Fusion Energy Sciences

Funding Profile by Subprogram

(dollars in thousands)

	FY 2004 Comparable Appropriation	FY 2005 Original Appropriation	FY 2005 Adjustments	FY 2005 Comparable Appropriation	FY 2006 Request
Fusion Energy Sciences					
Science	142,723	156,301	-1,238[a]	155,063	142,771
Facility Operations	85,690	90,673	-730[a]	89,943	127,519
Enabling R&D	27,446	29,136	-239[a]	28,897	20,260
Total, Fusion Energy Sciences	255,859[b]	276,110	-2,207	273,903	290,550

Public Law Authorization:

Public Law 95-91, "Department of Energy Organization Act, 1977"

Public Law 103-62, "Government Performance and Results Act of 1993"

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 with 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, and the efficient destruction of chemical and radioactive wastes.

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 an energy-generating, sustained burning plasma. Although site selection for ITER is still being decided, it is the objective of all

[a] Reflects a rescission in accordance with P.L. 108-447, the Consolidated Appropriations Act, 2005.
[b] Includes reductions of $1,555,000 rescinded in accordance with the P.L. 108-137, Consolidated Appropriations Act, 2004, $5,979,000, which was transferred to the SBIR program, and $717,000 which was transferred to the STTR program.

international parties involved to reach consensus and finalize the ITER agreement in FY 2005. The "U.S. Contributions to ITER" is a proposed Major Item of Equipment (MIE) project, which supports the multilateral internationally-based project called ITER. The mission for ITER is to demonstrate the scientific and technological feasibility of fusion energy. In preparation for the start of ITER and the U.S. Contributions to ITER MIE, FES is placing increasing 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 and longer-term fusion devices;
- 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;
- Continuing support of our National Compact Stellarator Experiment (NCSX) to keep it on budget and on schedule for completion in FY 2009 to improve our understanding of magnetic confinement of plasma;
- 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 activities described above uphold many of the program priorities recommended by the Fusion Energy Sciences Advisory Committee.

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.

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 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 of plasmas in various configurations; 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.

A major portion of the FES program contribution to this goal is going to be achieved through participation in ITER, an international collaboration to build the first fusion science experiment capable of producing a sustained fusion reaction, called a “burning plasma.” A sustained, burning (or self-heated) plasma is the next frontier in fusion science. In September 2002, the Fusion Energy Sciences Advisory Committee (FESAC) concluded that the fusion program is technically and scientifically ready to proceed with a burning plasma experiment and recommended joining the ongoing negotiations to construct the international burning plasma experiment, ITER. The National Research Council of the National Academy of Sciences subsequently endorsed this strategy (Burning Plasma: Bringing a Star to Earth released September 2003). Based in part on these recommendations, plus an Office of Science assessment of the credibility of the cost estimate for the construction of ITER, the President decided in January 2003 that the United States should join the ITER negotiations. This proposed international collaboration will test the scientific and technical feasibility of fusion power. In FY 2003 and FY 2004, the ITER Parties completed much of the international agreement for proceeding with the ITER program and attempted to reach agreement on a construction site in Japan or France. The host candidates, Japan and the European Union, are conducting bilateral discussions in an attempt to resolve the site selection choice.

The FY 2006 Budget provides for the start in mid-FY 2006 of the Major Item of Equipment (MIE) project entitled the "U.S. Contributions to ITER"; this title is chosen to make clear the distinction between the international ITER project, in which the U.S. will be one of many participating parties, and the MIE for which the U.S. has full responsibility. The Total Project Cost, including Total Estimated Cost (TEC) and Other Project Costs (OPC), for the U.S. Contributions to ITER MIE is summarized below in the Significant Program Shifts section and consists of two parts; the Total Estimated Cost is identified in the Facilities Operations subprogram and Other Project Costs are identified in the Enabling R&D subprogram.

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.

Annual Performance Results and Targets

FY 2001 Results	FY 2002 Results	FY 2003 Results	FY 2004 Results	FY 2005 Targets	FY 2006 Targets
Program Goal 05.24.00.00 (World-Class Scientific Research Capacity)					
Science					
				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.[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 2006, FES will inject 2 MW of neutral power in the counter direction on DIII-D and measure the change in plasma toroidal rotation.
				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.	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.

[a] 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 will be compared to model predictions, and will be documented in a *Target Completion Report* in September 2005.

FY 2001 Results	FY 2002 Results	FY 2003 Results	FY 2004 Results	FY 2005 Targets	FY 2006 Targets
Facility Operations					
Kept deviations in weeks of operation for each major facility within 10% of the approved plan. [met goal]	*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%.*	*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 approved baselines; achieved planned cost and schedule performance for dismantling, packaging, and offsite shipping of the Tokamak Fusion Test Reactor (TFTR) systems. [met goal]	*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%.*	*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. The proposed international burning plasma experiment called 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 tokamak experimental physics. Longer range technology activities have been phased out or 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 the 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 are preparations for the international project and the U.S. component fabrication for ITER. The FY 2006 request for ITER continues these preparations until mid-FY 2006 when the ITER MIE TEC and OPC are scheduled to begin. For the latter half of FY 2006, TEC funds are identified for the U.S. Contributions to ITER MIE in the Facility Operations subprogram. Certain funds within the Enabling R&D subprogram are redirected in the latter half of FY 2006 to Other Project Cost activities, focused on directly-related, specific R&D needed to support the procurements in the U.S Contributions to ITER MIE. These funds are needed 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 broadly applicable to future 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 TEC or TPC.

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. Checkpoint reviews at the 3-year point provide interim assessment of program quality. 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 2005 and FY 2006 Budget Requests 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). FES developed an action plan to respond to the findings and recommendations of the COV within 60 days of receiving the report. This action plan is also available on the web at (http://www.ofes.fusion.doe.gov/More_HTML/FESAC/COVLettertoHazeltine.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 needs to be developed. In response, FESAC has been tasked to write a report that identifies and prioritizes scientific issues and respective campaign strategies. An interim report was completed in July 2004 and a final report is expected in FY 2005. This report will form the basis of an FES strategic plan which will also include efforts in ITER. Completion of this plan is targeted for September 2005.

Funding by General and Program Goal

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
General Goal 5, World-Class Scientific Research Capacity			
Program Goal 05.24.00.00, Bring the Power of the Stars to Earth			
Science	142,723	155,063	142,771
Facility Operations: Non-ITER	82,535	84,996	75,519
Facility Operations: ITER Preparations	3,155	4,947	6,000
ITER MIE TEC	0	0	46,000
Enabling R&D: Non-ITER	27,446	28,897	16,760
Enabling R&D: ITER MIE OPC	0	0	3,500
Total, General Goal 5, World-Class Scientific Research Capacity	255,859	273,903	290,550

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 fusion:

- The transport of plasma heat from the core of the plasma outward to the plasma edge and to the material walls as a result of electromagnetic turbulence in the plasma;
- The stability of magnetic configuration and its variation in time as the plasma pressure, density, turbulence level, and population of high energy fusion products change;
- The role of the colder plasma at the plasma edge and its interaction with both material walls and the hot plasma core;
- The interaction of electrons and ions in the plasma with high-power electromagnetic waves injected into the plasma for plasma heating, current drive and control; and
- The development of reliable and economical superconducting magnets, plasma heating and fueling systems, vacuum chamber, and heat extraction systems and materials that can perform satisfactorily in an environment of fusion plasmas and high energy neutrons.

These issues have been codified into four 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;
- Materials, Components and Technologies that include enabling technologies and fusion-specific materials science (closely coupled to the Basic Energy Sciences (BES) materials science program).

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 Committee 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: theory and computation, confinement innovations, general plasma sciences, tokamak research, and enabling research and development. In March 2004, a COV completed its review of the research portfolio and peer review process for the FES theory and computation program. It concluded that this FES-supported research program was of very high quality. Further, the COV was impressed with both the success of the FES and its implementation of a comparative peer review, which had improved significantly over the last three years, and with the quality of the reviewers chosen by the FES theory team.

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. Currently, FESAC is assisting 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. FESAC's objectives will include a prioritized balancing of the content, scope, and level of U.S. activities in fusion. Their efforts will aim to 1) identify major program issues in science and technology that need to be addressed, 2) recommend how to organize campaigns to address those issues, and 3) recommend the order of priority in which these campaigns will be pursued. FESAC's report on this activity is expected to be completed in fiscal year 2005.

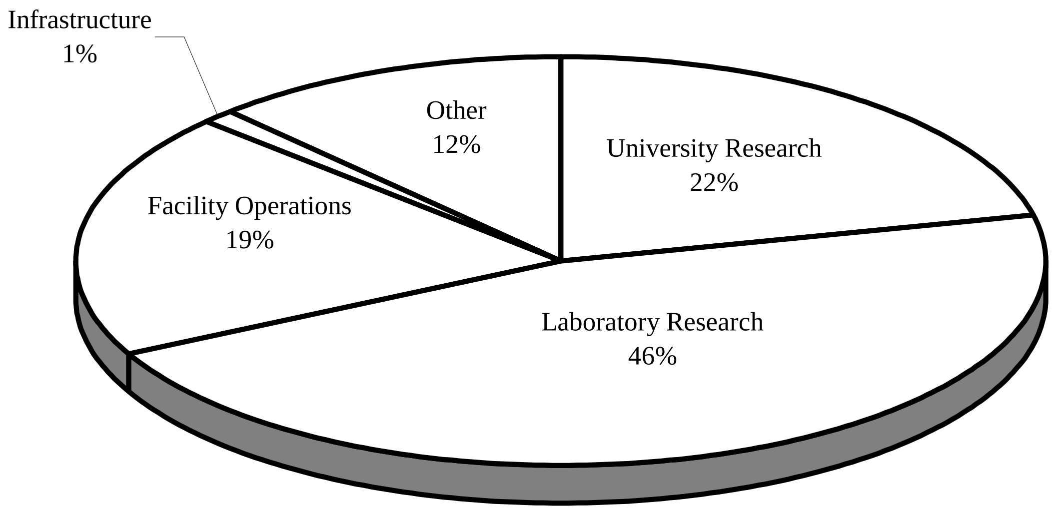
A variety of sources of information and advice, as noted above, are integrated with peer reviews of research proposals. These, combined with high-level program reviews and assessments, provide the basis for prioritizing program directions and allocations of funding.

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. In addition to a major research facility at Massachusetts Institute of Technology (MIT), there are several smaller experimental facilities located at universities. There are two other major facilities, located at a national laboratory (Princeton Plasma Physics Laboratory), and a private sector institution (General Atomics [GA]). Technology supports and improves the technical capabilities for ongoing experiments and provides limited long-term development for future fusion power requirements.

The balance of funding levels and priorities are reviewed by the FESAC. The following chart illustrates the allocation of funding to the major program elements.

Fusion Energy Sciences Budget Allocation
FY 2006



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 brought 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 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 Engineering and Environmental 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 FWPs 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 2006 request is $290,550,000, an increase of $16,647,000, 6.1% over the FY 2005 Appropriation. The FY 2006 budget continues the redirection of the fusion program to prepare for and participate in the ITER project.

Operation of the three major fusion research facilities will be reduced from a total of 48 weeks to 17 weeks. There will be a net decrease of approximately 150 scientists, engineers, and supporting staff from the program. The largest reductions will be mainly at ORNL, PPPL, General Atomics, LBNL, and LLNL; however, the reductions will affect other fusion program participants as well.

Within the overall priorities of the FY 2006 FES budget, $15,900,000 is requested for the National Compact Stellarator Experiment (NCSX), a joint ORNL/PPPL advanced stellarator experiment being built at PPPL. The FY 2006 request is $1,600,000 less than FY 2005, and the schedule for completion is extended to May 2009 with an estimated TEC of $90,839,000. A new cost and schedule performance baseline consistent with the FY 2006 request and expected outyears will be developed in the mid-FY 2005 timeframe.

Other program shifts include a reduction of $7,255,000 from the FY 2005 level in the Inertial Fusion Energy/High Energy Density Physics program. This will be accomplished by reducing the level of research on heavy ion beams at Lawrence Berkeley National Laboratory, the Lawrence Livermore National Laboratory, the Princeton Plasma Physics Laboratory and the associated universities supporting the heavy ion beams research. Within the reduced funding level, this program element will concentrate on the use of ion beams for high energy density physics research, and other innovative approaches to high energy density physics, including Fast Ignition, as recommended by the national Task Force on High Energy Density Physics commissioned by the Office of Science and Technology Interagency Working Group on the Physics of the Universe. In addition, the Materials Research program will be eliminated in favor of reliance upon the general BES materials effort for scientific advances in areas of fusion interest.

ITER

Multilateral ITER negotiations continued in FY 2004 and into FY 2005. In collaboration with the ITER parties, a comprehensive process to prepare the written ITER Agreement covering all phases of the ITER project has been put in place. This includes incorporation of input on all topics by topical experts from each negotiating party, discussion by representatives of each party and resolution of differences by the negotiators. A negotiated agreement is expected to be completed in FY 2005 for consideration and approval within the parties' governmental systems. In addition, representatives of the parties addressed critical implementation decisions on detailed arrangements including assignment of management personnel. As part of the continuing preparations for the international ITER project, DOE selected PPPL in partnership with ORNL to manage the U.S. ITER Project Office based upon a competitive selection process involving all the DOE fusion laboratories. This office is responsible for U.S. ITER preparations and the provision of U.S. contributions to ITER, including hardware, personnel and cash for the U.S. share of common costs at the ITER site such as installation and testing.

The FY 2006 request for the U.S. Contributions to ITER MIE includes Total Estimated Cost (TEC) funding of $46,000,000 in the Facilities Operations subprogram and Other Project Cost (OPC) funding of $3,500,000, redirected within the Enabling R&D subprogram. The TEC and OPC funding for FY 2006 through FY 2013 are reflected below.

The ITER International Agreement is currently being negotiated and is expected to be completed by the end of FY 2005. The Agreement will finalize the current provisional list of equipment to be provided by each ITER Party 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 following MIE project cost estimates for U.S. Contributions to ITER are preliminary until the Agreement is completed, following which the baseline scope, cost and schedule for the MIE project will be established.

U.S. Contributions to ITER
Annual Profile

(budget authority in thousands)

Fiscal Year	Total Estimated Costs	Other Project Costs	Total Project Costs[a]
2006	46,000	3,500	49,500
2007	130,000	16,000	146,000
2008	182,000	18,800	200,800
2009	191,000	16,500	207,500
2010	189,000	10,300	199,300
2011	151,000	9,300	160,300
2012	120,000	6,200	126,200
2013	29,000	3,400	32,400
Total	1,038,000	84,000	1,122,000

[a] Discussions are proceeding on whether ITER Preparation costs should also be accounted for within the ITER TPC. A determination will be part of the Critical Decision – 1 process.

Estimated TEC, OPC and TPC Costs

	(dollars in thousands)	
	Current Estimate	Previous Estimate
Fabrication Costs		
Procurement of U.S. in-kind equipment (~10% of ITER need)	573,800	n/a
Installation of U.S. in-kind equipment	71,900	n/a
Assignment of U.S. scientists and engineers to ITER Org (~10% of ITER need)	87,300	n/a
Contribution of funds for support personnel at ITER Org (~10% of ITER need)	36,200	n/a
Operation of U.S. ITER Project Office including management, QA, procurement, etc.	123,600	n/a
Subtotal	892,800	n/a
Contingencies at approximately 16% of above costs	145,200	n/a
Total Estimated Costs (TEC)	1,038,000	n/a
Other Project Costs - Base Program R&D and Design Support for above tasks	68,000	n/a
Contingencies at approximately 24% of OPC costs	16,000	n/a
Total Other Project Costs (OPC)	84,000	n/a
Total Project Costs (TPC)	1,122,000	n/a

Related Annual Funding Requirements

	(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.	58,300	n/a
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.	17,000	n/a

FY 2006 funding of $49,500,000 is for the startup of the U.S. Contributions to ITER MIE. The total U.S. Contributions to ITER MIE, $1,122,000,000, consists of both the TEC funding for the fabrication of the equipment, provision of personnel, and limited cash for the U.S. share of common project expenses at the ITER site, as well as the OPC funding for 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.

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. project is established (defined as Critical Decision 2 under DOE Order 413.3). With the exception of possible changes in OMB-established inflation rates, and currency exchange rates affecting about 15% of the TPC funding, the overall TPC for the U.S. Contributions to ITER MIE will remain $1,122,000,000 when the performance baseline is established. The estimated timeframe for establishing the performance baseline is within the first or second quarter of FY 2006, and by this time the ITER Director General and key staff are expected to be in place.

The TEC funds for the U.S. Contributions to ITER MIE provide for the U.S. share, about 10%, of the international ITER project construction cost. The U.S. share includes fabrication of equipment, assignment of personnel to the ITER project organization and cash for equipment installation and common expenses. TEC funds are needed starting in mid-FY 2006 based on an FY 2005 ITER site selection and an FY 2006 start of the international project. These funds are budgeted within the Facility Operations subprogram.

The OPC funds for the U.S. Contributions to ITER MIE support R&D and design activities focused on ITER and also are broadly applicable to the overall burning plasma program. MIE OPC funds are also needed starting in mid-FY 2006. These OPC funds are budgeted within the Enabling R&D subprogram.

FY 2004 Awards

- A fusion scientist at Princeton University received an E.O. Lawrence Award in the nuclear technology category for his discovery of ways to use plasma waves to produce currents in tokamaks.
- A research physicist on the National Spherical Torus Experiment (NSTX) won the United States Presidential Department of Energy Early Career Award for his studies on how to achieve optimum stability in high performance plasmas in a very compact tokamak, which impact the design and physics basis for NSTX and future spherical torus (ST) reactors.
- A fusion materials scientist has been elected as General Chairman of the "Second International Conference on Multiscale Modeling of Materials," the largest worldwide activity in Computational Materials Science.
- A member of the DOE-funded Plasma Science Fusion Center was named Head of the MIT Department of Nuclear Engineering.
- The University of Milan conferred an honorary doctorate upon an eminent fusion scientist. A Symposium on "Plasmas in the Universe" was held in his honor in connection with the award.
- A fusion scientist at the University of Wisconsin received the 2004 James Clerk Maxwell Prize for Plasma Physics
- Five fusion scientists received the American Physical Award for Excellence in Plasma Physics Research.
- Ten fusion scientists were made Fellows of the American Physical Society.
- Two fusion scientists were named Fellows of the American Association for the Advancement of Science.

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 mission areas with the goal of achieving breakthrough scientific advances through computer simulation that are impossible using theoretical or laboratory studies alone.

The power of computers and networks is increasing exponentially. By exploiting advances in computing and information technologies as tools for discovery, SciDAC encourages and enables a new model of multi-discipline collaboration among the scientific disciplines, 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 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 have completed three-year research projects in the areas of magnetic reconnection, macroscopic stability, electromagnetic wave-plasma interaction, simulation of turbulent transport of energy and particles, and atomic physics relevant to edge plasma physics. 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. The fusion SciDAC projects were completed in FY 2004, and a new round of three-year SciDAC awards was initiated in the 4th quarter of 2004. These newly funded projects are focused on the topics of microturbulence simulation, extended MHD modeling, and simulation of electromagnetic wave-plasma interaction. In 2005, the Fusion Energy Sciences program and the Advanced Scientific Computing Research program will fund one or two prototype focused integration initiatives, based on a competitive peer review process.

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. These three facilities are each unique in the world's fusion program and offer opportunities to address specific fusion science issues that will contribute to the expanding knowledge base of fusion. Taken together, these facilities represent nearly $1,000,000,000 of capital investment by the U.S. Government, in current year dollars.

The funding requested will provide research time for about 230 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 2004	FY 2005	FY 2006
Optimal hours	3,000	3,000	3,000
Planned hours	2,320	1,920	680
Hours operated as percent of planned hours	100%	TBD	TBD

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 2004	FY 2005	FY 2006
Completed final design of NCSX and began fabrication.	Award, through a competitive process, production contracts for the NCSX modular coil winding forms and conductor and vacuum vessel. Complete winding of the first modular coil.	Complete fabrication of vacuum vessel subassemblies and one-third of the modular coil winding forms.

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 2004, the FES program supported 435 graduate students and post-doctoral investigators. Of these, approximately 40 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 2004	FY 2005 est.	FY 2006 est.
# University Grants	208	223	200
# Permanent PhD's (FTEs)[a]	722	732	669
# Postdoctoral Associates (FTEs)	126	128	121
# Graduate Students (FTEs)	264	264	254
# PhD's awarded	45	45	45

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

Science

Funding Schedule by Activity

	(dollars in thousands)				
	FY 2004	FY 2005	FY 2006	$ Change	% Change
Science					
Tokamak Experimental Research	44,842	45,147	43,765	-1,382	-3.1%
Alternative Concept Experimental Research	57,319	60,874	49,940	-10,934	-18.0%
Theory	25,367	25,460	24,640	-820	-3.2%
SciDAC	3,319	4,275	4,275	0	--
General Plasma Science	11,876	12,341	13,900	+1,559	+12.6%
SBIR/STTR	0	6,966	6,251	-715	-10.3%
Total, Science	142,723	155,063	142,771	-12,292	-7.9%

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, 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 heat to escape. The Science subprogram supports exploratory research to combine the favorable features of, and the knowledge gained from, magnetic 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

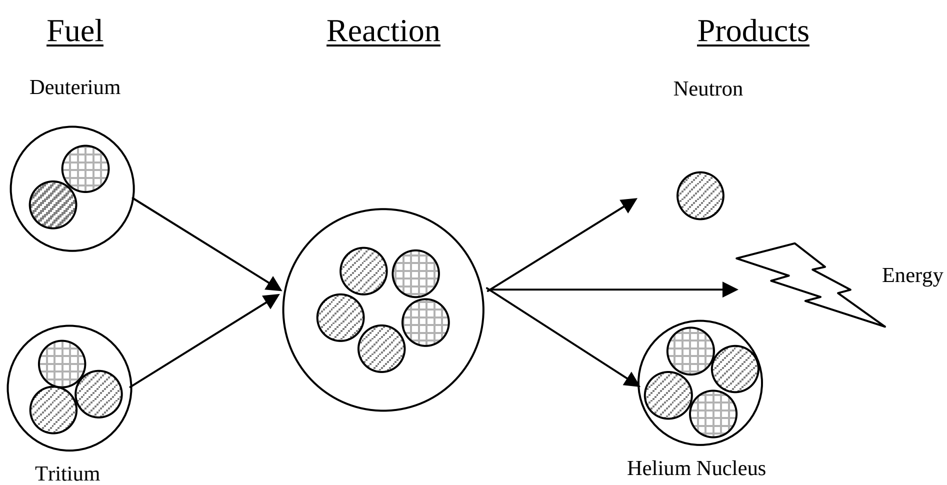
Plasmas, the fourth state of matter, comprise over 99% of the visible universe and are rich in complex, collective phenomena. During the past decade there has been considerable progress in our fundamental understanding of key individual phenomena in fusion plasmas, such as transport driven by micro-turbulence, 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 will focus 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. An ongoing “Centers of Excellence in Fusion Science” 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 Inertial Fusion Energy (IFE), the two major science issues are: (1) high energy density physics that describes intense laser-plasma and beam-plasma interactions; and (2) non-neutral plasmas, as is seen in the formation, transport, and focusing of intense heavy ion beams.

FY 2004 Science Accomplishments

Research funded by the Fusion Energy Sciences program in FY 2004 is focused on developing a predictive understanding of burning plasmas, finding improved magnetic confinement configurations, and exploring high energy density physics relevant to inertial fusion energy. The U.S. decision to join the ITER negotiations has energized the research in tokamaks, enhancing collaborations among the international tokamak programs and encouraging closer collaborations between theory and experiments. Substantial effort is being put into computer simulations to enhance tools for predictive capability for ITER. The experimental research and the theory and simulations on advanced tokamaks contribute both to the predictive understanding of burning plasmas and to configuration optimization.

Jointly funded by FES and Advanced Scientific Computing Research (ASCR), the National Fusion Collaboratory is developing an infrastructure to enable scientific collaboration for all aspects of magnetic fusion energy research. This effort includes creating a robust, user-friendly collaborative software environment and deploying this to the more than 1,000 scientists in 40 institutions who perform magnetic fusion research in the United States and abroad. The ultimate goal of this collaborative software environment (referred to as the National Fusion Grid) is to allow scientists at remote sites to participate as fully in experiments and computational activities as if they were working at a common site, thus creating a virtual organization of the U.S. fusion community. The main data repositories at the three major experimental facilities have been made securely accessible via Fusion Grid. Additionally, the first fusion code placed on Fusion Grid, “TRANSP”—a widely used system for simulation of fusion experiments, has performed over 1,500 simulations taking over 10,000 CPU hours for nine different experimental fusion devices. Also, the simulation code that is used to study low-frequency turbulence in magnetized plasmas was recently made securely available on Fusion Grid. This collaborative technology is scalable to an international project like ITER.

Predictive Capability for Burning Plasmas

Intensive efforts during the past year have produced advances 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. Some of these advances have been made possible through the development of a sophisticated plasma control system that integrates theory, modeling, and planning of discharge scenarios described below, and some through careful planning and execution of complementary experiments among several relevant tokamaks to resolve important scientific issues. Some of these advances have been focused on projections of results from the present experiments to the larger ITER in the future. Several major highlights from these 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 (Culham Laboratory, UK) have obtained a result that indicates 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. Recent studies have shown that these experiments can vary beta by a factor of 3 without penalty to energy confinement. This result implies higher beta or plasma pressure affording either higher fusion power output and/or more ready access to steady-state operating modes in ITER.

- **Comprehensive Simulations of Transport from Turbulence in Tokamaks**

  Presently the most advanced code for calculating the heat and particle transport losses arising from turbulence in tokamak plasmas is ready to support a major advance in our understanding of turbulent transport once the computer resources available for this code are significantly increased to allow multiple runs for comparison with experiments.

- **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 tokamak. Over the last year, experiments have revealed why: 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, reducing the outward flow of energy.

- **Internal Transport Barriers**

  The plasma parameters of the internal transport barrier regime discovered 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.

To confine a plasma at the temperatures and densities required for fusion energy production requires either a high magnetic field or an efficient confinement configuration. Achieving the latter requires an understanding of magnetohydrodynamic (MHD) equilibrium and stability. Since a plasma confined by a magnetic field is not in thermodynamic equilibrium, a variety of large-scale instabilities can occur.

An important instability that limits plasma pressure (and therefore fusion energy) is the "tearing mode," in which chains of magnetic islands, each only a few centimeters wide, form in the plasma, causing great heat loss and reducing energy confinement. Theory and experiment have established that these magnetic islands can be diminished by driving high frequency electrical current with surgical precision into them. However these islands are continually moving as the pressure and current in the plasma around them change. The challenge is to keep the high frequency electrical current focused on the moving islands. An example of this effort is the sophisticated feedback system being developed for ITER on the DIII-D tokamak, which automatically moves the plasma position (or adjusts the magnetic field magnitude) to keep the microwaves focused on the islands. Automatic correction using a unique real-time calculation to predict dynamic changes in plasma pressure has enabled stabilization of the largest and most difficult tearing modes with record accuracy and duration.

Proving the Role of Self-Driven Plasma Current in Instabilities at the Plasma Edge

Tokamak plasmas that would operate in ITER's nominal operating mode have regular pulsed instabilities in the plasma edge that produce pulsed heat and particle loads on the material surfaces in contact with plasma exhaust. If these pulses are too large, they can excessively erode the surfaces. Hence it is important to understand these instabilities. A new code, jointly developed by U.S. and U.K. scientists, successfully predicts most properties of these instabilities. A key feature in the theory is the existence of a large peak in the electrical current flowing in the plasma at the edge. While this current peak is expected from theory to be self-driven by the plasma, this prominent and unusual feature was never measured until this past year. Spectroscopic observations of an injected Lithium beam in the DIII-D tokamak measured this current peak for the first time. The magnitude and location of the current peak confirmed the theory of the edge instabilities and were close to the predicted values of the plasma's self-driven current. The confirmed theory of these instabilities will be valuable in devising ITER operating scenarios that minimize erosion of surfaces.

- **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. Recently it was shown in the DIII-D tokamak that this most important 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 and implying a stabilizing mechanism connected with the rotation that dissipates the energy driving the instability. An elegant experimental technique (dubbed MHD spectroscopy) has been developed that allows the measurement of damping rates and rotation frequencies of these important modes. A set of coils is used as an antenna to apply a pulsed or rotating magnetic field with a large overlap in spatial structure with the basic unstable modes, and resonances are found. These measurements can now be compared to detailed code calculations that test various stabilizing mechanisms.

- **High Value of Plasma Pressure**

  During the past year, NSTX researchers successfully repaired toroidal magnetic field coils damaged during the FY 2003 experimental run, installed new diagnostic instruments, and began a new 18-week experimental campaign. At high plasma currents (1.2 million Amperes), very high values of plasma pressure were obtained, consistent with theoretical predictions (a ratio of plasma pressure to magnetic field pressure of nearly 40% was achieved).

- **Mode Conversion in Tokamak Plasmas**

  The first mapping of radio frequency wave mode conversion in tokamak plasmas was accomplished using a novel laser diagnostic. Both the long and short wavelength mode converted waves were simultaneously measured, and these modes were shown to drive DC electric current, with significant potential for current density profile control.

- **Control of Tokamak Instabilities**

  Very small asymmetries in magnetic fields, of the order of 1 ten-thousandth of the total field strength, can lead to "locked modes," which severely degrade performance and even lead to complete loss of confinement in tokamak plasmas. Experiments in C-Mod, together with coordinated experiments on other facilities around the world, including DIII-D, have established a basis for predicting the threshold for these effects in ITER and demonstrated successful suppression of these modes by application of compensating fields from specially designed external coils.

Understanding the interaction of plasma particles with electromagnetic waves is a fundamental topic in plasma science that has practical application to plasma heating and current drive.

- **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. The key was the use of high power millimeter waves at high frequencies (110GHz) to drive the current and control its spatial distribution. At lower plasma currents, 100% non-inductive operation was achieved with the transformer coil actually turned off and has afforded the first view of an almost completely self-organized tokamak plasma (except for being self-heated by the fusion reactions—ITER is needed for that). These plasmas and the “hybrid” scenarios reported last year are building the basis for ITER to achieve its high fusion energy gain and high fluence missions simultaneously.

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 around the plasma and the confinement of heat and particles in the core of the plasma.

- **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. To obtain more definitive data, experiments were carefully executed following carbon-13 tracer elements that were injected into the plasma edge. Subsequent analysis of tile surfaces 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. While Advanced Tokamak is included in the earlier section for its contributions to the Burning Plasma objective, it also contributes to Configuration Optimization by pushing the frontiers of tokamak research. The remaining material below reports only the accomplishments in concepts other than Advanced Tokamaks.

- Self organization of plasma plays an important role in the dynamics of fusion plasmas. The approach to self organization in plasma typically involves a relaxation process called Taylor relaxation. Taylor relaxation produces magnetic fluctuations that tend to degrade energy confinement. Recent research at University of Wisconsin using a small, reversed field pinch experiment successfully suppressed these magnetic fluctuations, leading to a ten-fold improvement in energy confinement. As a result, the plasma temperature in this experiment broke through the 10 million degree Celsius level. Research in the past year revealed that transport in the new mode of operation might be dominated by electrostatic fluctuations.

- 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. In a small university-scale experiment at the University of California in Davis, small balls of magnetic helicity (called compact toroids) have been accelerated to 200 km/s repetitively at a rate of 0.1 Hz in a self-switching coaxial plasma accelerator, and are being studied potentially for refueling tokamaks or modifying its density profile. In the past year the project demonstrated the scaling law for stopping a compact toroid in a toroidal magnetic field. Magnetic compression of the compact toroid upon injection into an axial magnetic field was measured. Injecting magnetic helicity into a tokamak is also a candidate for non-inductive start-up and for producing electrical currents in tokamak. Experiments addressing this application are in progress at the University of Washington in Seattle and at Caltech.
- 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 a 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, an important milestone in spheromak research was accomplished at the Sustained Spheromak Physics Experiment (SSPX) at the LLNL, in which short pulses of magnetic helicity were injected sequentially into the spheromak, and were successfully retained by the spheromak. In the past year, important advances were made in the computational modeling of this pulsed helicity injection technique.
- One method of heating plasma consists of compressing magnetized plasma by an imploding material wall, which may be solid, liquid, or gaseous. Currently an experiment is planned for studying the physics of such a compression which involves imploding a hollow cylindrical metallic shell by passing a large electrical current (about 10 megamperes) through the shell between two planar electrodes. A hole is present in at least one of the electrodes in order to insert magnetized plasma into the hollow of the shell. Therefore the body of the cylindrical shell needs to be imploded while the ends of the shell need to be sufficiently constrained in their motion so that they do not slide into the holes in the electrodes and thus lose electrical contact with the electrodes. The first experiment to address this issue was met with great success. An aluminum shell (containing no plasma), with a precise thickness profile designed with the help of detailed 2-D magnetohydrodynamic modeling guided by analytical theory, was successfully imploded with the desired imploding trajectory. Good electrical contact was maintained between the shell and the electrodes throughout the implosion. A radial convergence ratio of about 17 to 1 was achieved.
- A confinement configuration being investigated consists of a levitated magnetic dipole. The configuration is inspired by nature's way of confining plasma in planetary magnetospheres. After four years of development, the main components of the experimental system are finally installed. Initial testing of the system is expected to begin in the fall this year.

High Energy Density Physics

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 an emerging field of physics called High Energy Density Physics, which cuts across several fields of contemporary physics including astrophysics. Plasmas at these energy densities are characterized by having pressures exceeding a million atmospheres.

The impact of heavy ion beams with a metallic hohlraum to produce highly energetic and intense x-rays to implode a material capsule has been considered an attractive approach to create fusion reactions and plasma states of high energy densities. Instead of using ions with energy in the range of 100's of billions of electron-volts (GeV) that are very expensive to produce, ions with much lower energy (and cost) in the 10's of million of electron-volts (MeV) may be used if the underlying plasma science issues could be understood and overcome. In the past year, significant progress has been made in understanding the plasma science of heavy ion beams, as well as in the physics of interaction of intense laser beams with materials.

- Ions carry electrical charges and create a net electric field, called the space-charge field, in an ion beam. The space-charge electric field acts to separate the ions and thus creates difficulties in focusing the beam to achieve high energy density. One approach to overcome this difficulty consists of passing the beam through a plasma, allowing the electrons in the plasma which are electrically opposite to neutralize the space-charge electric field of the ions. With the space-charge electric field significantly reduced or eliminated, the ions can then be focused by arranging their ballistic trajectories to converge. Experiments to demonstrate this focusing mechanism continue in the Neutralized Transport Experiment (NTX) at the LBNL, with more measurements of the beam parameters and with more comparisons with 3-D particle-in-cell modeling of the beam dynamics. In these experiments, ion beams of approximately 10 cm in diameter were focused down to a spot of less than a few millimeters. Separately, the High Current Experiment (HCX) at LBNL is studying the key physics related to beam transport at high intensities, including the effects of imperfections in alignment and focusing fields, image charge effects from beam proximity to the conducting wall, collective oscillations and instabilities, beam halo particles and electron effects.
- An exciting new scientific development in recent years in the area of high energy density physics is the use of petawatt (a thousand-trillion-watt) lasers to heat an already dense solid. As applied to inertial fusion, the concept consists of using a petawatt laser to heat and ignite a fusionable capsule that is pre-compressed by another laser. The concept is called Fast Ignition. When the intense laser beam impinges on the capsule, the intense radiation accelerates the electrons in the capsule to relativistic velocities. The transport of these relativistic electrons in the material governs the effectiveness of heating the capsule. In the past year, researchers at General Atomics and Lawrence Livermore National Laboratory, working with British and Japanese experimental groups and facilities, continued to generate experimental data that will elucidate the transport of these relativistic electrons in dense matter.

Detailed Justification

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
Tokamak Experimental Research	**44,842**	**45,147**	**43,765**

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.

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**	**24,241**	**22,842**	**22,663**

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 two years, the investigation of ITER relevant discharge scenarios has gained emphasis in the DIII-D experimental program. The level of effort for all DIII-D physics research topics in FY 2006 decreases from FY 2005, but the effort to support burning plasma physics, specifically for ITER, will remain a priority. This research elucidates the effects of plasma edge instabilities and high pressure in various plasma confinement regimes, extending the duration of stable plasma operation, and helping build cross-machine data bases using dimensionless parameter techniques.

The program will also continue the investigation of the scientific basis for optimization of the tokamak approach to fusion production. This research includes investigation of different modes of operation of fusion plasmas for enhancing the attractiveness of tokamak systems. Research on four topical sciences areas mentioned above will continue. The refurbishment and commissioning of the Ion-Cyclotron Radio Frequency (ICRF) system, that was built about 4 years ago, started in FY 2003, and it will be available for these experiments in FY 2006. This system will provide additional electron heating capability and improve the current drive provided by the ECH system and further increase capability to control current profile. The activities in all these areas are interrelated, and they will improve the physics basis and demonstration of a long-pulse, high-performance tokamak.

	FY 2004	FY 2005	FY 2006
▪ **Alcator C-Mod Research**..	**8,268**	**8,636**	**8,433**

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 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 future, much larger fusion tokamaks, 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 2006, 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, noninductively 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. A 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. Active MHD spectroscopy, a novel method for sensing the onset of instability, will continue in FY 2006. The new lower hybrid (microwave) current drive system will be in operation, and experiments will continue using it for control of the current density profile. Challenges resulting from the use of higher power levels than ever before will be dealt with in relation to all of the particular efforts mentioned above.

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
▪ **International Collaborations**..	**4,802**	**4,863**	**4,860**

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 on the design of plasma diagnostics for the long-pulse, superconducting, advanced tokamak (KSTAR). These collaborations provide a valuable link with the 80% of the world's fusion research that is supported and conducted outside the United States.

International collaboration will continue on these unique facilities abroad at the same level of effort. In FY 2006, an expansion on joint International Tokamak Physics Activity (ITPA) with Japan, Europe, and Russia will continue to enhance collaboration on physics issues related to tokamak burning plasmas. In FY 2006, the collaborations with international programs will also focus on ways of using the unique aspects of these facilities to make progress on the four key MFE Science issues—energy transport, stability, plasma-wave interaction and boundary physics.

▪ **Diagnostics**..	**3,926**	**3,870**	**3,870**

Support of the development of unique measurement capabilities (diagnostic instruments) that provide an understanding of the plasma behavior in fusion research devices will continue. Some of this research supports diagnostics for burning plasma physics, which will be first demonstrated on current experiments such as DIII-D in the U.S. and JET in Europe (through collaborative programs) 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 2006 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. Currently supported programs underwent a competitive peer review in FY 2004.

▪ **Other**	**3,605**	**4,936**	**3,939**

Funding for educational activities in FY 2006 will support research at historically black colleges and universities, graduate and postgraduate fellowships in fusion science and technology, summer internships for undergraduates, a summer workshop for minority high school students, and outreach efforts related to fusion science and enabling R&D.

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
Alternative Concept Experimental Research	**57,319**	**60,874**	**49,940**

A significant amount of research is focused on alternative concepts, aimed at extending fusion science and identifying innovative 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.

▪ **NSTX Research**	**16,428**	**16,466**	**16,172**

NSTX is one of the world's two largest spherical torus confinement experiments. NSTX has a unique, nearly spherical plasma shape that complements the doughnut shaped tokamak and provides a test of the theory of toroidal magnetic confinement as the spherical limit is approached. Plasmas in spherical tori have been predicted to be stable even when high ratios of plasma-to-magnetic pressure and large self-driven current fractions exist simultaneously in the presence of a nearby conducting wall bounding the plasma. If these predictions are verified in detail, it would indicate that spherical tori use applied magnetic fields more efficiently than most other magnetic confinement systems and could, therefore, be expected to lead to more cost-effective fusion power systems. An associated issue for spherical torus configurations is the challenge of driving plasma current via radio-frequency waves or biased 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 velocity fast ions with a large radius of gyration relative to plasma size that could potentially lead to new plasma behaviors of interest. In FY 2006, NSTX will not operate, but the proposed funding will allow the NSTX national team to analyze data from FY 2004-2005 and carry out scenario modeling and planning for future experiments. This will help the NSTX team to achieve high plasma pressure and good energy confinement efficiency for pulse lengths much longer than the energy replacement time when operations resume in FY 2007.

▪ **Experimental Plasma Research**	**21,075**	**21,791**	**18,832**

With the emphasis on developing the fundamental understanding of the plasma science that underpins innovative fusion concepts, this research 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.

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.

Examples of the research being pursued in these experiments include:

- 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. Its goal is to demonstrate the feasibility of stabilizing instabilities in high pressure tokamak plasma 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 at the University of Wisconsin explores the symmetry characteristics that make quasisymmetrical stellarators different from all other toroidal confinement systems. It 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). The main experimental goal in FY 2006 is to form a clean RMF generated FRC so that detailed physics investigations of its energy confinement and transport characteristics could begin.
- Spheromaks are plasmas with self-organized internal plasma currents which generate magnetic fields that confine the plasma, eliminating 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 to create fusion reactions at a plasma density considerably higher than conventional Magnetic Fusion Energy (MFE), but using drivers considerably less powerful and cheaper than Inertial Fusion Energy. The main experimental objectives by FY 2006 are to produce high-density magnetized plasma with sufficient lifetime and to translate the magnetized plasma into a mock-up liner, and to resolve the issue of using a deformable liner or an alternative liner for compressing the plasma.
- 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.

A review is planned of all the major experiments with annual budgets of about $1,000,000 or more, with the intention of reducing the number of concepts pursued. The projects to be subjected to this review include the Spheromak experiment (SSPX) at Lawrence Livermore National Laboratory, the Field Reversed Configuration experiment at the University of Washington – Seattle, and the Magnetized Target Fusion experiment at the Los Alamos National Laboratory, together with the experiments that would be normally due for review in FY 2005.

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
▪ **High Energy Density Physics**	**13,876**	**15,341**	**8,086**

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. With a reduction of $7,255,000 in heavy ion beam research in FY 2006, research in heavy ion beams will be focused on studying the scientific basis for spatial and temporal compression of the beams to create extremely bright beams for high energy density physics research in the near term. The research efforts in Fast Ignition and high Mach number plasma jets will be retained at a level of about $3,000,000. Both Fast Ignition and dense plasma jets are exciting new fields of HEDP, which are attracting world-wide scientific attention. This is evidenced by the numerous papers on these two subjects at the recent 2004 American Physical Society Division of Plasma Physics meeting. The relativistic physics of thermal transport in Fast Ignition will be explored. Modest efforts will be initiated to explore experimental techniques to produce high Mach number, high density plasma jets in the laboratory, and study their application to HEDP. Research in this area will be guided by the recommendations of the recent Report of the Office of Science and Technology Interagency Working Group 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."

▪ **Madison Symmetrical Torus**..	**5,174**	**6,503**	**6,150**

The goal of the Madison Symmetric Torus (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 FY 2003, FY 2004 and FY 2005 will enable in FY 2006 productive studies 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 2006 will be to measure the improved confinement and sustainment in MST with greatly reduced dynamo activity.

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
▪ **National Compact Stellarator Experiment (NCSX)**	**766**	**773**	**700**

NCSX Research supports the research portion of the program to be executed with the NCSX Experiment at PPPL. This 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 systems. The NCSX team will adapt tools that are available, or being developed, to establish requirements and physics designs for magnetic diagnostic upgrades and e-beam mapping. Finally, a research forum will be held to invite and encourage participation by the U.S. community in the research and diagnostics preparations for NCSX.

Theory	**25,367**	**25,460**	**24,640**

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 industries. 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 while 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	**3,319**	**4,275**	**4,275**

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. In late FY 2004, a new round of FES SciDAC projects was initiated. The selected projects are focused on the topics of microturbulence simulation, extended magnetohydrodynamics modeling, and simulation of

	FY 2004	FY 2005	FY 2006

(dollars in thousands)

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. In late 2005, the FES program and the Advanced Scientific Computing Research program are planning to begin one or two prototype focused integration initiatives, based on a competitive peer review process.

In FY 2006, these prototype focused integration initiatives, along with the three continuing SciDAC projects, will emphasize the latest 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 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 advancements in computation should enable good progress on problems that once seemed intractable. The objective of the advanced computing activities, including the 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.

	FY 2004	FY 2005	FY 2006
General Plasma Science...	**11,876**	**12,341**	**13,900**

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, the Plasma Physics Junior Faculty Development Program and the basic and applied plasma physics program at DOE laboratories. In FY 2006, 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 plans to spend approximately $2,000,000 on the Fusion Science Center program each year in FY 2005 and FY 2006. 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.

	FY 2004	FY 2005	FY 2006
SBIR/STTR..	**0**	**6,966**	**6,251**

FY 2004 excludes $5,979,000 and $717,000 which was transferred to SBIR and STTR programs, respectively. The FY 2005 and FY 2006 amounts are the estimated requirements for the continuation of these programs.

	FY 2004	FY 2005	FY 2006
Total, Science..	**142,723**	**155,063**	**142,771**

Explanation of Funding Changes

	FY 2006 vs. FY 2005 ($000)
Tokamak Experimental Research	
▪ **DIII-D** This reflects the decrease in DIII-D research efforts consistent with the reduction in experimental operations reflected under the Facility Operations subprogram.	-179
▪ **Alcator C-Modification** This decrease will reduce the effort in experiments on controlling the tokamak current density by means of the lower hybrid microwave system.	-203
▪ **International** This decrease will reduce the effort slightly on the JET diagnostic collaboration.	-3
▪ **Other** The decrease will reduce funding for educational programs.	-997
Total, Tokamak Experimental Research	**-1,382**
Alternate Concept Experimental Research	
▪ **National Spherical Torus Experiment (NSTX)** Since NSTX will not be operating, less travel funding for collaborators is required.	-294
▪ **Experimental Plasma Research** This decrease will eliminate one major Innovative Confinement Concept from the program. In the reduction, $955,000 comes from a one-time add-on to several “small experiments” included in the FY 2005 appropriation.	-2,959
▪ **High Density Physics** This reduction will reduce the level of research on Heavy Ion Beams at the Lawrence Berkeley National Laboratory, the Lawrence Livermore National Laboratory, the Princeton Plasma Physics Laboratory, and university research supporting heavy ion beams at the University of Maryland, MIT, and elsewhere.	-7,255
▪ **Madison Symmetric Torus (MST)** This reduction reflects the one-time add-on in FY 2005 toward the partial purchase of the hardware components for a programmable power supply.	-353
▪ **National Compact Stellarator Experiment (NCSX)** This decrease will eliminate the establishment of requirements and physics designs for control algorithms and trim coils.	-73
Total, Alternative Concept Experimental Research	**-10,934**
Theory This decrease will eliminate support for one grant in the theory portfolio and result in the reduction of two scientists doing theory work at national laboratories.	-820

	FY 2006 vs. FY 2005 ($000)
General Plasma Science	
The increase will expand the number of grant applications funded under the NSF/DOE Partnership in Basic Plasma Science and Engineering, and fund the renewal and expansion of the DOE national laboratory-based Opportunities in Basic Plasma Science program.	+1,559
SBIR/STTR	
Support for SBIR/STTR is provided at the mandated level.	-715
Total Funding Change, Science	**-12,292**

Facility Operations

Funding Schedule by Activity

(dollars in thousands)

	FY 2004	FY 2005	FY 2006	$ Change	% Change
Facility Operations					
DIII-D	30,194	32,849	28,711	-4,138	-12.6%
Alcator C-Mod	14,014	13,402	13,097	-305	-2.3%
NSTX	19,189	18,069	14,535	-3,534	-19.6%
NCSX	15,921	17,500	15,900	-1,600	-9.1%
ITER Preparations	3,155	4,947	6,000	+1,053	+21.3%
ITER MIE TEC	0	0	46,000	+46,000	--
GPP/GPE/Other	3,217	3,176	3,276	+100	+3.1%
Total, Facility Operations	85,690	89,943	127,519	+37,576	+41.8%

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 new facilities such as NCSX, and for participation in the international collaboration on ITER through the preparation for and the start of the U.S. Contributions to ITER MIE project. TEC funds are budgeted in this sub-program. OPC funds are budgeted in Enabling R&D sub-programs.

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 also provided for the continuation of the National Compact Stellarator Experiment (NCSX) MIE project at PPPL. In FY 2006, the project will be in its fourth year; PPPL will continue with the fabrication of the device with the focus being on winding the modular coils and assembling the vacuum vessel.

Funding is also provided for ITER preparations, in which U.S. scientists and engineers in laboratories, universities, and industry will be involved in various technical activities that support both ITER negotiations for an international ITER program as well as planning for the U.S. Contributions to ITER project. This MIE is planned to start in mid-FY 2006 assuming negotiations are completed in FY 2005. U.S. activities in support of ITER will be managed by the U.S. ITER Project Office located at PPPL.

In the expectation that the U.S. Contributions to ITER MIE begins in FY 2006, funding is identified for the U.S. contributions of equipment, personnel, and limited amount of cash for the U.S. share of common costs on site such as installation and testing. As an MIE, the cost and schedule baselines will be managed in accordance with DOE Order 413.3 project management requirements. A Total Project Cost (TPC) funding profile is identified in the Significant Program Shifts section of the FES budget, consisting of Total Estimated Cost (TEC) funding requested in this subprogram and Other Project Costs (OPC) funding requested in the Enabling R&D subprogram. The TEC includes all direct costs for the MIE including all U.S. hardware procurements, hardware installation, U.S. personnel assigned to the ITER project abroad, cash for common needs such as ITER project infrastructure, contingency and operation of the U.S. ITER Project Office. The OPC includes R&D and design tasks in support of the procurements comprising the U.S. Contributions to ITER MIE. These OPC tasks will be performed by U.S. fusion scientists and engineers currently part of the fusion program.

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 2004 Facility Operations Accomplishments

In FY 2004, 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 completed the strengthening of the internal “plasma control” coils for stability experiments.
- PPPL NCSX has ordered both the modular coil winding forms and vacuum vessel sector prototypes from each of four industrial supplier teams and has received both vacuum vessel sector prototypes.

  PPPL awarded contracts to two industrial teams in October 2003 for manufacturing development of the NCSX modular coil winding forms. These are steel structures that support the modular coil windings and locate them to high accuracy. The purpose of these contracts was to develop the manufacturing processes for the forms through fabrication of full-scale prototypes. The project awarded a follow-on contract for the production order to one of these teams in early FY 2005. In addition, PPPL awarded contracts in October 2003 to two industrial suppliers for manufacturing development of the NCSX vacuum vessel. The vacuum vessel is a highly shaped structure with stringent requirements on vacuum quality and magnetic permeability. The purpose of these contracts was to develop the manufacturing processes to be used in the fabrication of the vessel through fabrication of a prototype sector. Just like the modular coil winding forms, the project awarded a follow-on contract for the production order to one of these suppliers in early FY 2005.

- Operation of Alcator C-Mod was extended at high field to plasma currents up to 2 million amperes, opening up new operational space for physics investigations.
- New non-axisymmetric magnetic field coils were designed, constructed, and installed on Alcator C-Mod and are now in routine operation. They provide a critical new tool to investigate the effects of error fields on the dynamics of MHD instabilities, and have permitted the extension of operation to higher plasma currents.

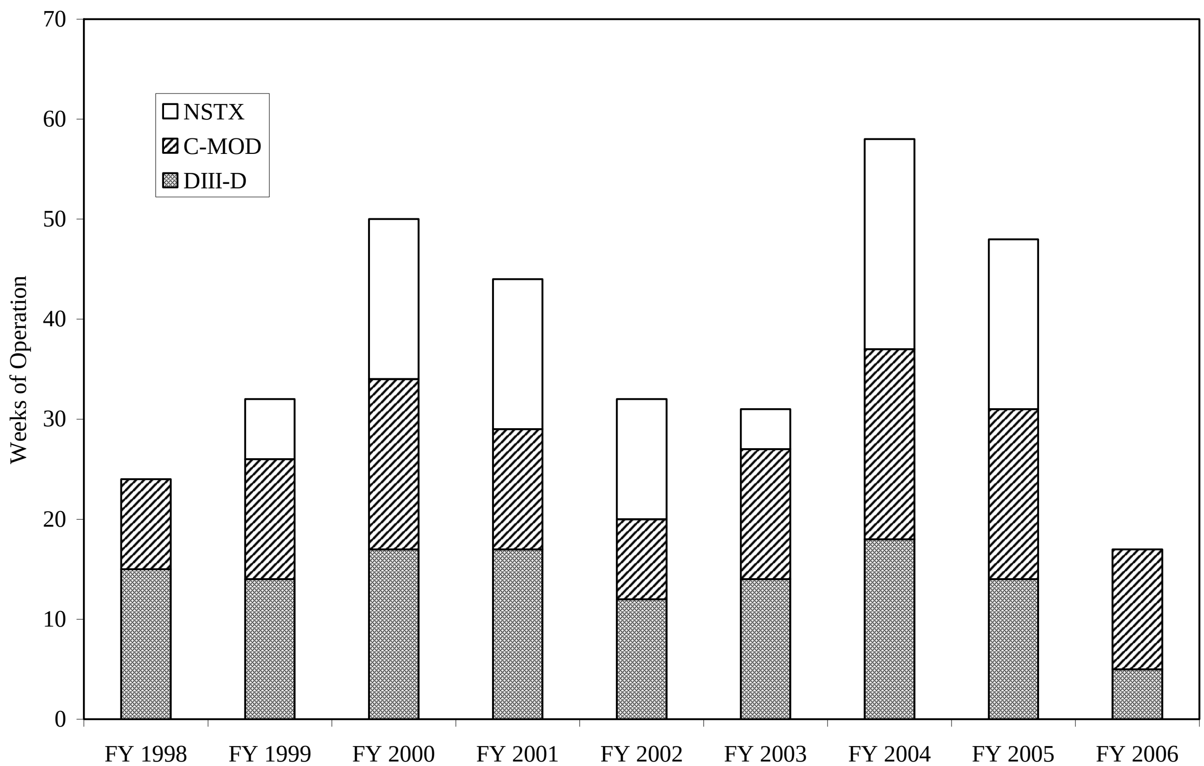
The table and chart below summarize the recent and longer-term history of operation of the major fusion facilities.

Weeks of Fusion Facility Operation

(weeks of operations)

	FY 2004 Results	FY 2005 Target	FY 2006 Target
DIII-D	18	14	5
Alcator C-Mod	19	17	12
NSTX	21	17	0
Total	58	48	17

Historical Perspective on Operations
of the Major Fusion Experimental Facilities



Detailed Justification

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
DIII-D	**30,194**	**32,849**	**28,711**

Provide support for operation, maintenance, and improvement of the DIII-D facility and its auxiliary systems. In FY 2006, these funds support 5 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 completing the rotation of a neutral beam line and modest progress on other high priority DIII-D upgrades and refurbishments.

Alcator C-Mod	**14,014**	**13,402**	**13,097**

Provide support for operation, maintenance, and improvement of the Alcator C-Mod facility and its auxiliary systems. In FY 2006, 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.

National Spherical Torus Experiment (NSTX)	**19,189**	**18,069**	**14,535**

Provide support for maintenance and minor upgrades, such as an imaging reflectometer, a neutron collimator, and an additional laser for the Thomson scattering system. In FY 2006, there is no funding for operation, only for minor facility upgrades that will enable long pulse, high beta experiments in the future. This reduction in operating weeks will delay progress in all areas of spherical torus research on NSTX.

National Compact Stellarator Experiment (NCSX)	**15,921**	**17,500**	**15,900**

Funding in the amount of $15,900,000 is requested 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-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 current total estimated cost (TEC) of NCSX increases to $90,839,000, with completion estimated to be in May 2009. A new cost and schedule performance baseline will be developed consistent with the FY 2006 budget request and expected out years in the mid-2005 time frame.

A key performance target for FES is to keep the cost-weighted mean percent variance for the NCSX project's cost and schedule baseline within 10%. To maintain this target, FES must monitor NCSX progress closely throughout the fiscal year. Utilizing PART, as well as effective project management both at DOE and PPPL, the project continues to be well within the 10% variance.

ITER Preparations	**3,155**	**4,947**	**6,000**

Funding in the amount of $6,000,000 is provided to continue to completion the ITER transitional activities such as safety, licensing, project management, preparation of specifications and system integration. U.S. personnel will participate in these activities in preparation for U.S. participation in the international ITER project. In addition, preparations will be made to qualify U.S. vendors to supply

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006

equipment for the project. The ITER Preparations activity is not part of the U.S. Contributions to ITER MIE, but is in preparation for the MIE. 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)	**0**	**0**	**46,000**

U.S. Contributions to ITER is a proposed MIE which supports the international project called ITER, whose mission is to demonstrate the scientific and technological feasibility of fusion energy and whose design and supporting R&D were essentially completed during the period 1992 to 2001. Currently, the U.S. is negotiating an international agreement with the European Union (EU), Japan, Russian Federation, China and South Korea not only for the fabrication of the facility, but also the operation, deactivation and decommissioning of ITER. For each of the ITER program phases, the U.S. is negotiating financial participation at approximately the 10% level. After the negotiated international agreement is completed and initialed by the negotiators and then signed by the parties' governments, an ITER legal entity would exist. Following the appointment of a Director General, the ITER Organization, which will be formed from personnel from all the parties and will be responsible for the realization of the ITER facility and program, would mobilize at the ITER site. The current schedule for these events is consistent with the need for all parties to begin their contributions to ITER in mid-FY 2006.

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 and procedures in support of long-lead procurement for the manufacture of the components.

DOE's involvement with ITER at the international site will be consistent with a level of participation of about 10% as one of five non-host participants. In addition to scientists and engineers assigned to the ITER Organization, the U.S. 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.

First year funding is required in FY 2006 for the MIE for procurement of long lead hardware, for 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, installation and testing of U.S. supplied hardware), contingency, and operation of the U.S. ITER Project Office (responsible for management of U.S. Contributions to ITER including management, quality assurance, procurement, and technical follow of procurements).

The U.S. ITER Project Office, a partnership of Princeton Plasma Physics Laboratory (PPPL) and Oak Ridge National Laboratory, will manage the U.S. Contributions to ITER MIE: specifically the component procurements, provision of U.S. personnel joining the international legal entity managing the ITER project (the ITER Organization) abroad, and the provision of cash for common needs. 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 U.S. ITER Project Office is expected to rely upon experts throughout the fusion program for technical assistance in the 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 the project office.

The U.S. ITER Project Office has the appropriate infrastructure and experience for the procurement and project management functions necessary to carry out this task in accordance with DOE Project Management Order 413.3, and also has extensive experience in the fusion energy sciences program.

The provisional list of U.S. hardware contributions, also called "in-kind" contributions to ITER, is indicated below. The ITER International Agreement is currently being negotiated and is expected to be completed by the end of FY 2005. The Agreement will finalize the current provisional list of equipment to be provided by each ITER Party 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.

- Niobium Tin (Nb3Sn) Superconducting Strand – Niobium, tin and copper filaments formed into long strands.
- Superconducting Cable - multi-stage cable including strand, insulation wraps and central spiral spring for cooling path.

	(dollars in thousands)	
FY 2004	FY 2005	FY 2006

- Central Solenoid Coil - the U.S. has the lead role for this contribution consisting of 4 of the 7 modules; 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), 10% of the first wall area, 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 includes High Voltage DC supplies, Radio Frequency Heating sources, and transmission lines, de-coupler, and tuning requirements.
- Heating and Current-Drive Components for Electron Cyclotron Heating frequencies - a U.S. contribution includes transmission lines, twenty-four DC power supplies, and three 1MW 120GHv gyrotrons.
- 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.
- 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 Agreement is completed, following which the baseline scope, cost and schedule for the MIE project will be established. However, the overall TPC for this MIE project will not change with the exception of possible changes to 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				Total Estimated Costs ($000)
	Procurements Initiated	Procurements Complete	Personnel Assignments to Foreign Site Start	Personnel Assignments to Foreign Site Complete	
FY 2006 Budget Request (Preliminary Estimate)..................	3Q FY 2006	4Q FY 2012	2Q FY 2006	4Q FY 2013	1,038,000

Financial Schedule
Total Estimated Cost (TEC)

(budget authority in thousands)

Fiscal Year	MIE TEC
2006	46,000
2007	130,000
2008	182,000
2009	191,000
2010	189,000
2011	151,000
2012	120,000
2013	29,000
Total	1,038,000

Note, the Other Project Costs associated with these MIE TEC funds are budgeted in the Enabling R&D subprogram.

(dollars in thousands)

	FY 2004	FY 2005	FY 2006
General Plant Projects/General Purpose Equipment/Other	**3,217**	**3,176**	**3,276**

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 move of ORNL fusion personnel and facilities to a new location at ORNL.

Total, Facility Operations..	**85,690**	**89,943**	**127,519**

Explanation of Funding Changes

	FY 2006 vs. FY 2005 ($000)
DIII-D	
This decrease will result in curtailing or deferring some facility modifications and refurbishments and conducting 5 weeks of operation, a decrease of nine weeks from the FY 2005 planned operation.	-4,138

	FY 2006 vs. FY 2005 ($000)
Alcator C-Mod	
The decrease, when combined with increased costs for materials and services, will reduce the number of weeks of operation by five (compared to FY 2005) to 12 weeks.	-305
NSTX	
This decrease will eliminate operating time in FY 2006, a reduction of seventeen weeks compared to FY 2005 planned operations.	-3,534
NCSX	
This decrease will delay the procurement of some of the equipment for this MIE.	-1,600
GPP/GPE/Other	
This increase will allow continued improvement of the physical infrastructure at PPPL and continue the process of moving fusion personnel from the Y-12 site to the X-10 site at ORNL.	+100
ITER Preparations	
This increase allows final U.S. preparations for participation in the international ITER project to be completed during FY 2006, including additional funds for vendor qualification and project management preparations	+1,053
U.S. Contributions to ITER (MIE Total Estimated Cost)	
This funding initiates the TEC funding for the Major Item of Equipment project entitled U.S. Contributions to ITER..	+46,000
Total Funding Change, Facility Operations	**+37,576**

Enabling R&D

Funding Schedule by Activity

(dollars in thousands)

	FY 2004	FY 2005	FY 2006	$ Change	% Change
Enabling R&D					
Engineering Research	19,817	21,574	16,760	-4,814	-22.3%
Materials Research	7,629	7,323	0	-7,323	-100.0%
Enabling R&D for ITER	0	0	3,500	+3,500	--
Total, Enabling R&D	27,446	28,897	20,260	-8,637	-29.9%

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 liquid surface approaches to control plasma particle density and temperature, microwave generators with tunable frequencies and steerable launchers for fine control over plasma heating and current drive, and magnet technologies that could improve plasma confinement. This element includes research on tritium technologies that will be needed to produce, control, 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.

For the Materials Research element, no activities will be conducted. The substantial international effort on fusion materials research will be monitored, as will the work on nanosystems and computational materials science funded by the Basic Energy Sciences program and other government-sponsored programs.

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.

Research efforts will continue on the domestic plasma experiments and on the scientific foundations of innovative technology concepts for use in future experiments. Selected efforts will be redirected from the Engineering Research area to a new Enabling R&D for ITER category to concentrate on specific R&D supporting U.S. responsibilities for ITER procurement packages. In addition, some of these funds will be reoriented from the Materials Research area for R&D and design support in a number of areas, including magnets, plasma facing components, tritium processing, fueling and pumping, heating and current drive, and diagnostics, which support ITER.

Technology Accomplishments

A number of technological advances were made in FY 2004. Examples include:

- The electron cyclotron heating system on DIII-D tokamak at General Atomics was upgraded to 6 MW and was used in experimentation. A load tolerant prototype antenna was fabricated and successfully tested for the Joint European Torus program as part of the International Collaborations activity in the Science subprogram.
- PPPL completed a series of experiments in the Current Drive Experiment-Upgrade (CDX-U) to study the feasibility of liquid lithium surface plasma-facing components, which have the potential for higher surface heat and particle removal than solid surface components now in use. A toroidal tray near the bottom of the CDX-U was filled with liquid lithium, exposing plasma discharges to a large surface area of the liquid. With improvements made to achieving a high degree of surface cleanliness, substantial levels of particle removal took place and both plasma current and discharge duration were increased by 30% relative to discharges without the liquid lithium. The success of these experiments has provided the basis for decisions to develop lithium surface technology for NSTX, initially in the form of solid lithium coatings and eventually as a flowing liquid lithium module capable of highly efficient particle removal at high surface heat fluxes.
- The Safety and Tritium Applied Research (STAR) facility at the Idaho National Laboratory achieved full scale tritium operations capability. The STAR facility, which has been declared a National User Facility, provides a laboratory for fusion research pertaining to properties associated with tritium chemistry and material interactions. It also provides unique capabilities to conduct tritium safety experiments for current and future fusion facilities, such as ITER.
- The University of California, San Diego (UCSD), in collaboration with European laboratories, completed the first phase of experiments in the Plasma Interactive Surface Component Experimental Station (PISCES), a plasma edge simulation facility, to evaluate the potential for tritium accumulation in the ITER plasma chamber. Substantial accumulation of tritium in ITER could limit

its operating time if safety-related tritium inventory limits are reached. With its unique capability in the world to simulate the edge conditions of the ITER plasma with all of the materials to be used on the ITER plasma chamber (i.e., carbon, beryllium, and tungsten), experiments in the PISCES facility indicated that the presence of beryllium tends to suppress erosion of carbon surfaces, which could reduce tritium accumulation due to tritium bonding with carbon. The experiments are being used to identify means for mitigating formation of carbon deposits so that tritium accumulation will not be a major interference with ITER operation.

Detailed Justification

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
Engineering Research	**19,817**	**21,574**	**16,760**
▪ **Plasma Technology**	**13,615**	**18,411**	**14,200**

Engineering research efforts will continue on critical needs of domestic plasma experiments, on ITER R&D preparations and on the scientific foundations of innovative technology concepts for use in future experiments. In FY 2006, $3,500,000 is redirected to support the ITER OPC R&D efforts. Nearer-term experiment support efforts will be oriented toward plasma facing components and plasma heating and fueling technologies, while longer term efforts focus more on new concepts for surface heat and particle removal, tritium material science and safety research. During FY 2006, the following specific elements will be pursued:

- Testing of a super efficient (over 60 %) 110 gigahertz, 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.
- Testing of a high speed, compact vertical pellet injector system relevant to the fueling requirements of next step experiments will also be completed.
- Based on the experimental research and initial designs during FY 2005 for a first-generation system that allows flowing lithium to interact directly with the plasma, potentially revolutionizing the approach to plasma particle density and edge temperature control in plasma experiments, the preliminary design of a lithium module for future deployment in NSTX will be completed during FY 2006.
- Studies will continue in the PISCES facility at the University of California at San Diego, 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.
- In the STAR facility at INL, the final series of material science experiments will be initiated under a cost-sharing collaboration with Japan to resolve key issues of tritium behavior in materials proposed for use in fusion systems.
- Additional funds will be provided for plasma chamber design and analysis, as well as for research on heat extraction and processing technologies for blanket concepts that will be tested in ITER.
- Funds will be provided for research on superconducting magnets, which can be used in future experiments.

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006

- Funds will also be provided for safety research, and innovative technology research in the area of plasma-surface interaction sciences that will enable fusion experimental facilities to achieve their major scientific research goals and full performance potential.

▪ **Fusion Technology**..	**3,038**	**0**	**0**

The final year of funding for Fusion Technology efforts was FY 2004 in order to focus on research relevant to ITER. No activities are planned for FY 2005 and FY 2006.

▪ **Advanced Design**..	**3,164**	**3,163**	**2,560**

Funding for this effort will continue to focus on studies of compact stellarators. 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.

Materials Research	**7,629**	**7,323**	**0**

Materials Research efforts, which were focused on long-term development of structural materials for the chambers of fusion energy systems that might be constructed beyond ITER, are being terminated to provide resources for higher priority and nearer term activities.

Enabling R&D for ITER (Other Project Costs)	**0**	**0**	**3,500**

Enabling R&D funds for ITER activities are identified in FY 2006 for the start of the U.S. Contributions to ITER MIE. Funds are needed 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, materials, and diagnostics, which would be provided by the U.S. to 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 managed using DOE Order 413.3 project management tools for controlling schedule, cost and scope.

It is important to note that the ITER International Agreement is currently being negotiated and is expected to be completed by the end of FY 2005. The Agreement will finalize the current provisional list of equipment to be provided by each ITER Party 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 MIE project cost estimates for U.S. Contributions to ITER, including the Other Project Cost activities, are preliminary until the Agreement is completed, following which the baseline scope, cost and schedule for the MIE project will be established. However, the overall TPC for this MIE project will not change with the exception of possible changes to 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.

For the most part, these activities will be accomplished by focusing these same 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 2006, the following specific elements will be pursued:

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006

- Conduct R&D to support fabrication and final design of the first wall shield module for ITER.
- Conduct R&D to support qualification for manufacturing superconducting strand and jacket material for the ITER Central Solenoid.
- Conduct R&D to support design of two key systems, the high throughput continuous extruder and centrifuge accelerator, of the ITER Pellet Injector.
- Conduct R&D to support design of the ITER Fuel Cleanup System and develop a dynamic process modeling code of the ITER tritium system.
- Conduct R&D to support design of the ITER heating antenna.
- Conduct R&D 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)

(budget authority in thousands)

Fiscal Year	Other Project Costs
2006	3,500
2007	16,000
2008	18,800
2009	16,500
2010	10,300
2011	9,300
2012	6,200
2013	3,400
Total	84,000

Note, the MIE TEC funding associated with these Other Project Costs is budgeted in the Facility Operations subprogram.

	FY 2004	FY 2005	FY 2006
Total, Enabling R&D	**27,446**	**28,897**	**20,260**

Explanation of Funding Changes

	FY 2006 vs. FY 2005 ($000)
Engineering Research	
▪ **Plasma Technology**	
This decrease reflects a $3,500,000 redirection to R&D for ITER (MIE OPC) for efforts in magnets, plasma facing components, heating and fueling technologies, and a $711,000 reduction in a number of research areas including test blankets, tritium technology, safety, plasma facing components, heating and neutronics.	-4,211
▪ **Advanced Design**	
This decrease reflects the shift of the next step options program to more direct support of ITER R&D needs, and a slight reduction in support for the management of the Virtual Laboratory for Technology.	-603
Total, Engineering Research	**-4,814**
Materials Research	
Materials Research, which generally consists of longer range materials activities, will be terminated in FY 2005 and no activities are planned for FY 2006.	-7,323
Enabling R&D for ITER (MIE Other Project Costs)	
Funding is redirected from Plasma Technology to focus efforts in support of ITER in the magnet, plasma facing components, tritium processing, fueling and pumping, heating and current drive, materials and diagnostics areas.	+3,500
Total Funding Change, Enabling R&D	**-8,637**

Capital Operating Expenses and Construction Summary

Capital Operating Expenses

(dollars in thousands)

	FY 2004	FY 2005	FY 2006	$ Change	% Change
General Plant Projects	1,735	1,643	1,810	+167	+10.2%
Capital Equipment	23,229	23,488	65,504	+42,016	+178.9%
Total, Capital Operating Expenses	24,964	25,131	67,314	+42,183	+167.9%

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 2004	FY 2005	FY 2006	Acceptance Date
NCSX	103,251	90,839	7,897	15,921	17,500	15,900	FY 2009[a]
U.S. Contributions to ITER	1,122,000[b]	1,038,000[b]	0	0	0	46,000	FY 2013
Total, Major Items of Equipment				15,921	17,500	61,900	

[a] The FY 2005 Congressional budget reflected an estimated TEC range for NCSX of $87,000,000 - $89,000,000 with a completion range of FY 2008-FY 2009. The current estimated TEC is $90,839,000 with completion in May 2009. A new cost and schedule performance baseline will be developed in mid-FY 2005.

[b] Funding initiates 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) OFES estimates for personnel to be assigned abroad consistent with previous experience during the ITER Engineering Design Activities, (3) U.S. cash contributions for a 10% participant in the ITER project, and (4) OFES estimates for operation of the U.S. ITER Project Office including technical oversight of procurement.