 2036 dollars.	17,100	17,000

The Total Project Cost for the U.S. Contributions to ITER MIE project is $1,122,000,000, consisting of TEC funding for the fabrication of the equipment, provision of personnel and the U.S. share of cash for common project expenses at the ITER site, and the OPC funding for R&D and design activities supporting the TEC-funded procurements. This MIE is augmented by the technical output from a significant portion of the U.S. Fusion Energy Sciences community research program. The U.S. is a major participant in the International Tokamak Physics Activity (ITPA), which delineates high priority physics needs for ITER and assists their implementation through collaborative experiments among the major international tokamaks, and analysis and interpretation of experiments for extrapolation to ITER. Virtually the entire FES program provides related contributions to such ITER-relevant research, not part of the TEC, OPC, and TPC, and prepares the U.S. for effective participation in ITER when it starts operations.

In FY 2007, the Total Project Cost remains unchanged from FY 2006, but the profile has changed and the funding requested in FY 2007 is lower than that shown in the FY 2006 President's Budget. The specific annual funding levels for TEC and OPC are subject to change when the performance baseline for scope, cost, and schedule of the U.S. MIE project is established (defined as Critical Decision 2 under DOE Order 413.3, Program and Project Management for the Acquisition of Capital Assets). There was significant progress in the Fall 2005 international negotiations, indicating the designation of the nominee Director General. The next steps include designation of the other key managers of the ITER project, completion of the ITER Agreement, governmental approval and signing of the Agreement, which for the United States requires a mandate from the U.S. Department of State, and Congressional approval, all of which leads to operation of a fully functioning ITER Organization working in concert with the Domestic Agencies (anticipated in the Summer 2007).

Accordingly, the estimated timeframe for establishing the U.S. performance baseline is the end of FY 2007.

FY 2005 Awards

FY 2005 awards or honors to and for researchers supported by FES include:

- Seven fusion scientists were made Fellows of the American Physical Society.
- A fusion materials scientist at ORNL has been named a UT-Battelle corporate fellow in recognition of his sustained and outstanding research contributions in the development of fusion materials.
- A fusion engineer at INL has been named a "Laboratory Fellow" because of his record of outstanding technical contributions, and recognition for his expertise both nationally and internationally in the fusion safety research area.
- A fusion scientist was named the DOE Office of Science Undergraduate Research Programs "Outstanding Mentor" of 2004.
- A graduate student working on a fusion experiment at the University of Wisconsin received the 2005 APS-DPP Marshall N. Rosenbluth Outstanding Doctoral Thesis Award in Plasma Physics.
- A fusion scientist received the Fusion Power Associates 2005 Leadership Award for his outstanding leadership of the DIII-D tokamak program at General Atomics.
- A fusion scientist at PPPL received the IEEE Particle Accelerator and Technology Award for 2005.
- A fusion scientist at the University of Texas at Austin received the 2004 State Scientific and Technological Cooperation Award of the People's Republic of China for contributing to Sino-U.S. cooperation in fusion.
- A fusion scientist at PPPL received the Chinese Institute of Engineers—USA Distinguished Achievement Award for outstanding leadership in fusion research and contributions to fundamentals of plasma science.
- A fusion scientist at Princeton University was awarded the American Physical Society's 2005 James Clerk Maxwell Prize for Plasma Physics for theoretical development of efficient radio-frequency-driven current in plasmas and for greatly expanding our ability to understand, analyze, and utilize wave plasma interactions.

- A fusion scientist at Lawrence Livermore National Laboratory and an another fusion scientist at General Atomics were jointly awarded the American Nuclear Society 2005 Edward Teller Prize for their contribution to the physics of inertial fusion.

Scientific Discovery through Advanced Computing (SciDAC)

The Scientific Discovery through Advanced Computing (SciDAC) program is a set of coordinated investments across all Office of Science program offices with the goal of achieving breakthrough scientific advances through computer simulation that are impossible using theoretical or laboratory studies alone. By exploiting the exponential advances in computing and information technologies as tools for discovery, SciDAC encourages and enables a new model of multi-disciplinary collaboration among scientists, computer scientists, and mathematicians. The product of this collaborative approach is a new generation of scientific simulation codes that can fully exploit terascale computing and networking resources. The SciDAC program will bring simulation to a parity level with experiment and theory in the scientific research enterprise as demonstrated by major advances in climate prediction, plasma physics, particle physics, and astrophysics.

During the past year, multidisciplinary teams of computational plasma physicists, applied mathematicians, and computer scientists began new three-year research projects in the areas of macroscopic stability, electromagnetic wave-plasma interaction, and simulation of turbulent transport of energy and particles. During the preceding three years, these teams achieved significant advances in the simulation of mode conversion of radio frequency waves in tokamak plasmas, modeling of the sawtooth instability in tokamaks with realistic plasma parameters, and understanding turbulent transport as a function of plasma size in tokamaks. In early FY 2006, the Fusion Energy Sciences program and the Advanced Scientific Computing Research program completed a competitive peer review process and funded two fusion simulation prototype centers—one on integrated simulation of tokamak edge plasmas, and one on integrated simulation of wave-plasma interaction and macroscopic stability.

Scientific Facilities Utilization

The Fusion Energy Sciences request includes funds to operate and use major fusion physics collaborative science facilities. The Department's three major fusion physics facilities are: the DIII-D Tokamak at General Atomics in San Diego, California; the Alcator C-Mod Tokamak at the Massachusetts Institute of Technology; and the National Spherical Torus Experiment (NSTX) at the Princeton Plasma Physics Laboratory.

The funding requested will provide research time for about 210 scientists in universities, federally sponsored laboratories, and industry, and will leverage both federally and internationally sponsored research, consistent with a strategy for enhancing the U.S. national science investment.

The total number of hours of operation at all of the major fusion facilities is shown in the following table.

	FY 2005	FY 2006	FY 2007
Optimal hours[a]	2,800	2,800	2,800
Planned hours	1,936	1,168	1,440
Hours operated as percent of planned hours	108%	TBD	TBD

[a] This consists of 40 hours per week for DIII-D and NSTX and 32 hours per week for C-Mod.

In addition to the operation of the major fusion facilities, the NCSX MIE project at PPPL is supported in the fusion program. Milestones for this project are shown in the following table.

FY 2005	FY 2006	FY 2007
Award, through a competitive process, production contracts for the NCSX modular coil winding forms, conductor, and vacuum vessel. Complete winding of the first modular coil.	Complete fabrication of a vacuum vessel subassembly and two modular coils.	Complete winding of one half of the modular coils.

Workforce Development

The FES program, the Nation's primary sponsor of research in plasma physics and fusion science, supports development of the R&D workforce by funding undergraduate researchers, graduate students working toward masters and doctoral degrees, and postdoctoral associates developing their research and management skills. The R&D workforce developed as a part of this program provides new scientific talent to areas of fundamental research. It also provides talented people to a wide variety of technical and industrial fields that require finely honed thinking and problem solving abilities and computing and technical skills. Scientists trained through association with the FES program are employed in related fields such as plasma processing, space plasma physics, plasma electronics, and accelerator/beam physics as well as in other fields as diverse as biotechnology and investment and finance.

In FY 2005, the FES program supported 430 graduate students and post-doctoral investigators. Of these, approximately 60 students conducted research at the DIII-D tokamak at General Atomics, the Alcator C-Mod tokamak at MIT, and the NSTX at PPPL. A Junior Faculty development program for university plasma physics researchers and the NSF/DOE partnership in basic plasma physics and engineering focus on the academic community and student education.

Data on the workforce for the FES program are shown in the table below.

	FY 2005	FY 2006 estimate	FY 2007 estimate
# University Grants	204	202	200
# Permanent PhD's (FTEs)[a]	692	685	678
# Postdoctoral Associates (FTEs)	103	102	101
# Graduate Students (FTEs)	327	324	320
# PhD's awarded	40	40	40

The Fusion Energy Sciences Advisory Committee conducted a study of the fusion workforce status and needs and published its findings in "Fusion in the Era of Burning Plasma Studies: Workforce Planning for 2004 to 2014," March 2004. FES recognizes the urgency in addressing the FESAC recommendations to meet future workforce needs, which requires tracking the number of current fusion researchers, encouraging new scientists in the field, especially from underrepresented groups, and developing opportunities for research. In response to the FESAC report, FES has increased the number of fusion fellowships for graduate students and postgraduate researchers, and faculty and students are encouraged

[a] Permanent PhD's includes faculty, research physicists at universities, and all PhD-level staff at national laboratories.

to conduct collaborative research on major fusion facilities. In FY 2005, an FES fellowship was awarded to an HBCU postdoctoral researcher to work at a DOE national laboratory. FES collects data on the retention of graduate students and postdoctoral fellows in fusion research, on the number of Plasma Physics Junior Faculty Development Program award recipients who have received tenure, and on staffing at all FES research institutions. FES encourages new institutions and researchers to the fusion program through the Plasma Physics Junior Faculty Development Program, the NSF/DOE Partnership, and the ICC program, and enhances the visibility of fusion researchers through programs in coordination with the APS-DPP and the Office of Science/Presidential Early Career Scientist and Engineer Award program.

External Independent Reviews

Beginning in FY 2005, the costs of conducting External Independent Reviews (EIRs) for Capital Asset Projects greater than $5,000,000 within SC have been funded by SC. Examples of EIRs include conducting Performance Baseline EIRs prior to Critical Decision-2 (CD-2) to verify the accuracy of cost and schedule baseline estimates and conducting Construction/Execution Readiness EIRs, which are done for all Major System projects prior to CD-3. These funds, which are managed by the Office of Engineering and Construction Management, are exclusively used for EIRs directly related to these projects funded within SC. Beginning in FY 2007, the EIR business line will be financed via the Working Capital Fund to achieve parity on how EIRs are funded and to standardize the administration of these critical activities.

Science

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
Science			
Tokamak Experimental Research	47,052	46,517	45,838
Alternative Concept Experimental Research	59,484	60,550	56,302
Theory	25,749	24,928	23,900
SciDAC	4,033	4,222	6,970
General Plasma Science	12,176	13,760	13,941
SBIR/STTR	—	6,945	7,262
Total, Science	148,494	156,922	154,213

Description

The Science subprogram fosters fundamental research in plasma science aimed at a predictive understanding of plasmas in a broad range of plasma confinement configurations. There are two basic approaches to confining a fusion plasma and insulating it from its much colder surroundings—magnetic and inertial confinement. In the former, funded by the FES program, carefully engineered magnetic fields isolate the plasma from the walls of the surrounding vacuum chamber; while in the latter, a pellet of fusion fuel is compressed and heated so quickly that there is no time for the mass of the resultant plasma to escape during the time when significant fusion reactions occur. The target physics and major experiments in inertial fusion are funded by NNSA. The scientific feasibility of inertial fusion is underpinned by the pertinent subfields of high energy density physics. The FES program in high energy density physics leverages and collaborates with NNSA's program efforts to pursue non-defense experiments on NNSA's facilities. The Science subprogram supports exploratory research to combine the favorable features of, and the knowledge gained from, magnetic confinement and/or inertial confinement, both for steady-state and pulsed approaches, in new, innovative fusion concepts. There has been great progress in plasma science during the past three decades, in both magnetic and inertial confinement, and today the world is at the threshold of a major advance in fusion energy development—the study of burning plasmas, in which the self-heating from fusion reactions dominates the plasma behavior.

Benefits

The Science subprogram provides the fundamental understanding of plasma science needed to address and resolve critical scientific issues related to fusion burning plasmas. The Science subprogram also explores and develops diagnostic techniques and innovative concepts that optimize and improve our approach to creating fusion burning plasmas, thereby seeking to minimize the programmatic risks and costs in the development of a fusion energy source. Finally, this subprogram provides training for graduate students and post docs, thus developing the national workforce needed to advance plasma and fusion science.

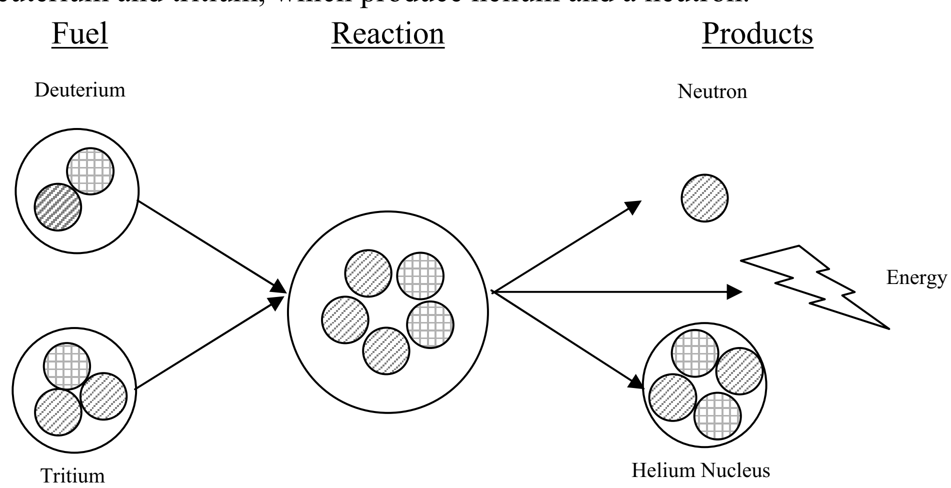
Supporting Information

Plasmas, the fourth state of matter, comprise over 99% of the visible universe and are rich in complex, collective phenomena. During the past decade there has been considerable progress in our fundamental understanding of key individual phenomena in fusion plasmas, such as transport driven by micro-turbulence, and macroscopic equilibrium and stability of magnetically confined plasmas. Over the next ten years the Science subprogram will continue to advance our understanding of plasmas through an integrated program of experiments, theory, and simulation as outlined in the Integrated Program Planning Activity for the Fusion Energy Sciences Program prepared for FES and reviewed by the FESAC. This integrated research program focuses on well-defined plasma scientific issues including turbulence, transport, macroscopic stability, wave particle interactions, multiphase interfaces, hydrodynamic stability, implosion dynamics, fast ignition, and heavy-ion beam transport and focusing. We expect this research program to yield new methods for sustaining and controlling high temperature, high-density plasmas, which will have a major impact on a burning plasma experiment, such as ITER. This integrated research program also will benefit from ignition experiments performed at the NNSA-sponsored National Ignition Facility (NIF).

An additional objective of the Science subprogram is to broaden the intellectual and institutional base in fundamental plasma science. Two activities, an NSF/DOE partnership in plasma physics and engineering, and the Junior Faculty development grants for members of university plasma physics faculties, will continue to contribute to this objective. The ongoing Fusion Science Center program will also foster fundamental understanding and connections to related sciences.

Plasma science includes not only plasma physics but also physical phenomena in a much wider class of ionized matter, in which atomic, molecular, radioactive transport, excitation, and ionization processes are important. These phenomena can play significant roles in partially ionized media and in the interaction of plasmas with material walls. Plasma science contributes not only to fusion research, but also to many other fields of science and technology, such as industrial processing, national security, space propulsion, and astrophysics.

Fusion science, a major sub-field of plasma science, is focused primarily on describing the fundamental processes taking place in plasmas, or ionized gases, in which peak temperatures are greater than 100 million degrees Celsius, and densities are high enough that light nuclei collide and fuse together, releasing energy and producing heavier nuclei. The reaction most readily achieved in laboratory plasmas is the fusion of deuterium and tritium, which produce helium and a neutron.



The Fusion Process

Fusion science shares many scientific issues with plasma science. For Magnetic Fusion Energy (MFE), these include: (1) chaos, turbulence, and transport; (2) stability, magnetic reconnection, self-organization, and dynamos; (3) wave-particle interaction and plasma heating; and (4) sheaths and boundary layers. Progress in all of these fields is likely to be required for ultimate success in achieving a practical fusion source.

For High Energy Density Physics, the major fusion science issues are: (1) high energy density physics that describes intense laser-plasma and beam-plasma interactions; (2) implosion dynamics and stability; (3) target physics and the science of target fabrication; and (4) non-neutral plasmas, as is seen in the formation, transport, and focusing of intense heavy ion beams.

FY 2005 Science Accomplishments

Progress on the international agreement to build ITER has energized fusion research around the world, enhancing international collaborations and encouraging closer collaborations between theory, simulation, and experiments. The number of experiments planned jointly by the International Tokamak Physics Activity (ITPA) on multiple facilities with different parameter regimes to investigate burning plasma and ITER related issues increased substantially in FY 2005. Greater effort is also focused on computer simulation tools to enhance predictive capability for advanced tokamaks and ITER.

Jointly funded by FES and Advanced Scientific Computing Research (ASCR), the National Fusion Collaboratory is continuing to develop and deploy collaborative software tools for use throughout magnetic fusion energy research. This effort includes creating a robust, user-friendly collaborative software environment (referred to as the National Fusion Grid) and deploying it to the more than 1,000 scientists in 40 institutions who perform magnetic fusion research in the United States and abroad. The main data repositories at the three major experimental facilities have been made securely accessible via Fusion Grid. Additionally, several fusion codes are now available on Fusion Grid including TRANSP, GATO—and GS2. One of these codes, “TRANSP”—a widely used system for simulation of fusion experiments—has performed over 2,000 simulations taking over 10,000 CPU hours for nine different experimental fusion devices. This collaborative technology is scalable to an international project like ITER.

Predictive Capability for Burning Plasmas

Experiments on the three major U.S. facilities (C-Mod, DIII-D, and NSTX) and coordinated experiments with international tokamaks under the ITPA/IEA Joint Experimental program have led to increased understanding of basic physics in the four major topical areas of fusion science (turbulence and transport, macroscopic equilibrium and stability, wave-plasma interactions and plasma heating, and edge/boundary layer plasma physics) and in critical physics issues for ITER. A key example of these issues is the development of plasma scenarios for both high performance operation to achieve high fusion gain (Q~10) in burning plasmas and for steady-state high performance operation to optimize future fusion power applications. Other important results include: elimination of edge localized modes (ELMs) through creation of resonant magnetic fields at the plasma edge in DIII-D using the internal control coils; plasma rotation studies and error field control in C-Mod and NSTX; stabilization of internal neo-classical tearing modes (NTMs) by driving plasma current in precise locations inside the plasma with electron cyclotron current drive; and measurement of energetic ions and a range of Toroidal Alfvén Waves created by them in DIII-D and NSTX. The planning and implementation of these and other similar experiments were made possible by extensive use of plasma control algorithms and active feedback stabilization assisted by high-speed computers.

Several major highlights from the experiments and advanced computing are discussed below.

- **Favorable Confinement Projection for ITER**

  Collaborative experiments between the United States and Europe on the DIII-D tokamak (at General Atomics) and the JET tokamak (UKAEA Culham Science Center) have obtained results that indicate ITER might perform better than its baseline design assumption. Until now, the standard projections of energy confinement for ITER have implied a strong degradation of energy confinement as the ratio of plasma pressure to magnetic pressure ("beta") was increased. In these experiments researchers could vary beta by a factor of 3 without penalty to energy confinement, thus implying that ITER could operate at a higher beta or plasma pressure and achieve either higher fusion power output and/or more ready access to steady-state operating modes in ITER. Confidence in this positive result was enhanced recently through a joint examination of confinement data from NSTX and MAST.

- **Plasma Flows and Plasma Rotation**

  It has long been known that plasma conditions near the edge of a tokamak can have profound impact on energy confinement deep within the plasma. Over the last year, experiments on C-Mod have revealed that plasma flowing along magnetic field lines that do not close on themselves allows coupling of momentum from the edge into the center of the plasma, which may be related to the up-down asymmetry in the power requirement for transition to high confinement. Using newly commissioned non-axisymmetric external field coils, an external control capability of plasma rotation was demonstrated on NSTX. The measured rotation damping profile from applied fields follows neoclassical toroidal viscosity theory.

- **Internal Transport Barriers**

  The plasma parameters of the internal transport barrier regime recently observed on C-Mod have been significantly extended, in which profiles spontaneously peak with off-axis radio-frequency heating. Using increased levels of both on- and off-axis power (4 MW total), both temperature and density profiles became highly peaked, leading to a greatly increased central pressure approaching four atmospheres. The plasma parameters of the ion internal transport barrier regime, regularly produced in High Confinement Mode plasmas on NSTX, have entered a new regime for many energy confinement times. This regime is characterized by high normalized plasma pressure, good confinement, and absence of significant MHD activities. This new regime suggests a new way to enhance the plasma performance for the ITER hybrid mode.

- **Plasma Microturbulence Code Achieves High Multi-Teraflop Performance**

  The Gyrokinetic Toroidal Code (GTC), the featured code in the SciDAC "Center for Gyrokinetic Particle Simulation for Turbulent Transport in Burning Plasmas" achieved an unprecedented 7.2 teraflop sustained performance using 4096 processors on the Earth Simulator Computer (ESC) in Japan. Since it used over 13 billion particles, the simulation was able to reach an extremely high statistical resolution which enabled systematic studies of key scientific questions, including the long-time temporal evolution of turbulence and the influence of nonlinear velocity-space dynamics in determining how quickly the plasma transport can reach saturation. The ability of the GTC code to scale so well and to effectively utilize greatly increased computational capability holds exciting promise for accelerating the pace to new scientific discoveries in this key area of fusion plasma research.

- **Nonlinear Simulations of Edge Localized Modes**

  The onset and nonlinear evolution of Edge Localized Modes (ELMs) were studied for the first time using two-fluid extended MHD models. ELMs are repetitive MHD oscillations occurring at the edge of magnetically confined plasmas and can affect global confinement and first wall performance. Both of the large nonlinear extended MHD codes being developed in the U.S.—NIMROD and M3D—produced remarkable simulations of the edge of the DIII-D tokamak undergoing an instability and, for the first time, provided us with an estimate of the heat flux to the surrounding wall due to the ELM activity. Understanding and controlling ELMs is very important for the operation of ITER because these instabilities can move large amounts of energy from the plasma core to the first wall and divertor plates of the device.

- **Active MHD Spectroscopy**

  Fusion power is proportional to the square of the plasma pressure. An upper limit to plasma pressure is set by the lowest order instability predicted by magnetohydrodynamic (MHD) theory. Referred to as the "kink mode," it leads to termination of the plasma discharge. Previously on DIII-D, it has been shown that this instability could be stabilized if the plasma is bounded by a nearby conducting wall and is rotating rapidly, allowing operation at up to twice the conventional pressure limit. NSTX has recently extended these results by reaching central plasma pressures up to 100% of the applied magnetic field pressure at the plasma major radius. Further information on MHD instabilities has been gained on DIII-D and NSTX by using a set of coils as an antenna (dubbed MHD spectroscopy) to apply a pulsed or rotating magnetic field with a large overlap in spatial structure with the basic unstable modes and finding the resonances. These measurements are now being compared to detailed code calculations that test various stabilizing mechanisms.

- **ITER level plasma pressure obtained in C-Mod**

  Using an all-metallic vacuum vessel wall coated with a thin layer of boron, Alcator C-Mod scientists have achieved a world record absolute pressure (about 6 atmospheres peak) for magnetic confinement experiments. Significantly, they achieved this result at the same value of plasma pressure relative to stability limits that is planned for the ITER baseline operation. This follows the removal of all low-Z materials from the C-Mod vessel at the end of FY 2004.

- **Simulation of Energetic Ion Driven Modes for Burning Plasma**

  The burning plasmas in ITER will be heated by "super-Alfvénic" energetic ions that move faster than the intrinsic "Alfvén" velocity of the magnetic plasma perturbations. NSTX, among major magnetic fusion facilities, is the only experiment designed to operate with such energetic ions under the normal conditions, where all parameters including the internal magnetic field can be measured. The Compressional Alfvén Eigenmodes (CAEs) and the Global Alfvén Eigenmodes (GAEs), previously predicted by theory, have been observed in a wide range of plasma conditions in NSTX. The presence of these modes is often (but not always) associated with a depleted distribution of the super-Alfvénic ions that interact strongly with such modes. Characterizing the interactions of these fast ions and the driven modes is important to establish a predictive understanding of their potential impact on the burning plasma performance in ITER.

- **DIII-D Control System for Fusion Plasma Discharges**

  Major progress has been made in feedback control of many plasma parameters using the highly-sophisticated DIII-D digital control system. This system involves representation of complex plasma physics issues in real time analysis of sensor data and determination of the required instructions to actuators to control the plasma parameters and their profiles. The system thus makes it possible to produce plasmas near their theoretical pressure limits for long pulses, mitigates disruptions, tests discharge scenarios against simulations, and sets up discharge scenarios very efficiently and effectively. The DIII-D control system is now being provided to several U.S. and international tokamaks (NSTX, KSTAR, EAST, and MAST) and it has high potential to be extrapolated to ITER.

- **Steady-State Plasmas for ITER**

  To operate ITER steady-state requires driving the plasma's electrical current (~10MA) by a combination of electromagnetic waves, particle beams, and the plasma's self-generated bootstrap current instead of using transformer coil induction. Plasma states were recently achieved in the DIII-D tokamak in which 100% of the plasma current was so obtained non-inductively, meeting or exceeding the parameters of ITER's projected steady-state operating scenario. At modest current where steady-state tokamaks are projected to operate, sufficient plasma pressure was obtained for an energy gain of 5 in ITER with 100% non-inductive operation and plasma confinement quality exceeding nominal expectations. On NSTX, a new rapid-response plasma control system improved the feedback control for vertical stability, enabling routine operation with plasmas of substantially stronger shaping (higher elongation and triangularity), improved stability, and increased bootstrap current, and leading to more stable plasmas with 50% longer pulse lengths in 2005 than achieved in previous years. Plasmas were developed with high elongations and triangularities, pulse lengths up to 50 times the plasma energy confinement times, and routine sustained plasma betas greater than 25%.

- **Edge Plasma Physics**

  Understanding edge plasma physics is important for tokamaks because the properties of the edge plasma affect both the flux of heat and particles to the material walls and the confinement of heat and particles in the core of the plasma. A very critical issue for ITER is the determination of the expected level of tritium retention by graphite plasma facing components (PFC), which are now commonly used in present tokamaks. The two approaches to this issue are the replacement of graphite PFCs with an all-metal wall and divertor system which does not retain tritium, or by developing techniques to easily remove tritium from graphite surfaces.

- **Measurements of Structure and Motion of Edge Turbulence**

  The 2-D structure of edge plasma turbulence in NSTX was measured by viewing the emission of deuterium or helium spectral lines locally enhanced by gas puffing with an ultra-high speed CCD camera. Transitions from low-confinement mode to high-confinement mode could appear as an evolution from a turbulent "blob-like" or intermittent state to a quiescent state over a period of 0.1 ms. However, no evidence was found, through the measured motion of the edge turbulence, to indicate a simultaneous occurrence of sheared plasma flow at the plasma edge during the confinement transition. Edge Localized Modes (ELMs) were observed to be closely associated with a sudden increase in the intermittent bursts of multiple "blobs." Understanding of these ELMs will contribute to avoiding large ELMs and their induced divertor erosion in ITER.

- **Predicting Tritium Co-deposition in ITER**

  In tokamaks with carbon first wall materials, the hydrogenic fuel species (tritium in ITER) is co-deposited on material surfaces with eroded carbon. Tritium thus trapped in ITER must be periodically removed. A first step toward such a removal scheme is to know where the tritium will be co-deposited. In the DIII-D tokamak, measurements and code simulations showed characteristic plasma flow patterns in the plasma boundary that implied deposits would form dominantly where the inner divertor leg contacted material surfaces. Carefully executed experiments using carbon-13 tracer elements that were injected into the plasma edge showed essentially all the carbon-13 was deposited where the inner divertor leg contacted material surfaces, confirming the result previously seen in the JET tokamak. These results suggest that in a divertor tokamak, the co-deposition area might be localized and predictable, the first step in being able to devise a tritium removal procedure.

Configuration Optimization

Since the inception of this program element in 1997, significant progress has been made in many confinement concepts. The highlights below cover the accomplishments in concepts other than Advanced Tokamaks in FY 2005.

- In the reversed field pinch experiment, the Madison Symmetric Torus (MST) at the University of Wisconsin in Madison, the plasma current has been increased to about 500 kilo-amps, resulting in an increase in the plasma temperature by 60% to near fusion-relevant levels of 16 million degrees Celsius.
- Coaxial Helicity Injection (CHI) has produced on NSTX the largest size and longest sustained spherical tokamak plasmas without use of an ohmic solenoid. The experiment utilized the transient CHI technique successfully tested earlier on the Helicity Injected Tokamak-II (HIT-II) of the University of Washington, extended the plasma volume and current generation efficiency by an order of magnitude, and doubled the plasma duration. This proves that the open magnetic field lines carrying the helicity-injected plasma current can reconnect and self-organize into toroidal plasmas of closed magnetic flux surfaces, indicating concrete progress toward enabling solenoid-free initiation and ramp-up of the plasma current in future Spheromak and spherical tokamak experiments.
- Magnetic helicity is nature's way of "trapping" magnetic flux and electrical currents in some self-organized manner that allows magnetic and plasma energy to be transported in space and time. When magnetic helicity is captured in a toroidal form in a simple vacuum vessel instead of a toroidal chamber, the configuration is a spheromak. The spheromak has the potential of a magnetic toroidal confinement system without the inconvenience (and cost) of the center stack of a tokamak. Because magnetic helicity decays due to dissipative processes, a fundamental issue in spheromak research is its sustainment. To that end, short pulses of magnetic helicity were injected into the Sustained Spheromak Physics Experiment (SSPX) at the LLNL and were successfully retained by the spheromak. Concurrently, better pulse-shaping through computational modeling has enabled the quality of energy confinement in the plasma to be improved by nearly an order of magnitude, leading to a dramatic increase in the plasma temperature from 2.5 million degrees to over 4 million degrees Celsius, the highest temperature ever achieved in a spheromak with helicity injection.
- The actual self-organization of the magnetic flux and electrical currents to create magnetic helicity to form a spheromak involves reconnection of magnetic field lines, a phenomenon of a high degree of physical complexity. The complex sequence of events was captured experimentally for the first time in a small university-scale experiment at the California Institute of Technology. The merging of eight plasma-filled magnetic flux and current tubes were observed to form a plasma jet which undergoes kink instability leading to magnetic reconnection and helicity creation and eventually the formation of a spheromak.
- One method of heating plasma consists of compressing magnetized plasma by an imploding material wall. This involves imploding a hollow cylindrical metallic shell by passing a large electrical current (about 10 megamperes) through it between two planar electrodes. Since there must be a hole in at

least one of the electrodes in order to insert magnetized plasma into the hollow shell, the body of the cylindrical shell must be imploded while the ends of the shell are sufficiently constrained that they do not slide into the holes in the electrodes. In the past year, aluminum shells (containing no plasma), were successfully imploded, achieving a radial convergence ratio of about 17 to 1. Good electrical contact was maintained between the shell and the electrodes throughout the implosion. The experiment is now poised to compress a magnetized plasma to temperatures potentially in excess of 10 million degrees Celsius.

- A configuration in which a plasma torus with a predominantly toroidal current is contained within a solenoidal magnetic field is called a Field Reversed Configuration (FRC). The ratio of the plasma thermal pressure to the magnetic field energy density, called beta, is a measure of the efficiency at which the magnetic configuration is used to confine the plasma (a high value of plasma beta is an attractive feature of a confinement configuration). An FRC has a plasma beta close to unity, which is among the highest of all magnetic confinement configurations. High densities will further enhance the attractiveness of an FRC. In the FRX-L experiment at the Los Alamos National Laboratory, an FRC with a density of 4×10^{16} ions per cm^3, the highest density achieved in a compact FRC with a temperature exceeding about 4 million degrees Celsius, has been created in the past year. While FRCs have reached this plasma density previously, they were much larger in size. This class of FRCs is suitable for compressional heating studies of magnetized plasma.
- A confinement configuration being investigated consists of a levitated magnetic dipole, an experiment in progress at MIT in collaboration with Columbia University. The configuration is inspired by nature's way of confining plasma in planetary magnetospheres. After several years of development, the experiment is now operational. Results include (1) record levels of diamagnetic flux exclusion that indicate high plasma pressure, (2) clear indications of a relationship between power deposition and pressure profile, and (3) improved time response measurements of x-ray emission showing the effects of magnetohydrodynamic activity at pressure limits.

High Energy Density Physics

- In heavy ion beam research, the most significant challenge in the near term is developing techniques for the compression of the beam to achieve ion beams of extremely high intensity, and exploring the physics limits of the compression. In the past year, compression of the ion beams with an intensity multiplication of 50 times has been demonstrated with a new technique of compressing the beam longitudinally in a neutralizing plasma, by chirping the beam so that the tail of the beam is accelerated and the head of the beam is decelerated. As the beam drifts in the neutralizing plasma, the beam compresses itself longitudinally.
- In fast ignition, the most critical issue at present is unraveling the physics of the propagation of relativistic electron jets produced by a petawatt laser in a dense plasma. In the past year, experiments have revealed for the first time the spread in the trajectories of the electron jets in a dense plasma of solid density and its correlation to the effects of the electrical resistivity of the cold dense plasma.

Detailed Justification

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
Tokamak Experimental Research	**47,052**	**46,517**	**45,838**

The tokamak magnetic confinement concept has thus far been the most effective approach for confining plasmas with stellar temperatures within a laboratory environment. Many of the important issues in fusion science are being studied in coordinated programs on the two major U.S. tokamak facilities, DIII-D at General Atomics and Alcator C-Mod at the Massachusetts Institute of Technology. Both DIII-D and Alcator C-Mod are operated as national collaborative science facilities with research programs established through public research forums, program advisory committee recommendations, and peer review. There is also a very active program of collaboration with comparable facilities abroad aimed at establishing an international database of Tokamak experimental results. In association with the International Tokamak Physics Activity (ITPA), both DIII-D and Alcator C-Mod continue to increase their efforts on joint experiments with other major facilities in Europe and Japan in support of ITER-relevant physics issues.

U.S. tokamak research, including experiments on the DIII-D and C-Mod tokamaks in the U.S. and collaborations on the new and operating international tokamaks, will expand the effort in support of burning plasmas and ITER. DIII-D will have the opportunity to further exploit new experimental flexibilities acquired through hardware improvements in FY 2005 and FY 2006. C-Mod will pursue a program with high power densities approaching those of ITER while contributing to answering ITER-relevant questions. In international collaborations, the scope of joint ITPA experiments will be enhanced to accommodate new experiments in support of ITER. These activities will enhance the understanding of key ITER physics issues, including plasma stability control and disruption mitigation, control of intermittent edge plasma instabilities (ELMs) through manipulation of magnetic flux at the plasma edge, energy and particle transport, and development of improved plasma discharges for burning plasma studies on ITER.

There will also be some preparatory work for enhanced collaboration on new superconducting tokamaks in Korea and China to investigate steady state physics and technology issues.

Both DIII-D and Alcator C-Mod will focus on using their flexible plasma shaping and dynamic control capabilities to attain good confinement and stability. They do this by controlling the distribution of current in the plasma with electromagnetic wave current drive. The interface between the plasma edge and the material walls of the confinement vessel is managed by means of a “magnetic divertor.” Achieving high performance regimes for longer pulse duration, approaching the steady state, will require simultaneous advances in all of the scientific issues listed above.

▪ **DIII-D Research**	**24,042**	**24,412**	**24,300**

The DIII-D tokamak is the largest magnetic fusion facility in the United States. DIII-D provides for considerable experimental flexibility and has extensive diagnostic instrumentation to measure the properties of high temperature plasma. It also has unique capabilities to shape the plasma and provide feedback control of error fields that, in turn, affect particle transport in the plasma and the stability of the plasma. DIII-D has been a major contributor to the world fusion program over the past decade in the areas of plasma turbulence, energy and particle transport, electron-cyclotron plasma heating and current drive, plasma stability, and boundary layer physics using a “magnetic divertor" to control the magnetic field configuration at the edge of the plasma. The divertor is produced by magnet coils that bend the magnetic field at the edge of the tokamak out into a region where plasma particles following the field are neutralized and pumped away.

The DIII-D experimental program contributes to all four key Magnetic Fusion Energy (MFE) fusion topical science areas of energy transport, stability, plasma-wave interactions, and boundary physics, and to various thrust areas that integrate across topical areas to support the goal of achieving burning plasma. In the past three years, the investigation of ITER relevant discharge scenarios has gained emphasis in the DIII-D experimental program. The DIII-D experimental flexibility is being greatly increased by hardware improvements in FY 2005 and FY 2006. These include acquisition of three long pulse (10 seconds) gyrotrons for high power heating and current drive, addition of particle pumping in the lower divertor, rotation of one of the neutral beam lines in order to control plasma rotation, and improvements to the cooling tower and bus bars in order for high performance plasmas to be operated for long pulses.

In FY 2007, the DIII-D program will aggressively exploit the new experimental flexibility acquired in FY 2005 and FY 2006. With an operating time of 12 weeks, a five week increase over FY 2006, the DIII-D program will be able to accommodate a larger number of ITPA joint experiments with the international community. The DIII-D experiments will emphasize support of burning plasmas and ITER physics, in addition to exploring the basic physics issues in energy transport, plasma stability, and wave particle interactions which help grow the field of plasma physics and its relationship to other fields of science such as astrophysics. These experiments will enhance the understanding of energy and particle transport, the role of plasma rotation and its impact on plasma transport and stability, and prepare the U.S. fusion community to better exploit burning plasma physics studies on ITER.

	FY 2005	FY 2006	FY 2007
▪ **Alcator C-Mod Research**	**8,636**	**8,510**	**8,890**

Alcator C-Mod is a unique, compact tokamak facility that uses intense magnetic fields to confine high-temperature, high-density plasmas in a small volume. It is the only tokamak in the world operating at and above the ITER design magnetic field and plasma densities, and it produces the highest pressure tokamak plasma in the world, approaching pressures expected in ITER. It is also unique in the use of metal (molybdenum) walls to accommodate high power densities.

By virtue of these characteristics, Alcator C-Mod is particularly well suited to operate in plasma regimes that are relevant to ITER, as well as to compact, high field, high density burning plasma physics tokamaks. Burning plasmas can be achieved for short pulses in a low cost tokamak by trading high magnetic field for large size (and cost). Alcator C-Mod has made significant contributions to the world fusion program in the areas of plasma heating, stability, and confinement in high field tokamaks; these are important integrating issues related to ignition and burning of fusion plasma.

In FY 2007, C-Mod will conduct an aggressive research program with studies and comparisons of high-Z vs. low-Z first walls and performance of the tungsten divertor module under ITER-like high power density. The physics of RF wave synergies will be studied in cases showing promise for efficient current drive. ITER hybrid scenarios will be examined under ITER-relevant ion/electron temperature equilibrated conditions. ITER quasi-steady-state operating scenarios using Lower

	(dollars in thousands)	
FY 2005	FY 2006	FY 2007

Hybrid microwaves and radio frequency waves will be developed. Strong plasma rotation in the absence of direct torque application, also very important to ITER stability, will be explored.

Compact, high field tokamak regimes and operating scenarios required for ignition in compact devices will be further explored. Resources will be increasingly focused on ITER-relevant topics such as understanding the physics of the plasma edge in the presence of large heat flows, measuring the effects of and mitigating disruptions in the plasma, controlling the current density profile for better stability, non-inductively driving a large part of the plasma current and helping build cross-machine data bases using dimensionless parameter techniques.

Research will also continue to examine the physics of the operational density limit, power, and particle exhaust from the plasma, mechanisms of self-generation of plasma flows, and the characteristics of the operating modes achieved when currents are driven by electromagnetic waves. It will also focus on studying transport in the plasma edge at high densities and in relation to the plasma density limit. The new diagnostic neutral beam will further improve visualization of turbulence in the edge and core of high density plasmas, and new diagnostics will shed light on the physics of temperature and density profiles, whose features are now thought to be the key to predicting tokamak behavior.

- **International**.. **5,116** **4,826** **5,064**

  In addition to their work on domestic experiments, scientists from the United States participate in leading edge scientific experiments on fusion facilities abroad, and conduct comparative studies to enhance understanding of underlying physics. The Fusion Energy Sciences program has a long-standing policy of seeking collaboration internationally in the pursuit of timely scientific issues. This allows U.S. scientists to have access to the unique capabilities of facilities that exist abroad. These include the world's highest performance tokamaks (JET in England and JT-60 in Japan), a stellarator (the Large Helical Device) in Japan, a superconducting tokamak (Tore Supra) in France, and several smaller devices. In addition, the U.S. is collaborating with South Korea and China on the design of plasma diagnostics, control systems, and preparations for physics operations on the new long-pulse, superconducting, advanced tokamaks, KSTAR and EAST, respectively. These collaborations provide a valuable link with the 80% of the world's fusion research that is supported and conducted outside the United States.

  The increase from the FY 2006 level will allow continued U.S. participation in high priority research activities in support of ITER. These include joint ITPA experiments on the large tokamaks JET and JT-60U in the EU and Japan, respectively, some joint experiments on medium sized tokamaks such as TEXTOR and ASDEX-UG in the EU, and other joint ITER-relevant experiments in the areas of plasma wall interactions, plasma instabilities, and first wall design considerations for ITER. In addition, the level of U.S. participation in steady-state physics and technology issues in Tore Supra in the EU, KSTAR in Korea, and EAST in China will be maintained. These activities will prepare U.S. scientists for participation in burning plasma experiments on ITER.

- **Diagnostics** **3,894** **3,763** **3,854**

  Support of the development of unique measurement capabilities (diagnostic instruments) that provide an understanding of the plasma behavior in fusion research devices will continue. The development of new diagnostics is needed to obtain data on current experiments such as DIII-D in

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007

the United States and JET in Europe (through collaborative programs) in order to investigate their applicability to ITER. Among the key areas of diagnostic research are the development of: (1) techniques to measure the loss of energy/heat and particles from the core of magnetically confined plasmas, including techniques aimed at understanding how barriers to energy/heat loss can be formed in plasmas; (2) methods to measure the production, movement, and loss/retention of the particles that are needed to ignite and sustain a burning plasma; and (3) new approaches that are required to measure plasma parameters in alternate magnetic configurations, which add unique constraints due to magnetic field configuration and strength, and limited lines of sight into the plasma. The requested funding level in FY 2007 supports research that will enhance our understanding of critical plasma phenomena and the means of affecting these phenomena to improve energy and particle confinement in tokamaks and innovative confinement machines.

▪ **Other**	**5,364**	**5,006**	**3,730**

Funding for educational activities in FY 2007 will support research at historically black colleges and universities (HBCUs), graduate and postgraduate fellowships in fusion science and technology, summer internships for undergraduates, and outreach efforts related to fusion science and enabling R&D. Funding is reduced in order to support higher priority activities within the program.

Alternative Concept Experimental Research	**59,484**	**60,550**	**56,302**

The properties of a magnetically confined plasma depend on the structure of the confining magnetic field. For example, the structure of the confining magnetic field can affect the upper limit of the plasma pressure. Since fusion energy production increases with the square of the plasma pressure, understanding the cause of the pressure limit and optimizing the confinement configuration to achieve high pressure are important issues for fusion scientists. Thus, a significant amount of research is focused on alternative confinement approaches, aimed at extending fusion science and identifying innovative confinement concepts that could improve the economic and environmental attractiveness of fusion, thereby lowering the overall programmatic risk and cost of the Fusion Energy Sciences program in the long term. The largest element of the alternative concepts program is the NSTX at Princeton Plasma Physics Laboratory that began operating in FY 2000. Like DIII-D and Alcator C-Mod, NSTX is also operated as a national collaborative scientific facility. The Madison Symmetric Torus (MST) is at an intermediate stage of development between a small-scale experiment and a major facility.

▪ **National Spherical Torus Experiment (NSTX) Research**	**15,992**	**15,845**	**16,696**

NSTX and the MAST device in the U.K. are the world's two largest spherical torus confinement experiments. Spherical toruses have a unique, nearly spherical plasma shape that complements the doughnut shaped tokamak and provides a test bed for the theory of toroidal magnetic confinement as the spherical limit is approached. Plasmas in a spherical torus are predicted to be stable even when high ratios of plasma-to-magnetic pressure and large self-driven current fractions exist simultaneously, provided there is a nearby conducting wall bounding the plasma. If these predictions are verified in detail, it would indicate that a spherical torus uses applied magnetic fields more efficiently than most other magnetic confinement systems and could, therefore, be expected to lead to a more cost-effective fusion power system. An associated issue for spherical torus configurations is the challenge of starting and maintaining the plasma current via radio-frequency waves or biased

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007

electrodes. Such current drive techniques are essential to achieving sustained operation of a spherical torus.

The spherical torus plasma, like all high beta plasmas, is characterized by high temperature, fast ions with a large radius of gyration relative to plasma size that could potentially lead to new plasma behaviors of interest. In FY 2007, NSTX research will focus on topics that are important to ITER, as well as to the development of the spherical torus concept. Research on turbulence and transport will emphasize short wavelength turbulence and electron transport. Macroscopic stability studies will concentrate on the use of feedback stabilization and strong shaping to control pressure-limiting modes. Specific experimental campaigns will focus on assessing the onset conditions and impact of an instability called a "tearing mode," characterizing the effectiveness of feedback control of resistive wall modes, and investigating the effect of active feedback control of unstable modes on longer pulse, high performance plasmas. Wave-particle research will contribute to the understanding of fast-ion driven modes, which will be important for ITER. Boundary physics studies will focus on understanding transport barriers and intermittent transport of heat and particles in the plasma edge. Finally, integrated scenario investigations will center on non-inductive current ramp-up and sustainment of high performance plasmas.

▪ **Experimental Plasma Research**	**21,656**	**21,778**	**19,990**

This element undertakes cutting-edge research to explore innovative, improved pathways to plasma confinement to produce practical fusion energy. The emphasis is on developing the fundamental understanding of the plasma science that underpins innovative fusion concepts. This element is a broad-based research activity, conducted in 25 experiments and theory-support projects, involving 30 principal investigators and co-principal investigators in 11 universities, 4 national laboratories and industry. Because of the small size of the experiments and the use of sophisticated technologies, the research provides excellent educational opportunities for students and post-docs, and helps to develop the next generation of fusion scientists. In order to foster a vigorous breeding ground for research, each project is competitively peer reviewed on a regular basis of three to five years, so that a portfolio of projects with high performance is maintained. This is an area of magnetic fusion research where the United States has a commanding lead over the rest of the world. Because of its innovative and cutting-edge nature, this research element incubates and engenders the future of our quest for fusion energy. It has strong appeal to young and talented undergraduates who desire to make a major impact on the quest for fusion energy, attracting them to graduate studies in fusion energy sciences.

Current projects in this program element include fundamental investigations into concepts such as, advanced stellarator configurations, tokamak innovations, the levitated dipole, field-reversed configurations (FRC), spheromaks, and magnetized target fusion.

In FY 2007, funding is reduced by $1,788,000 to meet higher priority needs of the program which will lead to a reduction of all the projects in this area.

Examples of the research being pursued in this element includes:

- Complementing the advanced tokamak research on DIII-D and Alcator C-Mod is the exploratory work on the High Beta tokamak (HBT) at Columbia University. This small tokamak's goal is to demonstrate the feasibility of stabilizing instabilities in high pressure tokamak plasmas using a combination of a close-fitting conducting wall and active feedback. This work is closely coordinated with the DIII-D program, and promising results have already been achieved on DIII-D.

- Research in advanced stellarators, such as the Helically Symmetric Experiment (HSX) at the University of Wisconsin explores the symmetry characteristics that make quasisymmetrical stellarators different from all other toroidal confinement systems. HSX is studying transport attributable to fluctuations, and exploring stability and beta limits. Such studies will be applicable to the NCSX, a proof of principle experiment currently under fabrication.
- Field-reversed configurations and spheromaks are toroidal plasma confinement configurations like the tokamak but without the need of a center pole, making them candidates for highly compact fusion reactors. In field-reversed configurations (FRC), current research is exploring an avenue to form and sustain the FRC using a rotating magnetic field (RMF).
- Spheromaks are plasmas with self-organized internal plasma currents which generate magnetic fields that confine the plasma, eliminating the need for the toroidal magnets and ohmic heating transformer which necessarily thread the vacuum vessel in the tokamak. Current research aims at generating, amplifying and sustaining these internal plasma currents (related to its magnetic helicity) by the use of coaxial plasma guns (known as coaxial helicity injection).
- Research in magnetized target fusion aims at combining the favorable features of both magnetic and inertial confinement, without using the expensive magnets of conventional magnetic fusion, while using drivers that are much less expensive than those necessary for conventional Inertial Fusion Energy research. This project is poised to produce a high-density, magnetized plasma to be imploded by a deformable liner to achieve temperatures over 10,000,000 degrees Celsius in FY 2007 and densities above 1,018 ions per cm^3.
- The Levitated Dipole Experiment (LDX) explores plasma confinement in a novel magnetic dipole configuration similar to the magnetic field that confines the plasma in the earth’s magnetosphere.

- **High Energy Density Physics** **14,640** **15,856** **11,949**

The combination of high plasma density and high plasma temperature needed for inertial fusion produces plasmas with very high energy densities. Energy densities in excess of 100 billion joules per cubic meter are of interest to inertial fusion, and their study is an emerging field of physics called High Energy Density Physics (HEDP), which cuts across several fields of contemporary physics including astrophysics. Plasmas at these energy densities are characterized by having pressures exceeding a million atmospheres. In the laboratory, these high energy density conditions are produced typically through the use of high power lasers, ion beams, or convergence of high density plasma jets.

In FY 2007, $3,762,000 is requested to sustain research in Fast Ignition and high Mach number plasma jets. Both Fast Ignition and dense plasma jets are exciting new fields of HEDP that are attracting worldwide scientific attention. This is evidenced by the numerous papers on these two subjects at the recent 2005 American Physical Society Division of Plasma Physics meeting. The relativistic physics of thermal transport in Fast Ignition is being explored. Modest efforts to explore

	(dollars in thousands)	
FY 2005	FY 2006	FY 2007

experimental techniques to produce high Mach number, high density plasma jets in the laboratory, and study their application to HEDP are being pursued. This research follows the recommendations of the OSTP National Task Force on High Energy Density Physics (July 2004) and two NRC reports, entitled "Frontiers in High Energy Density Physics" and "Connecting Quarks to the Cosmos." The research leverages and collaborates with NNSA's program efforts in non-defense areas of high energy density physics and makes use of NNSA's facilities. Collaboration will be extended to other Federal agencies as well, wherever appropriate, through an interagency process that is in progress.

In FY 2007, $8,187,000 is requested to continue research in heavy ion beam science. Non-defense research at the Atlas pulsed power facility will be discontinued.

	FY 2005	FY 2006	FY 2007
▪ **Madison Symmetrical Torus (MST)**	**6,423**	**6,320**	**6,970**

The goal of the MST experiment is to obtain a fundamental understanding of the physics of reversed field pinches (RFP), particularly magnetic fluctuations and their macroscopic consequences, and to use this understanding to develop the RFP fusion configuration. The plasma dynamics that limit the energy confinement, the ratio of plasma pressure to magnetic field pressure, and the sustainment of the plasma current in RFP are being investigated in the MST experiment. Magnetic fluctuations and its macroscopic consequences including transport, dynamo, stochasticity, ion heating, magnetic reconnection, and momentum transport, have applications across a wide spectrum of fusion science and astrophysics, to which the MST experiment thus contributes. MST is one of the four leading experiments in RFP research in the world, and is unique in that it pioneered the reduction of magnetic fluctuations by current density profile control. This approach has led to a ten-fold increase in energy confinement. Continual developments in the experimental facility and the theory build-up in the last few years will enable productive studies in FY 2006 of one or more of the following techniques as mechanisms for driving and controlling the current profile, as well as for heating and fueling the plasma: inductive electric field programming, electromagnetic waves, oscillating field helicity injection, neutral beams, and pellet injection. With potentially improved plasmas in MST obtained with one or more of the most highly developed of these techniques, separately or in combination, the major experimental undertaking in FY 2007 will be to continue the measurement and modeling of improved confinement and sustainment in MST with greatly reduced dynamo activity initiated in FY 2006.

	FY 2005	FY 2006	FY 2007
▪ **National Compact Stellarator Experiment (NCSX) Research**	**773**	**751**	**697**

This funding supports the research portion of the program to be executed with the NCSX Experiment at PPPL, which involves participation and a leadership role within the National Compact Stellarator Program (NCSP). PPPL, ORNL, and LLNL are the participants in NCSX research that keeps abreast of physics developments in domestic and international stellarator research, factoring those developments into the planning of the NCSX experimental program, as well as preparation of long-lead-time physics analysis tools for NCSX application. These tools have a dual use: setting physics requirements for hardware upgrades and interpreting data from future NCSX experiments. Some long-lead hardware upgrades will be designed, such as plasma control, first wall, and diagnostic systems. The NCSX team will (1) adapt analytical tools to establish requirements and physics designs for magnetic diagnostic upgrades, (2) prepare for experiments to elucidate key configuration characteristics by e-beam mapping, including the study of effects of field perturbations such as coil leads and feeds, and fabrication errors, and (3) adapt and apply analytical tools and incorporate experimental results from foreign stellarator divertor experiments to develop design requirements for plasma-facing components.

Theory	**25,749**	**24,928**	**23,900**

The theory and modeling program provides the conceptual underpinning for the fusion sciences program. Theory efforts meet the challenge of describing complex non-linear plasma systems at the most fundamental level. These descriptions range from analytic theory to highly sophisticated computer simulation codes, both of which are used to analyze data from current experiments, guide future experiments, design future experimental facilities, and assess projections of their performance. Analytic theory and computer codes represent a growing knowledge base that, in the end, is expected to lead to a predictive understanding of how fusion plasmas can be sustained and controlled.

The theory and modeling program is a broad-based program with researchers located at five national laboratories, over 30 universities, and three private companies. Institutional diversity is a strength of the program, since theorists at different types of institutions play different roles in the program. Theorists in larger groups, that are mainly at national laboratories and industry, generally support major experiments, work on large problems requiring a team effort, or tackle complex issues requiring multidisciplinary teams. Those at universities generally support smaller, innovative experiments or work on more fundamental problems in plasma physics.

The theory program is composed of two elements—tokamak theory and alternate concept theory. The main thrust of the work in tokamak theory is aimed at developing a predictive understanding of advanced tokamak operating modes and burning plasmas, both of which are important to ITER. These tools are also being extended to innovative or alternate confinement geometries. In alternate concept theory, the emphasis is on understanding the fundamental processes determining equilibrium, stability, and confinement in each concept.

SciDAC	**4,033**	**4,222**	**6,970**

An important element of the Office of Science's Scientific Discovery through Advanced Computing (SciDAC) program is the FES-funded portion. Major scientific challenges exist in many areas of plasma and fusion science that can best be addressed through advances in scientific supercomputing. Current projects are focused on the topics of microturbulence simulation, extended magnetohydrodynamics modeling, and simulation of electromagnetic wave-plasma interaction, which will provide a fundamental understanding of plasma science issues important to a burning plasma, and lay the groundwork for the fusion simulation project. The new projects will continue to involve collaborations among physicists, applied mathematicians and computer scientists, advancing both the fusion energy science and computational modeling fields. In FY 2006, the FES program and the Advanced Scientific Computing Research program initiated two fusion simulation prototype centers as part of the Fusion Simulation Project, following a competitive peer review process. One center is focused on integrated simulation of the edge plasma in a tokamak, and the other is concerned with the control of large-scale instabilities with electromagnetic waves.

In FY 2007, these prototype centers, along with the three continuing SciDAC projects, will emphasize development of new computing techniques and will make use of rapid developments in computer hardware to attack complex problems involving a large range of scales in time and space, including

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007

plasma turbulence and transport, large scale instabilities and stability limits, boundary layer/edge plasma physics, and wave-plasma interaction. These problems were beyond the capability of the fastest computers in the past, but it is now becoming possible to make progress on problems that once seemed intractable. The objective of the FES SciDAC program is to promote the use of modern computer languages and advanced computing techniques to bring about a qualitative improvement in the development of models of plasma behavior. This will ensure that advanced modeling tools are available to support the preparations for a burning plasma experiment and fruitful collaboration on major international facilities. In addition, two additional SciDAC projects will be competitively selected. One project will focus on developing the software tools for remote collaboration on foreign fusion facilities, and the other will focus on developing a framework for integrated simulations of fusion plasma systems.

General Plasma Science	**12,176**	**13,760**	**13,941**

The general plasma science program is directed toward basic plasma science and engineering research. This research strengthens the fundamental underpinnings of the discipline of plasma physics that make contributions in many basic and applied physics areas. Principal investigators at universities, laboratories and private industry carry out the research. A critically important element is the education of plasma physicists. Continuing elements of this program are the NSF/DOE Partnership in Basic Plasma Science and Engineering and the Plasma Physics Junior Faculty Development Program. The program will continue to fund proposals that have been peer reviewed. Funding will also continue for the Fusion Science Center program that was started in FY 2004. The Department is spending approximately $2,390,000 on the Fusion Science Center program each year in FY 2005 and FY 2006. These Centers perform fusion plasma science research in areas of such wide scope and complexity that it would not be feasible for individual investigators or small groups to make progress, and they strengthen the connection between the fusion research community and the broader scientific community. Basic plasma physics user facilities will be supported at both universities and laboratories, sharing costs with NSF where appropriate. Atomic and molecular data for fusion will continue to be generated and distributed through openly available databases. The FES program will continue to share the cost of funding the multi-institutional plasma physics frontier science center funded by NSF starting in FY 2003.

SBIR/STTR	**—**	**6,945**	**7,262**

In FY 2005, $6,211,000 and $745,000 was transferred to the Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) programs, respectively. The FY 2006 and FY 2007 amounts are the estimated requirements for the continuation of these programs.

Total, Science	**148,494**	**156,922**	**154,213**

Explanation of Funding Changes

	FY 2007 vs. FY 2006 ($000)
Tokamak Experimental Research	
▪ **DIII-D Research** The decrease will reduce the research effort on the optimization of tearing mode stabilization and the exploration of the ultimate stability limits of high triangularity double-null plasmas.	-112
▪ **Alcator C-Mod Research** The increase will fund initial demonstration of radio-frequency driven current profile control while continuing to conduct other collaborative experiments of strong relevance to ITER.	+380
▪ **International** The increase will maintain and enhance the collaborative effort on international tokamaks, allowing U.S. scientists to participate in ongoing tokamak experiments in the EU and Japan, and to participate in the new superconducting tokamaks in Korea and China.	+238
▪ **Diagnostics** The increase will maintain the level of effort for developing new base-program and ITER-relevant diagnostics.	+91
▪ **Other** The decrease will reduce support for education and HBCU programs due to the support needed for the other priority activities of the program.	-1,276
Total, Tokamak Experimental Research	**-679**
Alternate Concept Experimental Research	
▪ **National Spherical Torus Experiment (NSTX) Research** The increase will maintain the NSTX research team at current staffing levels and cover increased travel costs for collaborators.	+851
▪ **Experimental Plasma Research** The decrease will reduce research grants to universities and national laboratories for individual researchers by 8% in this program	-1,788
▪ **High Energy Density Physics** Research in Fast Ignition and high Mach number plasma jets will be reduced by $1,779,000, curtailing U.S. participation in Japan's FIREX-1 experiment, eliminating experiments at the OMEGA facility, especially experiments involving cryogenic targets, reducing development of computational capabilities for Fast Ignition and plasma jets, and eliminating investigations of magnetized	

	FY 2007 vs. FY 2006 ($000)
high energy density physics. Diagnostics development on the High Current Experiment for ion beams will be reduced by $1,138,000. Non-defense research at the ATLAS pulsed power facility in Nevada, which was funded by Congressional direction in FY 2006 at $990,000, will not be continued.	-3,907
▪ **Madison Symmetric Torus (MST)**	
The increase will allow the completion of the programmable power supply required for current profile control.	+650
▪ **National Compact Stellarator Experiment (NCSX) Research**	
The decrease will slightly reduce efforts on diagnostic upgrades for future NCSX experiments.	-54
Total, Alternative Concept Experimental Research	**-4,248**
Theory	
Funding for Theory is decreased to support higher priority activities. It will result in the termination of three to four university theory programs and their associated academic and research faculty. It will also result in the loss of up to eight graduate students and four postdoctoral fellows, and the loss of two research scientists from theory programs at national laboratories.	-1,028
SciDAC	
The increase will permit the initiation of two additional SciDAC projects, an integrated simulation development center, and a remote collaboration tool development project.	+2,748
General Plasma Science	
The increase will be used to support high-quality grants funded under the NSF/DOE Partnership in Basic Plasma Science and Engineering.	+181
SBIR/STTR	
Support for SBIR/STTR is provided at the mandated level.	+317
Total Funding Change, Science	**-2,709**

Facility Operations

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
Facility Operations			
DIII-D	31,709	30,280	32,362
Alcator C-Mod	13,402	13,207	13,941
NSTX	18,495	18,140	18,422
NCSX	17,500	17,019	15,900
GPP/GPE/Other	3,176	3,189	3,930
ITER Preparations	5,451	5,835	—
U.S. Contributions to ITER (MIE TEC)	—	15,866	37,000
Total, Facility Operations	89,733	103,536	121,555

Description

The mission of the Facility Operations subprogram is to manage the operation of the major fusion research facilities and the fabrication of new projects to the highest standards of overall performance, using merit evaluation and independent peer review. The facilities will be operated in a safe and environmentally sound manner, with high efficiency relative to the planned number of weeks of operation, with maximum quantity and quality of data collection relative to the installed diagnostic capability, and in a manner responsive to the needs of the scientific collaborators. In addition, fabrication of new projects and upgrades of major fusion facilities will be accomplished in accordance with the highest standards and with minimum deviation from approved cost and schedule baselines.

Benefits

The Facility Operations subprogram operates the major facilities needed to carry out the scientific research program in a safe and reliable manner. This subprogram ensures that the facilities meet their annual targets for operating weeks and that they have state of the art, flexible systems for heating, fueling, and plasma control required to optimize plasma performance for the experimental programs. Further, this subprogram fabricates and installs the diagnostics that maximize the scientific productivity of the experiments. Finally, this subprogram provides for the fabrication of newer facilities such as NCSX, and for participation in the international collaboration on ITER through the U.S. Contributions to ITER MIE project. The ITER MIE TEC funds are budgeted in this subprogram, while the OPC funds are budgeted in the Enabling R&D subprogram.

Supporting Information

This activity provides for the operation, maintenance and enhancement of major fusion research facilities; namely, DIII-D at General Atomics, Alcator C-Mod at MIT, and NSTX at PPPL. These collaborative facilities enable U.S. scientists from universities, laboratories, and industry, as well as visiting foreign scientists, to conduct world-class research funded in the Science and Enabling R&D subprograms. The facilities consist of magnetic plasma confinement devices, plasma heating and current drive systems, diagnostics and instrumentation, experimental areas, computing and computer networking facilities, and other auxiliary systems. The Facility Operations subprogram provides funds for operating and maintenance personnel, electric power, expendable supplies, replacement parts, system modifications and facility enhancements.

Funding is provided for the continuation of the National Compact Stellarator Experiment (NCSX) MIE project at PPPL. In FY 2007, the project will be in its fifth year; PPPL will continue with the fabrication of the device with the focus being on winding the modular coils and assembling the vacuum vessel.

The FY 2007 request provides for the second year of funding for the U.S. Contributions to ITER MIE project. The FY 2007 Total Estimated Costs (TEC) funding of $37,000,000 in the Facilities Operations subprogram provides for direct costs for the MIE including U.S. hardware contributions, U.S. personnel assigned to the international ITER Organization, and cash for common needs such as infrastructure, hardware assembly, and installation of ITER components. The funding cap of $1,122,000,000 is maintained. However, the profile shows a more modest first two years than was contained in the FY 2006 President's Budget. The MIE project is being managed by the U.S. ITER Project Office in accordance with DOE Order 413.3, Program and Project Management for the Acquisition of Capital Assets. There is a necessary shift indicated in the FY 2007 TEC and OPC categories to accommodate domestic and international project priorities under the revised funding profile. The OPC funding, in the Enabling R&D subprogram, includes R&D and design tasks in support of the procurements for the U.S. Contributions to ITER

Funding is also included in this subprogram for general plant projects (GPP) and general purpose equipment (GPE) at PPPL. The GPP and GPE funding supports essential facility renovations, and other necessary capital alterations and additions, to buildings and utility systems. Funding is also provided for the fourth year of a five year effort to support the move of ORNL fusion personnel and facilities to a new location at ORNL.

FY 2005 Facility Operations Accomplishments

In FY 2005, funding was provided to operate facilities in support of fusion research experiments and to upgrade facilities to enable further research in fusion and plasma science. Examples of accomplishments in this area include:

- GA initiated hardware improvements, including the rotation of a beam line for investigation of the role of plasma rotation on transport, installation of particle pumping in the lower divertor for effective use of the double-null configuration in DIII-D, and acquisition of three long pulse (10 second) gyrotrons for high power current drive and plasma control. Experimental operations totaling 15.6 weeks were achieved, in excess of the planned 14 weeks.
- PPPL NCSX placed orders for both the 18 modular coil winding forms (MCWFs) and vacuum vessel sectors in early FY 2005. The MCWFs are steel structures that support the modular coil windings and locate them to high accuracy. The vacuum vessel is a highly shaped structure with stringent requirements on vacuum quality and magnetic permeability. Fabrication of the MCWFs and vacuum vessel segments was initiated in FY 2005, and winding of the first MCWF is scheduled in FY 2006.
- The plasma control system for NSTX was upgraded to achieve approximately 1 millisecond response times. This faster control system, combined with the use of the real-time equilibrium fitting routine developed by GA, permits precise control of the plasma shape, enabling the achievement of higher elongation and triangularity.
- In FY 2005, installation of a new diagnostic neutral beam was completed on Alcator C-Mod. The new beam is expected to enhance performance of the many diagnostic systems it supports. C-Mod's

new lower hybrid radio frequency antenna system, which is predicted to have high plasma current drive efficiency, has also been installed. The results from experiments conducted with this antenna will help determine if such a system should be included in ITER. In addition, C-Mod set a new world record in volume-averaged tokamak plasma pressure of 1.8 atmospheres. Experimental operations totaling 18.4 weeks were achieved, in excess of the planned 17 weeks.

The table and chart below summarize the recent and longer-term history of operation of the major fusion facilities.

Weeks of Fusion Facility Operation

	(weeks of operations)		
	FY 2005 Results	FY 2006 Target	FY 2007 Target
DIII-D	15.6	7	12
Alcator C-Mod	18.4	14	15
NSTX	17.9	11	12
Total	51.9	32	39

Detailed Justification

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
DIII-D	**31,709**	**30,280**	**32,362**

Provide support for operation, maintenance, and improvement of the DIII-D facility and its auxiliary systems. In FY 2007, these funds support 12 weeks of single shift plasma operation during which time essential scientific research will be performed as described in the science subprogram. These funds also provide for beginning phased upgrading of the facility power infrastructure to support maximum utilization of the auxiliary heating systems that were improved in FY 2005 and FY 2006.

Alcator C-Mod	**13,402**	**13,207**	**13,941**

Support is provided for operation, maintenance, minor upgrades, and improvement of the Alcator C-Mod facility and its auxiliary systems, such as an advanced divertor module, a toroidal phase contrast imaging system, and a laser-induced fluorescence diagnostic for edge fluctuation mapping. In FY 2007, there is funding for 15 weeks of operation and a few minor facility upgrades that will enable additional ITER-relevant experiments in the future.

National Spherical Torus Experiment (NSTX)	**18,495**	**18,140**	**18,422**

Support is provided for operation, maintenance and minor upgrades, such as an interim poloidal charge exchange recombination spectroscopy system, a fast IR camera, divertor diagnostics, and preparation for next-step fluctuation diagnostics. In FY 2007, there is funding for 12 weeks of operation and a few minor facility upgrades that will enable long pulse, high beta experiments in the future.

National Compact Stellarator Experiment (NCSX)	**17,500**	**17,019**	**15,900**

Funding is requested in FY 2007 for the continuation of the NCSX Major Item of Equipment, which was initiated in FY 2003 and consists of the design and fabrication of a compact stellarator proof-of-

	FY 2005	FY 2006	FY 2007

principle class experiment. These funds will allow for the continuation of procurement of major items and fabrication of the device. This fusion confinement concept has the potential to be operated without plasma disruptions, leading to power plant designs that are simpler and more reliable than those based on the current lead concept, the tokamak. The NCSX design will allow experiments that compare confinement and stability, in tokamak and stellarator configurations. The new cost and schedule performance baseline, developed to be consistent with the FY 2006 budget request and approved in July 2005, increases the TEC of NCSX to $92,401,000, with completion in July 2009.

(dollars in thousands)	FY 2005	FY 2006	FY 2007
General Plant Projects (GPP)/ General Purpose Equipment (GPE)/Other	**3,176**	**3,189**	**3,930**

These funds provide primarily for general infrastructure repairs and upgrades for the PPPL site based upon quantitative analysis of safety requirements, equipment reliability, and research needs. Funds also provide for the continuing move of ORNL fusion facilities to a new location at ORNL.

ITER Preparations	**5,451**	**5,835**	**—**

Preparations funding for ITER ends in FY 2006 as the U.S. Contributions to ITER MIE begins. Funding was provided to continue the ITER transitional activities such as safety, licensing, project management, preparation of specifications and system integration. U.S. personnel are participating in these activities in preparation for U.S. participation in the international ITER Project. Discussions are proceeding on whether these costs should be accounted for within the ITER TPC. A determination will be part of the Critical Decision–1 process.

U.S. Contributions to ITER - (MIE TEC)	**—**	**15,866**	**37,000**

The U.S. Contributions to ITER MIE project provides hardware, personnel, and cash to the international ITER Project. Following the ITER site selection decision of Cadarache, France, in June 2005, the United States began negotiating the remaining details of the ITER Agreement with the other ITER parties of the European Union (EU), Japan, the Russian Federation, China, and South Korea, with completion of the Agreement anticipated by early 2006. During these negotiations, ending in December 2005, the text of the draft ITER Agreement and supporting documents were completed, the designation of the Director General Nominee was approved, and India joined the negotiations as a full non-host ITER participant. The U.S. Contributions to ITER MIE project supports the fabrication phase of the international Project; however, the international negotiations and the ITER Agreement will involve all phases of the ITER Program including construction, operation, deactivation and decommissioning. For each of the ITER program phases, the United States is negotiating financial participation at the non-host level. After the ITER Agreement is completed and accepted by the negotiators, then signed by the parties' governments and entered into force, an ITER legal entity will exist. The ITER Organization, being staffed from personnel from all the ITER parties, is responsible for the realization of the ITER facility and program. The personnel, a mix of secondees from organizations within the ITER parties' countries and employees of the ITER Organization, is mobilizing to the Cadarache site.

ITER has been designed to provide major advances in all of the key areas of magnetically confined plasma science. ITER's size and magnetic field will provide for study of plasma stability and transport in regimes unexplored by any existing fusion research facility worldwide. Owing to the intense plasma heating by fusion products, it will also access previously unexplored regimes of energetic particle physics. Because of the very strong heat and particle fluxes emerging from ITER plasmas, it will extend regimes of plasma-boundary interaction well beyond previous experience. The new regimes of plasma physics that can be explored for long duration, and the interactions among the anticipated phenomena, are characterized together as the new regime of “burning plasma physics.”

The ITER design is based on scientific knowledge and extrapolations derived from the operation of the world’s tokamaks over the past decades and on the technical know-how flowing from the fusion technology research and development programs around the world. The ITER design has been internationally validated by wide-ranging physics and engineering work, including detailed physics and computational analyses, specific experiments in existing fusion research facilities and dedicated technology developments and tests performed during from 1992 to the present.

The ITER device is a long pulse tokamak with elongated plasma shape and single null poloidal divertor. The nominal inductive operation produces a Deuterium-Tritium fusion power of 500 MW for a burn duration of 400 to 3000 seconds, with the injection of 50 MW of auxiliary power. This provides a power gain of up to a factor of 10.

Safety and environmental characteristics of ITER reflect a consensus among the parties on safety principles and design criteria for minimizing the consequences of ITER operation on the public, operators and the environment. This consensus is supported by results of analysis on all postulated events and their consequences.

DOE will comply with all U.S. environmental and safety requirements applicable to the ITER work that will be conducted in the U.S. Compliance with the National Environmental Policy Act for the U.S. effort will be consistent with the standard DOE process in support of long-lead procurement for the manufacture of the components.

DOE’s involvement with ITER at the international site will be at the level of approximately 9.1 percent, which is consistent with the other non-host participants. In addition to scientists and engineers assigned to the ITER Organization, the United States expects to provide at least one senior management staff member to the ITER Organization. All U.S. personnel assigned to the project will comply with the environmental and safety requirements of the host country and with the applicable U.S. legal requirements.

As a result of the extensive collaborative efforts during the ITER Engineering Design Activities (EDA) from 1992 to 1998, and its extension from 1999 to 2001, a mature ITER design exists including completed R&D prototypes of critical ITER components.

The MIE funding provides for procurement of long lead hardware, U.S. personnel assigned to the project abroad (the annual average number of engineers and scientists is ~22 FTEs as well as funding for support personnel at the international ITER site for ~34 FTEs), U.S. share of cash for ITER project common needs (ITER Organization infrastructure, hardware assembly and installation, and testing of U.S. supplied hardware), contingency, and operation of the U.S. ITER Project Office. The Project Office is responsible for management of U.S. Contributions to ITER including management, quality assurance, procurement, and technical follow of procurements.

DOE requires the U.S. ITER Project Office to assume a broad leadership role in the integration of ITER-related project activities throughout the U.S. Fusion Program and, as appropriate, internationally. For direct procurements with industry, the Project Office is expected to assemble experts throughout the fusion program for technical follow-up and execution of the procurements. Such experts, and their institutions, would become members of the U.S. ITER Project Office team although not necessarily located at Princeton or Oak Ridge.

Given the significant advances during the international ITER negotiations, it is the objective of the international ITER parties to obtain the negotiators' acceptance of the ITER Agreement by early 2006 indicating the end of the negotiations. The next step will be to obtain governmental signatures on the completed ITER Agreement later in FY 2006, by all ITER parties, thereby leading to a multilateral commitment for ITER. The Agreement finalizes the allocation of equipment to be provided by each ITER Party, including India, and finalizes the concepts for mode of operation among the ITER Parties and central project team during the construction, operation, and decommissioning phases of the ITER program.

The final allocation of equipment or hardware to be supplied by the United States, also called "in-kind" contributions to ITER, is indicated below.

- Niobium Tin (Nb3Sn) Superconducting Strand – Niobium, tin and copper filaments formed into long strands.
- Superconducting Cable – multi-stage cable including strand and insulation.
- Central Solenoid Coil – the U.S. has the lead role for this contribution consisting of six modules plus one spare module; and is responsible for module testing oversight and assembly oversight at the ITER site.
- Blanket Modules – a contribution consisting of 36 (of 360) modules around the tokamak vessel (plus 4 spares), 40 cm thick (including plasma facing components and shield).
- Vacuum Pumping Components – a U.S. contribution consisting of components required to create and maintain the vacuum inside the tokamak vessel.
- Tokamak Exhaust Processing System – a U.S. contribution to include recovery of hydrogen isotopes from impurities such as water and methane, delivery of purified, mixed hydrogen isotopes to the Isotope Separation System, and disposal of non-tritium species.
- Heating and Current-Drive Components for Ion Cyclotron Heating frequencies – the U.S. contribution consists of transmission lines.
- Heating and Current-Drive Components for Electron Cyclotron Heating frequencies – the U.S. contribution consists of transmission lines.
- Fueling Injector – provides for an ITER pellet injector.
- Steady-state Electrical Power System – a U.S. contribution consisting of a steady-state electric power network similar in scale and function to an "auxiliary system" of a large power plant.

(dollars in thousands)		
FY 2005	FY 2006	FY 2007

- Cooling Water System – the ITER tokamak water cooling systems is a U.S. contribution including the primary heat transfer system, the chemical and volume control system, and the draining, refilling and drying system.
- Diagnostics – a U.S. contribution involving 16% of the ITER Diagnostic effort providing six diagnostic systems such as visible and infrared cameras, toroidal interferometer/polarimeter, electron cyclotron emission, divertor interferometer, and residual gas analyzers; five cover plates on the tokamak vessel on which multiple diagnostics from U.S. and other parties are mounted; and integration of diagnostic systems from other ITER parties.

The preliminary schedule and TEC funding profile for the U.S. Contributions to ITER MIE are as follows. The MIE project cost estimate for U.S. Contributions to ITER is preliminary until the baseline scope, cost, and schedule for the MIE project is established. However, the overall TPC for this MIE project will not change with the exception of possible changes from the OMB-inflation rates that are in place at the time that the performance baseline is set, and changes in currency exchange rates affecting about 15% of the TPC funding.

U.S. Contributions to ITER

	Fiscal Quarter				
	Procurements Initiated	Procurements Complete	Personnel Assignments to Foreign Site Start	Personnel Assignments to Foreign Site Complete	Total Estimated Costs ($000)
FY 2006 Budget Request (Preliminary Estimate)	3Q FY 2006	4Q FY 2012	2Q FY 2006	4Q FY 2013	1,038,000
FY 2007 Budget Request (Preliminary Estimate)	4Q FY 2006	4Q FY 2012	2Q FY 2006	FY 2014	1,077,051[a]

[a] The funding profile is a preliminary estimate incorporating the key results of the December 2005 negotiations. In addition, shifts between OPC and TEC funding have been made consistent with the intentions of DOE 413.3 to provide for R&D and design in support of the MIE project. During FY 2006, several U.S. reviews are scheduled to validate the preliminary cost and schedule profile for the U.S. Contributions to ITER MIE project. In addition, international ITER Project activities in FY 2006 will also validate the international cost and schedule which can have an affect on the U.S. Contributions to ITER project. The performance baseline, including the funding profile, will be established at CD-2 planned for September 2007.

Financial Schedule

Total Estimated Cost (TEC)[a]

(budget authority in thousands)

Fiscal Year	MIE TEC[b]
2006	15,866
2007	37,000
2008	149,500
2009	208,500
2010	208,500
2011	180,785
2012	130,000
2013	116,900
2014	30,000
Total	1,077,051

(dollars in thousands)

	FY 2005	FY 2006	FY 2007
Total, Facility Operations	**89,733**	**103,536**	**121,555**

Explanation of Funding Changes

	FY 2007 vs. FY 2006 ($000)
DIII-D	
DIII-D will increase experimental operations to 12 weeks, a five week increase over FY 2006. Power systems infrastructure will begin to be upgraded to support the full capabilities of the auxiliary heating systems that were improved in FY 2005 and FY 2006	+2,082
Alcator C-Mod	
The increase will allow C-Mod to continue ITER-relevant experiments, such as studies in high-Z vs. low-Z wall materials and lower hybrid radio frequency injection, while making important upgrades to its divertor module and diagnostics for use in future advanced tokamak experiments. The increase will also allow C-Mod to conduct 15 weeks of operation, an increase of one week over FY 2006.	+734

[a] The funding profile is a preliminary estimate incorporating the key results of the December 2005 negotiations. In addition, shifts between OPC and TEC funding have been made consistent with the intentions of DOE 413.3 to provide for R&D and design in support of the MIE project. During FY 2006, several U.S. reviews are scheduled to validate the preliminary cost and schedule profile for the U.S. Contributions to ITER MIE project. In addition, international ITER Project activities in FY 2006 will also validate the international cost and schedule which can have an affect on the U.S. Contributions to ITER project. The performance baseline, including the funding profile, will be established at CD-2 planned for September 2007.
[b] Note that the Other Project Costs associated with these MIE TEC funds are budgeted in the Enabling R&D subprogram.

	FY 2007 vs. FY 2006 ($000)
National Spherical Torus Experiment (NSTX)	
The increase will allow NSTX to conduct 12 weeks of operation after carrying out 11 weeks of operation in FY 2006.	+282
National Compact Stellarator Experiment (NCSX)	
The request supports the current approved baseline...	-1,119
GPP/GPE/Other	
This increase will allow continued improvement of the physical infrastructure at PPPL and continue the process of moving fusion facilities from the Y-12 site to the X-10 site at ORNL.	+741
ITER Preparations	
ITER Preparations funding ends in FY 2006.	-5,835
U.S. Contributions to ITER (MIE Total Estimated Cost)	
This increase provides for the second year of funding for the Major Item of Equipment project consistent with the revised preliminary cost and schedule estimate. Funds are provided for major procurements of long-lead materials such as Nb3Sn superconductor and conduits as well as blanket materials. Funds are provided for U.S. scientists assigned to the ITER Organization abroad and associated infrastructure needs. Funds are also provided for design and procurement preparations for all components for which the United States is responsible.	+21,134
Total Funding Change, Facility Operations	**+18,019**

Enabling R&D

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
Enabling R&D			
Engineering Research	21,382	16,694	15,495
Enabling R&D for ITER (Other Project Costs)	—	3,449	23,000
Materials Research	7,338	7,043	4,687
Total, Enabling R&D	28,720	27,186	43,182

Description

The mission of the Enabling R&D subprogram is to develop the cutting edge technologies that enable both U.S. and international fusion research facilities to achieve their goals.

Benefits

The foremost benefit of this subprogram is that it enables the scientific advances in plasma physics accomplished within the Science subprogram. That is, the Enabling R&D subprogram develops, and continually improves, the hardware and systems that are incorporated into existing fusion research facilities, thereby enabling these facilities to achieve higher and higher levels of performance within their inherent capability. In addition, the Enabling R&D subprogram supports the development of new hardware that is incorporated into the design of next generation facilities, thereby increasing confidence that the predicted performance of these new facilities will be achieved. Finally, there is a broader benefit beyond the fusion program in that a number of the technological advances lead directly to "spin offs" in other fields, such as superconductivity, plasma processing and materials enhancements.

Supporting Information

The Engineering Research element addresses the breadth and diversity of domestic interests in enabling R&D for magnetic fusion systems as well as international collaborations that support the mission and objectives of the FES program. The activities in this element focus on critical technology needs for enabling both current and future U.S. plasma experiments to achieve their research goals and full performance potential in a safe manner, with emphasis on plasma heating, fueling, and surface protection technologies. While much of the effort is focused on current devices, a significant and increasing amount of the research is oriented toward the technology needs of future experiments, such as ITER. Enabling R&D efforts provide both evolutionary development advances in present day capabilities that will make it possible to enter new plasma experiment regimes, such as burning plasmas, and nearer-term technology advancements enabling international technology collaborations that allow the U.S. to access plasma experimental conditions not available domestically. A part of this element is oriented toward investigation of scientific issues for innovative technology concepts that could make revolutionary changes in the way that plasma experiments are conducted, such as microwave generators with tunable frequencies and steerable launchers for fine control over plasma heating and current drive. This element includes research on blanket technologies that will be needed to produce and process tritium for self-sufficiency in fuel supply. This element also supports research on safety-related issues that enables both current and future experiments to be conducted in an environmentally sound and safe manner. Another activity is conceptual design of the most scientifically challenging systems for fusion research facilities that may be needed in the future. Also included are analysis and studies of critical scientific and technological issues, the results of which will provide guidance for optimizing future experimental approaches and for understanding the implications of fusion research on applications of fusion.

The Materials Research element focuses on the key science issues of materials for practical and environmentally attractive uses in fusion research and future facilities. This element uses both experimental and modeling activities, which makes it more effective at using and leveraging the substantial work on nanosystems and computational materials science being funded by the Office of Basic Energy Sciences and other government-sponsored programs, as well as making it more capable of contributing to broader materials research in niche areas of materials science. Through a variety of cost-shared international collaborations, this element conducts irradiation testing of candidate fusion materials in the simulated fusion environments of fission reactors to provide data for validating and guiding the development of models for the effects of neutron bombardment on the microstructural evolution, damage accumulation, and property changes of fusion materials. This collaborative work supports both nearer-term fusion devices, such as burning plasma experiments, as well as other future fusion experimental facilities. In addition, such activities support the long-term goal of developing experimentally validated predictive and analytical tools that can lead the way to nanoscale design of advanced fusion materials with superior performance and lifetime.

Management of the diverse and distributed collection of technology R&D activities continues to be accomplished through a Virtual Laboratory for Technology (VLT), with community-based coordination and communication of plans, progress, and results.

In FY 2007, research efforts will continue supporting the development of enabling technologies that enhance plasma performance on both our current and planned domestic machines as well as for our international collaborations. In addition, consistent with the direction that was started in FY 2006, selected efforts will be redirected from both the Engineering Research and Materials Research categories to the Enabling R&D for ITER support category to concentrate on specific R&D supporting U.S. responsibilities for ITER procurement packages. These funds will be reoriented for R&D support in a number of areas, including magnets, first wall/shield modules, tritium processing, fueling and pumping, heating and current drive components, and diagnostics, which directly support our ITER hardware contributions. Most of the remaining resources in these two categories will be focused on getting ready to use ITER as a test bed for technology research and to address potential issues that may occur during ITER operation.

Technology Accomplishments

A number of technological advances were made in FY 2005. Examples include:

- As part of the U.S.-Japan (DOE-JAEA) fusion materials collaboration, a wide range of mechanical property specimens of the latest generation of high-performance reduced-activation steels were tested following exposure to fusion-relevant conditions in the High Flux Isotopes Reactor at ORNL. These materials are leading candidates for the structures of ITER test blanket modules and future demonstration fusion energy machines. These results demonstrate the superior performance of these materials under intense neutron irradiation compared to conventional steels, and offer significant improvement in performance compared to steels developed in the 1990s.
- The University of California, Los Angeles (UCLA) completed a first series of magnetohydrodynamic (MHD) experiments aimed at providing scientific understanding and quantitative data on the motion of liquid metal free surface flows under complex magnetic field environments typical of tokamak divertors. These studies are particularly valuable for understanding

the flow behavior of the liquid surface divertor experiment being developed as a particle and heat load control technology for NSTX. The experiments were aided by an extensive numerical simulation effort using a unique 3-D, multi-physics, free-surface liquid metal MHD simulation code (HIMAG) developed in collaboration between UCLA and Hypercomp - an SBIR grantee. The experiments and numerical modeling have helped to build a strong understanding of the flow regime and the unique phenomena that characterize these MHD free surface flows, and at the same time provide a unique test bed for continuing to study other integrated phenomena including coupling to plasma currents and momentum.

- Experiments in the Plasma Interaction with Surface and Components Experimental Simulator (PISCES) facility at the University of California, San Diego, in collaboration with European laboratories, have observed the formation of tungsten-beryllide alloys on tungsten surfaces exposed to beryllium during deuterium plasma bombardment. The $Be_{12}W$ alloy appears to be the most stable beryllide and has a melting temperature of only about 1,500°C. The plasma-material interaction properties of the beryllide alloys are now being systematically investigated with regard to their formation and consequences for ITER operation.
- ORNL, in collaboration with the Joint European Torus (JET) group, designed, built, and tested an ITER-like High Power Prototype Antenna. Based on results from the test, a full power antenna was designed in collaboration with JET. JET is fabricating and will be installing this antenna.

Detailed Justification

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
Engineering Research	**21,382**	**16,694**	**15,495**
▪ **Plasma Technology**	**18,403**	**14,205**	**12,945**

Plasma Technology efforts will focus its resources on developing enabling technologies for both current and future machines, and on addressing potential ITER operational issues in the area of plasma materials interactions. The remaining resources will be used to complete a U.S.-Japan Collaborative Program on blanket materials for use in future experiments and in testing high efficiency gyrotrons. In FY 2007, $1,260,000 is redirected to support the ITER Other Project Costs (OPC) R&D efforts. During FY 2007, the following specific elements will be completed:

- Testing of a highly efficient (over 50 %) 110 gigahertz, 1-1.5 megawatt industrial prototype gyrotron microwave generator, the most powerful and efficient of its kind for electron cyclotron heating of plasmas, will be completed.
- Studies will continue in the PISCES facility at UCSD, and the Tritium Plasma Experiment at INL, of tungsten-carbon-beryllium mixed materials layer formation and redeposition with attached hydrogen isotopes, and results will be applied to evaluate tritium accumulation in plasma facing components that will occur during ITER operation.

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007

- In the STAR facility at INL, the final series of material science experiments will be completed under the current cost-sharing collaboration with Japan (Jupiter II) to resolve key issues of tritium behavior in materials proposed for use in fusion systems.

Additional funds will be provided for research on plasma facing components, heating technologies, and blanket concepts that could be tested in ITER. Funds will also be provided for research in safety and plasma-surface interaction and modeling that will support potential issues that will be encountered during ITER operation.

	FY 2005	FY 2006	FY 2007
▪ **Advanced Design**	**2,979**	**2,489**	**2,550**

Funding for this effort will continue to focus on studies of fusion concepts for the future. Systems studies to assess both the research needs underlying achievement of the safety, economics, and environmental characteristics of such advanced magnetic confinement concepts will be conducted in an iterative fashion with the experimental community. A system study, based on the NCSX design of a compact stellarator power plant, will be completed.

	FY 2005	FY 2006	FY 2007
Enabling R&D for ITER (Other Project Costs)	**—**	**3,449**	**23,000**

Enabling R&D funds for ITER activities are identified in FY 2007 for R&D and design in support of equipment in a number of areas including magnets R&D and design, plasma facing components, tritium processing, fueling and pumping, heating and current drive components, materials, and diagnostics, which would be provided by the U.S. to ITER. The FY 2007 OPC funding level is slightly increased from the FY 2006 President's Budget to accommodate the domestic and international ITER project priorities due to the delayed start for ITER. The results of this R&D and design are also broadly applicable to future burning plasma experiments. These activities are directly associated with the ongoing base program and while they will be carried out by scientists and technologists as part of their ongoing efforts, once reorientation to ITER has been accomplished, these activities will be carried out using DOE Order 413.3 project management tools for controlling schedule, cost and scope, as well as through international collaboration as appropriate.

It is the objective of the international ITER parties to obtain the negotiators' acceptance of the ITER Agreement by March 2006 and to obtain governmental signatures on the completed ITER Agreement later in FY 2006. The Agreement finalizes the allocation of equipment to be provided by each ITER Party and finalizes the concept for the mode of operation among the ITER Parties and central project team during the construction, operation and decommissioning phases of the ITER program. The MIE project cost estimates for U.S. Contributions to ITER, including the Other Project Cost activities, are preliminary until the baseline scope, cost and schedule for the MIE project are established.

For the most part, the OPC activities are accomplished by focusing existing scientists and technologists on specific ITER tasks in a project mode. Based on the funding profile for these activities shown below, additional funds will be required for FY 2007-2009 in this subprogram. During FY 2007, the following specific elements will be continued, following progress in FY 2006:

- Conduct R&D/design to support fabrication of the first wall shield module for ITER.
- Conduct R&D/design to support fabrication of superconducting strand and jacket material for the ITER Central Solenoid.

	FY 2005	FY 2006	FY 2007
	(dollars in thousands)		

- Conduct R&D/design to support fabrication of two key systems, the high throughput continuous extruder and centrifuge accelerator, of the ITER Pellet Injector.
- Conduct R&D/design to support fabrication of the ITER Fuel Cleanup System and develop a dynamic process modeling code of the ITER tritium system.
- Conduct R&D/design to support fabrication of the ITER heating ICRH antenna.
- Conduct R&D/design to support fabrication of the ITER 1 MW, 120 GHz start-up gyrotron.
- Conduct R&D to support selection of different materials and components necessary for ITER diagnostics

U.S. Contributions to ITER Financial Schedule Other Project Costs (OPC)[a]

(budget authority in thousands)

Fiscal Year	Other Project Costs[b]
2006	3,449
2007	23,000
2008	10,500
2009	6,000
2010	1,500
2011	500
Total	44,949

	FY 2005	FY 2006	FY 2007
Materials Research	**7,338**	**7,043**	**4,687**

Materials Research remains the key element in establishing the scientific foundations for safe and environmentally attractive uses of fusion as well as providing solutions for materials issues faced by other parts of the Fusion Energy Sciences research program. The FY 2007 request will maintain a small, but highly beneficial Materials Research program that addresses material needs for longer term fusion devices. The funding will be used for both modeling and experimental activities aimed at the science of materials behavior in fusion environments, including research on candidate materials for the structural elements of fusion chambers.

	FY 2005	FY 2006	FY 2007
Total, Enabling R&D	**28,720**	**27,186**	**43,182**

[a] The funding profile is a preliminary estimate incorporating the key results of the December 2005 negotiations. In addition, shifts between OPC and TEC funding have been made consistent with the intentions of DOE 413.3 to provide for R&D and design in support of the MIE project. During FY 2006, several U.S. reviews are scheduled to validate the preliminary cost and schedule profile for the U.S. Contributions to ITER MIE project. In addition, international ITER Project activities in FY 2006 will also validate the international cost and schedule which can have an affect on the U.S. Contributions to ITER project. The performance baseline, including the funding profile, will be established at CD-2 planned for September 2007.
[b] Note that the MIE TEC funding associated with these Other Project Costs is budgeted in the Facility Operations subprogram.

Explanation of Funding Changes

	FY 2007 vs. FY 2006 ($000)
Engineering Research	
▪ **Plasma Technology**	
The decrease is due to a redirection to R&D for ITER (MIE OPC) for efforts in magnets, first wall/shield modules, heating and fueling technologies, tritium processing, materials, and diagnostics. Work on a U.S. Test Blanket Module for ITER will be phased out.	-1,260
▪ **Advanced Design**	
Funding supports slight increases in Virtual Laboratory for Technology management costs.	+61
Total, Engineering Research	**-1,199**
Enabling R&D for ITER (Other Project Costs)	
Funding increases are consistent with the revised preliminary cost and schedule estimate for the ITER MIE project. Funds have been redirected from Plasma Technology and Materials elements to focus efforts in support of ITER in the magnet, first wall/shield modules, tritium processing, fueling and pumping, heating and current drive components, materials, and diagnostics areas. The FY 2007 OPC funding level is further increased from the profile contained in the FY 2006 President's Budget to accommodate the domestic and international ITER project priorities due to the slowed start for ITER.	+19,551
Materials Research	
The decrease is due to a redirection to R&D for ITER (MIE OPC) for efforts in magnets, first wall/shield modules, heating and fueling technologies, tritium processing, materials, and diagnostics.	-2,356
Total Funding Change, Enabling R&D	**+15,996**

Capital Operating Expenses and Construction Summary

Capital Operating Expenses

(dollars in thousands)

	FY 2005	FY 2006	FY 2007
General Plant Projects	1,643	1,791	1,810
Capital Equipment	24,279	37,801	57,765
Total, Capital Operating Expenses	25,922	39,592	59,575

Major Items of Equipment *(TEC $2 million or greater)*

(dollars in thousands)

	Total Project Cost (TPC)	Total Estimated Cost (TEC)	Prior Year Appro-priations	FY 2005	FY 2006	FY 2007	Completion Date
NCSX	101,971	92,401	23,818	17,500	17,019	15,900	FY 2009[a]
U.S. Contributions to ITER	1,122,000[b]	1,077,051[b]	—	—	15,866	37,000	FY 2014
Total, Major Items of Equipment				17,500	32,885	52,900	

[a] The FY 2006 Congressional budget reflected an estimated increase to the TEC for NCSX to $90,839,000, with an estimated completion date of May 2009. The project was formally rebaselined in July, 2005 consistent with the funding profile requested in the FY 2006 budget. The new baseline TEC is $92,401,000, with completion in July 2009.

[b] Funding is for the second year of the Major Item of Equipment project, U.S. Contributions to ITER. These figures are preliminary estimates, though the TPC for U.S. Contributions to ITER would change only if OMB-established inflation rates change between now and when the performance baseline for scope, cost, and schedule is established after the ITER International Agreement is completed, and if currency exchange rates change affecting about 15% of the TPC funding. The estimates have been prepared based upon (1) U.S. industrial estimates for the hardware items the United States is likely to contribute, (2) FES estimates for personnel to be assigned abroad consistent with previous experience during the ITER Engineering Design Activities, (3) U.S. cash contributions for a non-host participant in the ITER project, and (4) FES estimates for operation of the U.S. ITER Project Office including technical oversight of procurement.