Fusion Energy Sciences

Funding Profile by Subprogram

(dollars in thousands)

	FY 2003 Comparable Appropriation	FY 2004 Original Appropriation	FY 2004 Adjustments	FY 2004 Comparable Appropriation	FY 2005 Request
Fusion Energy Sciences					
Science	136,198	150,660	0	150,660	150,815
Facility Operations	66,198	86,087	-1,555[a]	84,532	85,495
Technology	38,299	27,363	0	27,363	27,800
Subtotal, Fusion Energy Sciences	240,695	264,110	-1,555[a]	262,555	264,110
Use of Prior Year Balances	0	-529	0	-529	0
Total, Fusion Energy Sciences	240,695[bc]	263,581	-1,555[a]	262,026	264,110

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 basic research effort to advance plasma science, fusion science, and fusion technology—the knowledge base needed for an economically and environmentally attractive fusion energy source.

Benefits

Fusion is the energy source that powers the sun and stars. In the fusion process, nuclei of light elements such as hydrogen, fuse together to make heavier elements such as helium, giving off tremendous amounts of energy. Fusion could play a key role in U.S. long-term energy plans because it offers the potential for plentiful, safe and environmentally benign energy. A fusion power plant would produce no greenhouse gas emissions, use abundant and widely distributed sources of fuel, shut down easily, require no fissionable materials, operate in a continuous mode to meet demand, and produce manageable radioactive waste. A science-based approach to fusion offers the fastest 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

[a] Excludes $1,555,128 for a rescission in accordance with the Consolidated Appropriations Act, 2004, as reported in conference report H.Rpt. 108-401, dated November 25, 2003.

[b] Excludes $5,837,000 which was transferred to the SBIR program and $350,000 which was transferred to the STTR program.

[c] Excludes $1,615,228 for a rescission in accordance with the Consolidated Appropriations Resolution, FY 2003.

materials coatings, the efficient destruction of chemical and radioactive wastes, and more efficient space propulsion.

Strategic and Program Goals

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

Energy Strategic Goal
General Goal 4, Energy Security: Enhance energy security by developing technologies that foster a diverse supply of affordable and environmentally sound energy, improving energy efficiency, providing for reliable delivery of energy, exploring advanced technologies that make a fundamental change in our mix of energy options, and guarding against energy emergencies.

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, to advance the frontiers of knowledge in physical sciences and areas of biological, medical, environmental, and computational sciences, and to provide world-class research facilities for the Nation's science enterprise.

The FES program has one program goal which contributes to General Goals 4 and 5 in the "goal cascade":

Program Goal 04.24.00.00/05.24.00.00: Bring the power of the Stars to Earth — Answer the key scientific questions and overcome enormous technical challenges to harness the power that fuels a star.

Contribution to Program Goal 04.24.00.00 (Energy Security)
The Fusion Energy Sciences program contributes to this goal through participation in ITER, an experiment to demonstrate the sustained burning of fusion fuel. The next frontier in fusion science is a sustained, burning (or self-heated) plasma. 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 endorsed this strategy in December 2002 (and more recently, in November 2003). Based in part on these recommendations, plus an Office of Science assessment of the cost estimate for the construction of ITER, the President decided in January 2003 that the U.S. should join the ITER negotiations. This proposed international collaboration will test the scientific and technical feasibility of fusion power. In FY 2003, DOE began leading U.S. participation in the negotiations and supporting technical activities preparing the project for construction beginning in 2006.

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

The Fusion Energy Sciences 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) focusing on non-neutral plasma physics and high energy density physics; 6) developing the cutting edge technologies that enable fusion facilities to achieve their scientific goals; and 7) advancing the science base for innovative materials.

These activities require operation of a set of unique and diversified experimental facilities, ranging from smaller-scale university devices to larger national facilities that require extensive collaboration. These facilities provide scientists with the means to test and extend theoretical understanding and computer models—leading ultimately to an improved predictive capability for fusion science.

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

1. **Predictive Capability for Burning Plasmas:** Develop 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.
2. **Configuration Optimization:** Demonstrate enhanced fundamental understanding of magnetic confinement and improved basis for future burning plasma experiments through research on magnetic confinement configuration optimization.
3. **Inertial Fusion Energy and High Energy Density Physics**: Develop the fundamental understanding and predictability of high energy density plasmas.

Annual Performance Results and Targets

FY 2000 Results	FY 2001 Results	FY 2002 Results	FY 2003 Results	FY 2004 Targets	FY 2005 Targets
Program Goal 04.24.00.00/05.24.00.00 (Energy Security/World-Class Scientific Research Capacity)					
Facility Operations					
	Kept deviations in weeks of operation for each major facility within 10 percent of the approved plan. [met goal]	Kept deviations in weeks of operation for each major facility within 10 percent of the scheduled weeks. [met goal]	Kept deviations in weeks of operation for DIII-D and Alcator C-Mod each major facility within 10 percent of the approved plan. NSTX did not meet the target because of a coil joint failure. [Did not meet 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 percent 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 percent 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 percent 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%.	Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%.
			Completed the National Compact Stellarator Experiment (NCSX) Conceptual Design and began Preliminary Design. [met goal]		

Means and Strategies

The Fusion Energy Sciences program will use various means and strategies to achieve its program goals. However, various 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 self-sustained plasma reaction in a burning plasma physics experiment. The proposed international burning plasma experiment called ITER is the focal point of burning plasma fusion research around the world, and the Administration has decided to join the negotiations to conduct this experiment. In light of this decision, many elements of the fusion program that are broadly applicable to burning plasmas will now be 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. The U.S. funding commitment to ITER will increase significantly in the future as the project moves to construction and eventually to science operations.

Scientists from the United States participate in leading edge scientific experiments on fusion facilities abroad, and conduct comparative studies to supplement the scientific understanding they can obtain 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). These collaborations provide a valuable link with the 80 percent 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) that 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 Atomic Energy Implementing Agreements on tokamaks. In FY 2004, the United States began participating in the ITER Transitional Arrangements activities preparing the project for construction beginning in 2006.

All research projects undergo regular peer review and merit evaluation based on SC-wide procedures set down in 10 CFR 605 for the extramural grant program, and under a similar modified process for the laboratory programs and scientific user facilities. All new projects are selected by peer review and merit evaluation. FES formally peer reviews their scientific user facilities to assess the scientific output, user satisfaction, and the overall cost-effectiveness of each facility’s operations, and their ability to deliver the most advanced scientific capability to its user 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; user 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 construction of scientific facilities. In FES, construction of major research facilities has generally been on time and within budget. User facilities have as a goal to be operated and maintained so they operate more than 90%, 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) the 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 user 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 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 Budget Request and has taken or will take the necessary steps to continue to improve performance.

In the PART review, OMB gave the Fusion Energy Sciences (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. Although FES is establishing a Committee of Visitors (COV) to provide outside expert validation of the program's merit-based review processes for impact on quality, relevance, and performance, and this committee has met and prepared its report, FESAC has not yet met to receive the report. Once the COV issues a report, FES will develop an action plan to respond to the findings and recommendations within 30 days. The assessment found that FES has developed a limited number of adequate performance measures. However, OMB noted concerns regarding the collection and reporting of performance data. To address these concerns, FES will work with its Advisory Committee to develop research milestones for the long-term performance goals, will include the long term research goals in grant solicitations, will work to improve performance reporting by grantees and contractors, and will work with the CFO to improve FES sections of the Department's performance documents. The Administration strongly supports efforts to explore possible U.S. participation in ITER. OMB found that the FES budget is 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. FES will engage its advisory committee to prepare a top-to-bottom scientific prioritization for U.S. fusion and will then develop a strategic plan, based upon that input, by September 2005.

Funding by General and Program Goal

(dollars in thousands)

	FY 2003	FY 2004	FY 2005	$ Change	% Change
General Goal 4, Energy Security					
Program Goal 04.24.00.00, Advance Plasma Science, Fusion Science, and Fusion Technology					
Facility Operations: ITER	0	3,000[a]	7,000[b]	+4,000	+133.3%
General Goal 5, World-Class Scientific Research Capacity					
Program Goal 05.24.00.00, Advance Plasma Science, Fusion Science, and Fusion Technology					
Science	136,198	150,660	150,815	+155	+0.1%
Facility Operations: Non-ITER	66,198	81,532	78,495	-3,037	-3.7%
Technology	38,299	27,363	27,800	+437	+1.6%
Total, Program Goal 05.24.00.00, Advance Plasma Science, Fusion Science, and Fusion Technology	240,695	259,555	257,110	-2,445	-0.9%
Total, General Goal 4 and 5 (Fusion Energy Sciences)	240,695	262,555	264,110	+1,555	+0.6%
Use of Prior Year Balances	0	-529	0	+529	+100.0%
Total, Fusion Energy Sciences	240,695	262,026	264,110	+2,084	+0.8%

Overview

Fusion science is a subfield of plasma science that deals primarily with studying the fundamental processes taking place in plasmas where the temperature and density approach the conditions needed to allow the nuclei of two low-mass elements, like hydrogen isotopes, 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, where strong magnetic fields constrain the charged plasma particles, and inertial, where laser or particle beams compress and heat the plasma during very short pulses. Most of the world's fusion energy research effort, the U.S. included, is focused on the magnetic approach. But NNSA's supports a robust program in inertial fusion for stockpile stewardship but also provides a base for Fusion Energy Science work in this area. Thus FES depends on NNSA for the physics of the target-driver interaction.

[a] Reflects $3,000,000 in direct funding for ITER preparations. An additional $5,000,000 for ITER supporting activities is reflected within goal 5, bringing the total Fusion program resources in preparation for ITER to $8,000,000 in FY 2004.

[b] Reflects $7,000,000 in direct funding for ITER preparations. An additional $31,000,000 for ITER supporting activities is reflected within goal 5, bringing the total Fusion program resources in preparation for ITER to $38,000,000 in FY 2005.

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 outward to the plasma edge and to the material walls as a result of electromagnetic turbulence in the plasma (chaos, turbulence, and transport),
- the stability of the magnetic configuration and its variation in time as the plasma pressure, density, turbulence level, and population of high energy fusion products change (stability, reconnection, and dynamo),
- the role of the colder plasma at the plasma edge and its interaction with both material walls and the hot plasma core (sheaths and boundary layers),
- 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 (wave-particle interaction), 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 Theory and Modeling, as well as General Plasma Science;
- Configuration Optimization, that includes experiments on advanced tokamaks, magnetic alternates, and inertial fusion concepts, as well as facility operations and technology; and
- Materials, that includes fusion specific materials science closely coupled to the 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 the Fusion Energy Sciences (FES) program governance is the funding, management, and oversight of the program. FES has established an open process for obtaining scientific input for major decisions, such as 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 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 containing its advice and recommendations to the Department.

During FY 2001 and 2002, the Department undertook a multi-step process to plan the future directions of the FES program. In October 2000, the FESAC was charged to address the scientific issues of burning plasma physics. In its September 2001 report "Review of Burning Plasma Physics" (DOE/SC-0041), FESAC stated that "*Now*" is the time to take steps leading to the expeditious construction of its finding that a burning plasma experiment would bring enormous scientific benefits and technical rewards not only to the fusion program, but to several other fields as well. FESAC also found that the present scientific understanding and technical expertise were sufficient to allow such an experiment, no matter how challenging, to succeed with a high degree of confidence.

In the summer of 2002, at a two-week workshop involving a large part of the fusion research community, a statement about the need for burning plasma research received unanimous support of the attendees. In addition, a uniform technical assessment of the three leading proposals for a burning plasma experiment was developed.

With these steps in hand, FESAC that had been charged in February 2002 to recommend a strategy for burning plasma experiments, issued its report, "A Burning Plasma Program Strategy to Advance Fusion Energy" (DOE/SC-0060) in September 2002. The report states that the world effort to develop fusion is at a threshold of a new state in its research: the investigation of burning plasmas. This investigation, at the frontier of the physics of complex systems, would be a huge step in establishing the potential of magnetic fusion to contribute to the world's energy security. The report then outlines a consistent, aggressive strategy, taking advantage of international efforts, to develop the science and technology of plasmas.

These three steps fit together with the recommendation from the NRC following its review of burning plasmas, Burning Plasma: Bringing a Star to Earth", September 2003, in which NRC recommends that the United States participate in ITER, a burning plasma experiment and one of the three approaches assessed technically during the summer workshop in 2002.

A variety of other committees and groups provide input to program planning. Ad hoc activities by fusion researchers, such as the 2002 Snowmass meeting, 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. As noted, the National Research Council, who's 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 formed primarily from 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 programs 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 field work proposals for funding of both new and ongoing activities. These are subject to peer review according to procedures that are patterned after those given in 10 CFR Part 605 that govern 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 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. The CoV should not only report on process, but on how this process impacts the substance of the program quality, and perceived gaps in the overall research portfolio supported by the program under review. The CoVs should be answering questions such as: Are the best people and proposals being funded, and if not, why not?; Are the right reviewers being chosen?; Are the common variety of approaches to merit review (e.g., mail, panel, etc.) and competition being used in an appropriate manner?; Are poorly-rated proposals funded, and if so, why? The first CoV review will address the theory and computation program, reporting its result to the Department by March 2004.

Planning and Priority Setting

The FESAC carries out an invaluable role in the fusion program by identifying critical scientific issues and providing advice on medium- and long-term goals to address these issues.

The National Research Council (NRC), in its report on the Department's strategy for addressing the science of a burning plasma, recommended that a new effort be made to integrate the U.S. participation in the ITER project into the U.S. domestic program. The NRC report stated that this integration should be defined through a prioritized balancing of the content, scope, and level of the U.S. activities in fusion. The fusion community and FESAC were ready to act on this recommendation, and so the FESAC has been charged to assist the Department and the community in establishing priorities for the fusion program. The FESAC panel that will address this charge will 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 priority order in which those campaigns will be pursued. FESAC's report on this activity is scheduled to be completed in July 2004.

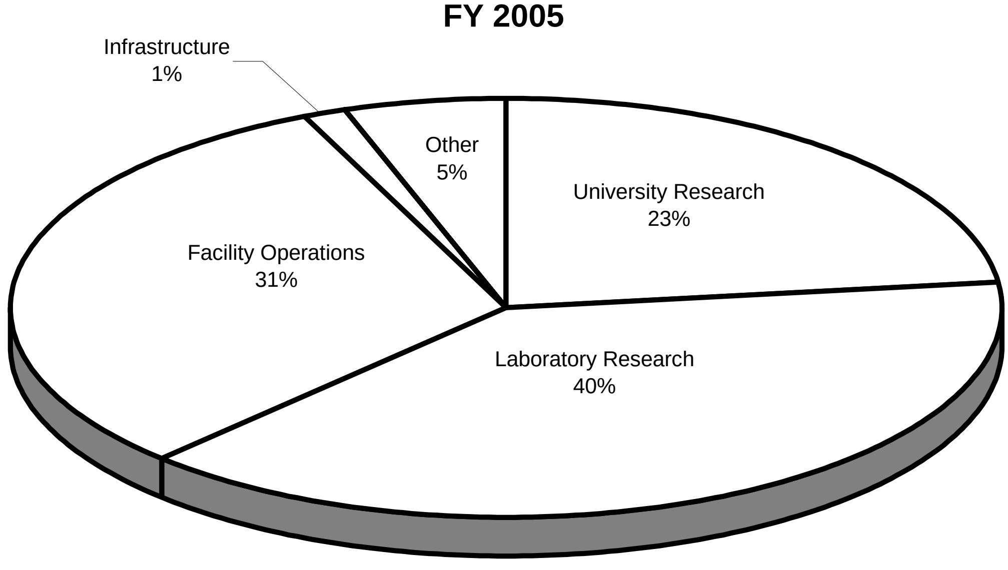
A variety of sources of information and advice, as noted above under the heading "Advisory Activities," are integrated with peer reviews of research proposals and when combined with high-level program reviews and assessments provide the basis for prioritizing program directions and allocations of funding.

How We Spend Our Budget

The FES budget has three components: Science, Facility Operations, and Technology. 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). 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 undergoes periodic scrutiny by the FESAC. The following chart illustrates the allocation of funding to the major program elements.

Fusion Energy Sciences Budget Allocation FY 2005



Research

The DOE fusion energy sciences program involves over 1,100 researchers and students at more than 70 U.S. academic, federal, and private sector institutions. The program funds research activities at 67 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 user science facility at 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 peers review proposals submitted in response to announcements of opportunity and funding is 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.

- **National Laboratory and Private Sector Research**

  The Fusion Energy Sciences program 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, and Los Alamos National Laboratory. In addition, one of the major research facilities is located at and operated by General Atomics in San Diego, California. The laboratory programs are driven by the needs of the Department, and research and development carried out there is tailored to take specific advantage of the facilities and broadly based capabilities found at the laboratories.

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

Significant Program Shifts

The budget requested for FY 2005 is slightly above the FY 2004 Appropriation. The FY 2005 budget continues the redirection of the fusion program to prepare for participation in the ITER program, while also supporting many of the program priorities recommended by the Fusion Energy Sciences Advisory Committee and supported by the Secretary of Energy Advisory Board and the National Research Council (NRC).

The principal program shifts comport with the President's decision to join the ITER negotiations to build a burning plasma experimental facility. Longer range technology activities will have been phased out in FY 2004 while engineering and technology R&D activities that directly support existing and near term experiments as well as preparations for the construction of the burning plasma device will be increased. The three major fusion research facilities will be operated for 14 weeks each, 56 percent of the maximum possible single-shift operation, to advance our understanding of the key physics issues governing toroidal fusion concepts, thereby contributing to future experiments on ITER.

The FY 2005 budget will also support the continuation of the Scientific Discovery through Advanced Computing (SciDAC) program, which is being focused on burning plasma physics and ITER.

A summary of program resources to be applied to ITER in FY 2005, as well as the corresponding level for FY 2004, is shown in the following table. For the DIII-D and Alcator C-Mod research programs, the fraction of research in support of ITER needs is increased in FY 2005 despite a reduction in total weeks of facility operation. Also, Plasma Technology research in support of ITER is significantly increased in FY 2005 relative to FY 2004 when specific ITER R&D needs began to be identified by the interim ITER project team.

Fusion Program Resources in Preparation for ITER

(dollars in thousands)

	FY 2004	FY 2005
DIII-D Experimental Program	$3,000	$10,000
Alcator C-Mod Experimental Program	1,000	5,000
Fusion Plasma Theory & Computation	1,000	3,000
ITER Preparations	3,000	7,000
Plasma Technology	~ 0	13,000
Total	$8,000	$38,000

ITER negotiations are continuing in FY 2004. A comprehensive process to prepare an international agreement covering all aspects of ITER construction, operation and decommissioning is in place. This includes input on all topics by experts from each negotiating Party, discussion by representatives of each Party and resolution of differences by the negotiators. The negotiating process is aiming at a negotiated agreement in early 2004 for subsequent consideration and approval within the Parties' governmental systems. In addition, representatives of the Parties are addressing critical decisions on siting, sharing of costs and assignment of management personnel. During FY 2004 a U.S. ITER Project Office will be selected to manage the preparations in FY 2004 and FY 2005 for ITER construction starting in FY 2006.

The FY 2005 budget request is consistent with the expected cost and schedule baseline for the design and fabrication of the National Compact Stellarator Experiment (NCSX), a joint ORNL/PPPL advanced stellarator experiment at the Princeton Plasma Physics Laboratory, that is now expected to begin operation in late FY 2008/early FY 2009.

Finally, the Inertial Fusion Energy research program will be focused on the science issues of non-neutral plasmas and high energy density physics research.

Awards

- Nine fusion researchers were elected Fellows of the American Physical Society in 2002.

- A recent PhD recipient from the University of Texas won the 2003 Marshall N. Rosenbluth Outstanding Doctoral Thesis Award for his first principles theoretical analysis of a plasma thruster that models the helicon plasma source, single-pass radio frequency heating, and particle and momentum balance.
- A fusion materials scientist was elected fellow of the American Society of Materials "for outstanding contributions to our understanding of the effects of radiation on the properties of materials, and the development of new, advanced materials for service in the challenging environment of fusion reactors.
- A PPPL Nobel Prize winning scientist has been elected a Fellow of the American Association for the Advancement of Science (AAAS).
- A recent graduate of Princeton University who did his thesis research at PPPL, was named an APS Congressional Science Fellowship winner.
- A PPPL engineer was named a Fellow of the American Society of Mechanical Engineers.

Scientific Discovery through Advanced Computing (SciDAC)

The Scientific Discovery through Advanced Computing (SciDAC) activity is a set of coordinated investments across all Office of Science mission areas with the goal to achieve breakthrough scientific advances through computer simulation that were 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 made progress 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. There have been significant advances in the simulation of mode conversion 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.

Scientific Facilities Utilization

The Fusion Energy Sciences request includes funds to operate and make use of major fusion scientific user 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 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 a nearly $1,000,000,000 capital investment by the U.S. Government, in current year dollars.

The funding requested will provide research time for about 465 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 weeks of operation at all of the major fusion facilities is shown in the following table.

	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005
Maximum weeks	75	75	75	75	75
Planned weeks	44	34	31	54	42
Weeks operated as % of planned weeks	100%	94%	81%	TBD	TBD

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

FY 2001	FY 2002	FY 2003	FY 2004	FY 2005
		Complete the NCSX Conceptual Design and begin the Preliminary Design.	Complete final design of NCSX and begin 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 C-Mod Lower Hybrid Upgrade Project		

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 2003, the FES program supported 384 graduate students and post-doctoral investigators. Of these, approximately 50 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.

	FY 2001	FY 2002	FY 2003	FY 2004, est.	FY 2005, est.
# University Grants	186	186	189	195	195
# Permanent PhD's [a]	741	731	745	775	775
# Postdocs	99	99	100	105	105
# Grad Students	266	279	284	295	295
# PhD's awarded	49	53	40	42	42

[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 2003	FY 2004	FY 2005	$ Change	% Change
Science					
Tokamak Experimental Research	47,050	49,519	48,406	-1,113	-2.2%
Alternative Concept Experimental Research	52,423	54,122	55,279	+1,157	+2.1%
Theory	24,478	25,228	25,340	+112	+0.4%
SciDAC	3,256	3,320	3,300	-20	-0.6%
General Plasma Science	8,991	11,725	11,700	-25	-0.2%
SBIR/STTR	0	6,746	6,790	+44	+0.7%
Total, Science	136,198	150,660	150,815	+155	+0.1%

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. In addition, the Science subprogram supports exploratory research to combine the favorable features of and the knowledge gained from magnetic and inertial confinement, steady-state and pulsed approaches, in new, innovative fusion approaches. 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 power 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.

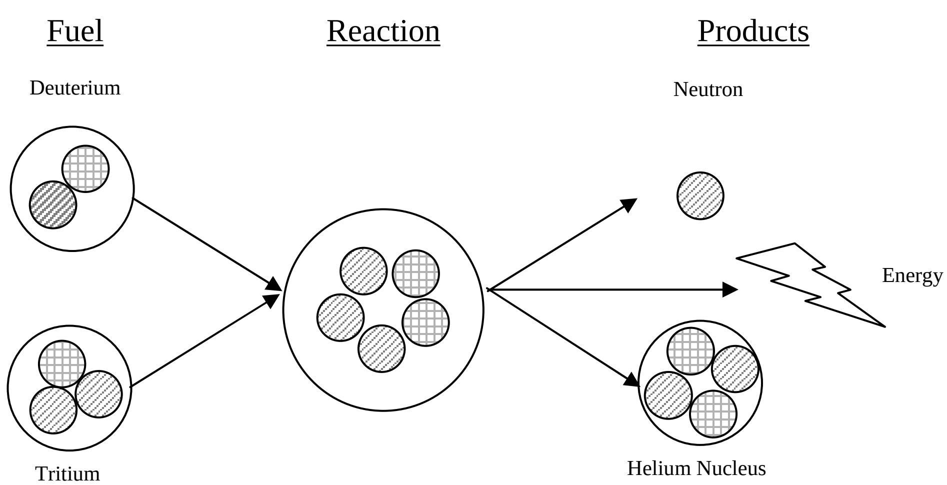
Supporting Information

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 the 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 Fusion Energy Sciences Advisory Committee. 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, and to benefit from ignition experiments on 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 Junior Faculty development grants for members of university plasma physics faculties, will continue to contribute to this objective. A new "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, radiative 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 where the peak temperatures are greater than 100 million degrees Celsius and densities 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 producing 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.

Science Accomplishments

Research funded by the Fusion Energy Sciences program in FY 2003 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.

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.

Turbulent transport is the dominant mechanism for energy and particle transport in high temperature tokamak plasmas. Understanding turbulent transport is one of the great challenges of plasma science and is essential to be able to optimize a burning plasma experiment.

- For the first time, a scientific code (GYRO) developed as part of the SciDAC program has been able to correctly predict the transport of heat in the core of a turbulent plasma. The code results were compared to experimental results from the DIII-D tokamak and found to predict the correct level of transport throughout the core of the plasma. This result is a big step in understanding turbulence and transport in tokamak plasmas.
- As our understanding of transport has evolved, we have discovered techniques for reducing energy transport. Internal transport barriers have been observed on both the DIII-D tokamak and the Alcator C-Mod tokamak. A key issue in tokamaks is reducing energy transport without reducing particle transport to the point where density and impurities accumulate in the plasma. Recent experiments with Internal Thermal Barriers (ITB's) generated by off-axis radio frequency (RF) heating on C-Mod have confirmed the ability to control the density peaking, and avoid impurity accumulation, through the application of simultaneous on-axis RF heating. Modeling of these discharges with the GS2 transport code has revealed that a small-scale instability (the Trapped Electron Mode), stimulated by the increased temperature gradients which result from the on-axis heating, appear to be primarily responsible for the enhanced diffusive particle transport, which controls the density peaking and the impurity confinement.

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.

- In a tokamak, a fast-growing instability can lead to a complete loss of magnetic confinement and a rapid transport of the plasma energy to the vacuum vessel walls. A new set of coils, controlled by a high-speed computer system, were installed inside the DIII-D vacuum vessel to stabilize the plasma at pressures that would otherwise be unstable. This active feed-back control system allowed DIII-D to operate with plasma pressures up to 40% higher than the conventional limits.

- One of the less severe but still significant instabilities in the tokamak arises from resistive diffusion of the plasma current so that it collects in clumps that form "magnetic islands" inside the plasma. These islands limit the energy content of the plasma by providing radial short circuits for heat flow across the island. Modern theory work has characterized a new form of these instabilities called Neoclassical Tearing Modes (NTMs), which are driven by a local deficit in plasma's bootstrap current, forming NTM islands. The drive for the NTM instabilities increases as the plasma pressure (or plasma density and temperature) increases. The growth of NTM islands can be arrested by providing localized current drive by microwaves. Experiments in DIII-D demonstrated the validity of the theory and the ability to stabilize these NTMs. In these experiments, conducted in several stages, radially-localized off-axis current was driven by high power microwaves, completely suppressing different modes of the NTM stability. After the islands were completely suppressed, it was possible to increase the plasma pressure with additional beam heating power.

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.

- Recent measurements on the Alcator C-Mod tokamak with the phase contrast imaging diagnostic show intermediate wavelength mode converted waves in the core of the plasma. Detailed modeling with the TORIC code has shown that these intermediate wavelength mode converted waves are in fact Ion Cyclotron Waves. This is the first definitive observation of these waves in a tokamak. The ion cyclotron wave propagates toward the low magnetic field region and may have favorable properties for plasma flow drive. Plasma flows are known to have a stabilizing effect on plasma turbulence.

- Electromagnetic wave current drive and/or profile modification are essential elements of all planned advanced, high-performance operating scenarios for ITER. Recent experiments on the DIII-D tokamak at General Atomics have demonstrated stationary plasma performance that projects to longer pulse length and/or higher gain operation in ITER than the present baseline scenario. The results from these experiments, that use a small amount of Ohmic heating transformer flux to support the plasma current and match ITER plasma shape, indicate that the ITER pulse length may be extended to about one hour duration (up from the 400 second baseline case) with full fusion power of about 500 MW. Alternatively, higher fusion power could be achieved for shorter pulses.

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.

- In High confinement discharges, an undesirable phenomenon is the formation of Edge Localized Modes (ELMs) that eject pulses of particles and energy to plasma facing components and may cause melting or erosion. Previous experiments in DIII-D discovered a new mode of operation with two radial regions of improved heat insulation (transport barriers). Recent experiments in DIII-D involve exhaust of plasma fuel particles and impurities through these barriers without generating ELMs at the plasma edge. The plasma edge in this new mode of operation is 'quiescent' with the absence of ELMs. Additional experiments and analysis during the past year showed that the quiescent double barrier mode in DIII-D resulted in high performance and could be sustained for 3.8 seconds. The conclusion is that this mode can lead to steady-state operation using external current drive. The DIII-D team worked with the ASDEX-Upgrade team in Germany to extend the DIII-D results to

ASDEX-UG, achieving quiescent plasmas (without ELMs) and further strengthening the conclusions reached in DIII-D.

- Experiments in DIII-D have revealed an alternate technique for controlling ELMs in DIII-D using 'chaotic' like magnetic fields in the plasma edge. An international team of scientists used a set of new internal coils to break the smooth magnetic surfaces at the narrow plasma edge into a 'chaotic' configuration. This chaotic edge configuration eliminated Edge Localized Modes (ELMs) that impart large transient heat loads to the plasma chamber walls and limit plasma performance.
- During the past year, NSTX scientists measured and analyzed the heat flux on the plasma facing components during high power operation. In high confinement mode operation, the dispersion of the heat flux on the divertor plates increased by a factor of three as the plasma triangularity was increased. Geometric effects accounted for less than a factor of two in the increase in the heat flux dispersion. This is a favorable result as increased triangularity is often needed to achieve high performance operation, and greater dispersion of the heat flux reduces peak heat loads on the divertor plates.

Configuration Optimization

Since the inception of this program element in 1997, significant progress has been made in many areas, such as transport in plasmas undergoing Taylor relaxation, the generation of magnetic helicity and its injection into toroidal plasma systems (including tokamaks), stability and generation of exoteric plasma configurations, and shear flow stabilization of plasmas.

- Self organization of plasma flows occurs in many of the important plasmas being studied for fusion, and plays an important role in the dynamics of these plasmas, for better or for worse. The approach to self organization in plasmas 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, has 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.
- 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. Injecting magnetic helicity into a tokamak, for example, is a candidate for non-inductive start-up and producing electrical currents in tokamak, that are among the most important issues in tokamaks. To that end, a major milestone was demonstrated in the past year in a small, university-scale experiment at the University of Washington. In this experiment, magnetic helicity was generated using a coaxial plasma gun and was injected into a spherical tokamak, resulting in a 30% increase in the toroidal current in the spherical tokamak. The physics underlying the generation of magnetic helicity is further elucidated by another university-scale experiment at Caltech, in which the processes leading to flux amplification are captured photographically and analyzed for the first time. In yet another small university-scale experiment at the University of California in Davis, small balls of magnetic helicity have been accelerated to 200 km/s in the past year, and are being studied as a candidate for refueling tokamaks.
- When magnetic helicity is captured in a toroidal form in a simple vacuum vessel (simply connected) instead of a toroidal chamber (doubly connected), 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. A fundamental issue in spheromak research is its sustainment, as magnetic helicity decays due to resistive dissipative processes. In the past year, an important milestone in spheromak research has been demonstrated at the Sustained Spheromak Physics Experiment (SSPX) at the LLNL. In this experiment, for the first time, short pulses of magnetic helicity were injected sequentially into a spheromak, and were successfully retained by the spheromak. Injection of helicity into a spheromak usually opens up the flux surfaces, causing sudden loss of energy confinement. Through better theoretical understanding gained from using modern diagnostics and computational modeling, researchers at LLNL learned to time the helicity injection properly to avoid significant loss of energy confinement. The overall energy confinement was improved by a factor of four, and the plasma temperature was raised from 1.4 million degrees Celsius to 2.6 million degrees Celsius.

- A potentially cost effective way to heat a plasma to fusion temperatures is to compress a magnetized plasma using a material wall, called a liner, that may be solid, liquid, or gaseous. The plasma science question that underpins the approach is the ability of extremely high magnetic field in providing thermal insulation of the material liner so that heat is not lost too rapidly to the liner during the compression of the plasma. Significant progress has been made during the past year in preparing for the feasibility experiment. A cylindrical, solid aluminum liner, 30 cm long and 10 cm in diameter, has been compressed electromagnetically achieving 13 times radial compression with velocities ~ 4 km/s. High density field reversed configurations suitable as magnetized plasmas for the compression experiment have been generated with a density of 3×10^{16} ions/cc, a temperature of 3.3 million degrees Celsius and sustainment time of 10–20 microseconds.
- In the past year, in yet another small-scale university experiment at the University of Washington, the stabilization of a magnetized plasma by a velocity shear in the plasma flow has been demonstrated. In this experiment, the growth rate of the magnetohydrodynamic instabilities was reduced by more than a factor of 700 in a long (0.5 m) Z-pinch plasma configuration.

Inertial Fusion Energy and 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, that 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 holhraum 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 have positive electrical charge and repel each other. This electrostatic repulsion creates difficulties in focusing them to achieve high energy density. One approach is to neutralize the ions electrically by passing them through a plasma, allowing the electrons in the plasma to recombine with the ions, thus converting the ions to neutral particles. The neutral particles can then be focused by arranging their ballistic trajectories to converge. This focusing mechanism was demonstrated experimentally in the Neutralized Transport Experiment (NTX) at the LBNL, in which an ion beam of approximately 10 cm in diameter was focused down to a spot of less than a few millimeters for the first time in the past year. 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. The experiment has used beam currents up to 0.2 amperes, that is high compared to other particle accelerators, such as those used in high energy physics.

- An exciting new scientific development in recent years in the area of inertial fusion and high energy density physics is the use of petawatt (a thousand-trillion-watt) lasers to heat an already dense solid. For fusion, the concept is to use such a laser to heat and ignite a fusionable capsule that is pre-compressed by another laser, the main compression laser. 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, have obtained the first experimental data that will throw the first light on the transport of these relativistic electrons in the material.

Specific FY 2005 goals leading toward the long-term performance measures for Fusion Energy Sciences are:

Tokamaks

- Develop a comprehensive experimental database of tokamak stability, transport, particle interaction, and edge effects that will be used to validate predictive models for burning plasmas.

  Obtain experimental data from DIII-D, C-MOD, and NSTX on the control of current profiles by different electromagnetic waves injected into the plasma (high power Electron cyclotron waves in DIII-D, lower hybrid waves in C-MOD, fast waves in NSTX) in order to improve plasma performance and extend pulse length. Compare these results with data from international tokamaks and theoretical predictions.

Alternates

- Assess the value of alternative magnetic confinement configurations to enhance the fundamental understanding of magnetic confinement and improve the basis for future burning plasma experiments.

  For the leading magnetic alternate concept, the spherical torus, complete a preliminary determination of its attractiveness for fusion applications, assessing stability, turbulence and transport, non-inductive current drive, scrape-off layer fluxes, and integration of high plasma pressure and high confinement efficiency for several energy replacement times.

High Energy Density Physics/IFE

- Assess the new physical phenomena that result from using high energy beams and lasers to explore extreme states of matter.

  A roadmap for an interagency high energy density program will be developed jointly with NSF and NNSA, using workshops and symposia to obtain input from the research community.

Detailed Justification

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005
Tokamak Experimental Research	**47,050**	**49,519**	**48,406**

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 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 have increased 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 by controlling the distribution of current in the plasma with electromagnetic wave current drive and the interface between the plasma edge and the material walls of the confinement vessel 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**	**24,420**	**25,538**	**24,926**

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 a 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—energy transport, stability, plasma-wave interactions, and boundary physics, and various thrust areas that integrate across topical areas to support the goal of achieving a burning plasma. The level of effort for most physics research topics in FY 2005 decreases from FY 2004, but a larger fraction of effort will support burning plasma physics, specifically for ITER. 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 (“wind tunnel”) 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

	(dollars in thousands)	
FY 2003	FY 2004	FY 2005

operation of fusion plasmas for enhancing the attractiveness of tokamak systems. In particular, the experimental program will aim at accomplishing the following related research goal in FY 2005: 1) demonstrate the technical benefits of operating plasmas with a normalized beta (a measure of plasma pressure) value above the "standard" value, made possible by feedback control of new internal wall stabilization coils installed in FY 2003. The initial experiments in FY 2003 with these coils were promising, leading to the planning of experiments in FY 2004. These will be further expanded in 2005. 2) Extend the "Negative Central Shear" mode of operation to higher performance and long pulse plasmas using the 6 MW Ion Cyclotron Radio Frequency (ICRF) system, and the 6 MW Electron Cyclotron Heating (ECH) system. The refurbishment and commissioning of the ICRF system, that was built about 4 years ago, started in FY 2003, and it will be available for these experiments in FY 2005. 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 AT.

	FY 2003	FY 2004	FY 2005
▪ **Alcator C-Mod Research**..	**7,123**	**8,458**	**8,500**

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 a fusion plasma. In FY 2005, 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 ("wind tunnel") 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 beam enabled diagnostics will shed light on the physics of temperature and density profile pedestals, 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 2005. 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.

▪ **International Collaborations**...	**4,696**	**4,862**	**4,900**

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 conducted outside the U.S.

International collaboration will continue on these unique facilities abroad. In FY 2005, an expansion on joint International Tokamak Physics Activity (ITPA) with Japan, Europe, and Russia will enhance collaboration on physics issues related to tokamak burning plasmas. In FY 2005, 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 cited in the Science Subprogram description.

▪ **Experimental Plasma Research (Tokamaks)**........................	**7,009**	**6,570**	**6,500**

Funding provided in this category, for FY 2005, will continue to support research on innovative tokamak experiments at universities and the development of diagnostic instruments.

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 a 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.

Support of the development of unique measurement capabilities (diagnostic systems) that provide an understanding of the plasma behavior in fusion research devices will continue at a number of institutions. This research provides the necessary information for analysis codes and theoretical interpretation. Some key areas of diagnostic research include the development of: (1) techniques to measure the cause of energy and particle loss from the core to the edge of magnetically confined plasmas, including techniques aimed at understanding how barriers to 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 2005 supports research that will enhance our understanding of critical plasma phenomena and the means of affecting these phenomena to improve energy and

	(dollars in thousands)	
FY 2003	FY 2004	FY 2005

particle confinement in tokamaks and innovative confinement machines. The funding will also support development of diagnostic systems related to the processes associated with burning plasmas, on U.S. and foreign facilities. Currently supported programs will be peer reviewed prior to awarding FY 2005 funds.

	FY 2003	FY 2004	FY 2005
▪ **Other**	**3,802**	**4,091**	**3,580**

Funding for educational activities in FY 2005 will support research at historically black colleges and universities, graduate and postgraduate fellowships in fusion science and technology, summer internships for undergraduates, and outreach efforts related to fusion science and enabling R&D.

	FY 2003	FY 2004	FY 2005
Alternative Concept Experimental Research	**52,423**	**54,122**	**55,279**

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 scientific user facility. The Madison Symmetric Torus (MST) is at an intermediate stage of development between a small-scale experiment and a major facility.

	FY 2003	FY 2004	FY 2005
▪ **NSTX Research**	**13,761**	**16,251**	**16,300**

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 self-driven current fraction 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, as are all high beta plasmas, is uniquely characterized by high velocity fast ions and with a large radius of gyration relative to plasma size that could potentially lead to new plasma behaviors of interest. In FY 2005, funding will allow the NSTX national team to carry out research in the areas of high-pressure stability, short wavelength turbulence, wave-particle interactions, boundary physics, and integrated operating scenarios. Several new diagnostics and control upgrades will become operational in FY 2005. Using these new diagnostics and control system enhancements, NSTX team members plan to produce and characterize plasmas near theoretically predicted limits. They will also measure short wavelength turbulence in the plasma core in a range of plasma conditions and explore its relationship to electron thermal transport. Building on experiments carried out in FY 2004, they will demonstrate full non-inductive current drive using combinations of radio frequency waves, neutral beam injection, and pressure driven

	(dollars in thousands)	
FY 2003	FY 2004	FY 2005

currents. Further, NSTX researchers plan to characterize heat and particle fluxes in the plasma edge and explore techniques for handling the high fluxes that are produced in high performance plasmas. Finally, they will begin to explore integrated scenarios to achieve high plasma pressure and good energy confinement efficiency for pulse lengths much longer than the energy replacement time. Comparison of all these experimental results with theory will contribute to the scientific understanding of these effects needed to make a preliminary assessment of the attractiveness of the spherical torus concept in late 2006.

- **Experimental Plasma Research (Alternatives)** **16,910** **18,049** **18,100**

With the emphasis in developing the fundamental understanding of the plasma science that underpins innovative fusion concepts, this research element is a broad-based research activity, conducted in twenty five 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 meritoriously high performance is maintained.

Other current projects in the balance of the magnetic alternate program include fundamental investigations into concepts such as, advanced stellarator configurations, advanced spherical torus, the levitated dipole, field-reversed configurations (FRC), spheromaks, and magnetized target fusion.

As examples of the research being pursued in these experiments:

- Research in advanced stellarators, such as the Helically Symmetric Torus at 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 target by FY05 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 (IFE). The main experimental objectives by FY 2005 are to produce magnetized plasma with three times the density and to begin exploring the problem of translating 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.

	FY 2003	FY 2004	FY 2005
▪ **Inertial Fusion Energy/High Energy Density Physics**.........	**12,753**	**13,877**	**13,900**

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 (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. The research activities in IFE will be redirected to encompass the emphases of a national roadmap in High Energy Density Physics currently being developed by an interagency task force jointly by NSF, DOE, NASA and NIST, following the recommendations of the two NRC reports "Frontiers in High Energy Density Physics" and "Connecting Quarks to the Cosmos." Most high energy density conditions are produced through the use of high power lasers, ion beams, or convergence of high density plasma jets. The impact of heavy ion beams with a metallic holhraum 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) which 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. The beam science program will become part of a more broadly based high energy density science program. This high energy density plasma physics program is a new and exciting area that we will begin to fund in FY 2005. This will require modifications to the existing IFE program, but offers attractive research opportunities in the future. Another exciting development in HEDP in recent years is the science of ultra-intense ultra-fast lasers and its applications to create states of high energy densities. A phenomenon receiving world-wide scientific attention is fast ignition, in which a petawatt laser is used to heat and possibly ignite a fusionable capsule that has been compressed by another slower laser. We are beginning to explore the physics of thermal transport under these conditions.

	FY 2003	FY 2004	FY 2005
▪ **Madison Symmetrical Torus**...	**5,189**	**5,174**	**6,200**

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,

	(dollars in thousands)	
FY 2003	FY 2004	FY 2005

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 and FY 2004 will enable in FY 2005 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 2005 will be to measure the improved confinement and sustainment in MST.

	FY 2003	FY 2004	FY 2005
▪ **National Compact Stellarator Experiment (NCSX)**	**3,810**	**771**	**779**

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 and ORNL are the participants in NCSX Research that maintains U.S. contact with major stellarator experiments in Germany, Japan and Spain. The overall objective of this work is to keep planning for NCSX research abreast of developments in stellarator research both domestically and internationally, during the fabrication phase of NCSX.

	FY 2003	FY 2004	FY 2005
Theory	**24,478**	**25,228**	**25,340**

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 a 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.

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005
SciDAC	**3,256**	**3,320**	**3,300**

An important element is the FES portion of the Office of Science's Scientific Discovery through Advanced Computing (SciDAC) program. Major scientific challenges exist in many areas of plasma and fusion science that can best be addressed through advances in scientific supercomputing. In FY 2004, the FES SciDAC projects are being re-competed. The selected projects will be focused on providing a fundamental understanding of plasma science issues important to a burning plasma, and laying the groundwork for the fusion simulation project. The new projects will continue to involve collaborations among physicists, applied mathematicians and computer scientists.

In FY 2005, the computation program will continue to emphasize advanced computing 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 computers in the past, but advancements in computation are allowing a new look at problems that once seemed almost 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, a set of innovative national experiments, and fruitful collaboration on major international facilities.

General Plasma Science	**8,991**	**11,725**	**11,700**

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 makes 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 Junior Faculty in Plasma Physics Development program and the basic and applied plasma physics program at DOE laboratories. In FY 2005, the program will continue to fund proposals that have been peer reviewed. Funding will also continue for the *"Centers of Excellence in Fusion Science"* program that was started in FY 2004, supporting one or two centers. Basic plasma physics user facilities will be supported at both universities and laboratories, cost sharing with NSF where appropriate. Atomic and molecular data for fusion will continue to be generated and distributed through openly available databases. The Office of Fusion Energy Sciences will continue to share the cost of funding the multi-institutional plasma physics frontier science center funded by NSF in FY 2003. In FY 2004 and FY 2005, the Department is planning to spend just over $2,100,000 for the work being done at these centers.

SBIR/STTR	**0**	**6,746**	**6,790**

FY 2003 excludes $5,837,000 and $350,000 that was transferred to SBIR and STTR programs, respectively. The FY 2004 and FY 2005 amounts are the estimated requirements for the continuation of these programs.

Total, Science	**136,198**	**150,660**	**150,815**

Explanation of Funding Changes

	FY 2005 vs. FY 2004 ($000)
Tokamak Experimental Research	
▪ The DIII-D decrease reflects the decrease in research efforts that accompanies the reduction in experimental operations from 18 weeks to 14 weeks.	-612
▪ The Alcator C-Mod research effort is essentially the same in FY 2005 as in FY 2004. The level of scientific analysis is maintained despite the reduction in experimental operations from 18 weeks to 14 weeks.	+42
▪ Funding for International Collaboration is increased to support mutually beneficial work on unique international facilities.	+38
▪ The Experimental Plasma Research (Tokamaks) funding is reduced slightly to support higher priority research efforts elsewhere in the program.	-70
▪ The funding in the "Other" category reflects the completion of an Intergovernmental Personnel Act assignment and a shift in funding for higher priority activities in other parts of the program.	-511
Total, Tokamak Experimental Research	**-1,113**
Alternate Concept Experimental Research	
▪ A small increase in NSTX research funding will support increased analysis of experimental data.	+49
▪ The small increase in funding for Experimental Plasma Research (ALT) will be used to partially fund the increased effort directed at understanding the physics of moving metal walls in stabilizing plasmas.	+51
▪ The small increase in IFE funding will provide a slight increase in effort as the program shifts emphasis to High Energy Density Physics research.	+23
▪ The increased MST Research funding will allow the experiment to initiate systematic research on the merits of various techniques in current drives and heating in the MST's reversed field pinch plasma in FY 2005, supported with the appropriate diagnostics, as recommended by competitive peer review.	+1,026
▪ Funding for NCSX research is increased slightly to provide additional support in preparation for operation.	+8
Total, Alternative Concept Experimental Research	**+1,157**
Theory	
▪ Funding for Theory is increased to support additional students.	+112
SciDAC	
▪ Funding is decreased to support higher priority research elsewhere in the program.	-20
General Plasma Science	
▪ Funding is decreased to support higher priority research elsewhere in the program.	-25

	FY 2005 vs. FY 2004 ($000)
SBIR/STTR	
▪ Support for SBIR/STTR is provided at the mandated level.	+44
Total Funding Change, Science	**+155**

Facility Operations

Funding Schedule by Activity

(dollars in thousands)

	FY 2003	FY 2004	FY 2005	$ Change	% Change
Facility Operations					
DIII-D	27,474	30,427	29,074	-1,353	-4.4%
Alcator C-Mod	12,039	13,764	13,000	-764	-5.6%
NSTX	16,367	18,427	17,300	-1,127	-6.1%
NCSX	7,897	15,921	15,921	0	0.0%
ITER	0	3,000	7,000	+4,000	+133.3%
GPP/GPE/Other	2,421	2,993	3,200	+207	+6.9%
Total, Facility Operations	66,198	84,532	85,495	+963	+1.1%

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 users. In addition, fabrication of new projects and upgrades of major fusion facilities will be accomplished in accordance with 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 sub-program provides for the construction of new facilities such as NCSX, and for participation in ITER.

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 user 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 Technology 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. In FY 2005, funding is requested to operate the major fusion facilities for 14 weeks.

Funding is also provided for the continuation of the National Compact Stellarator Experiment (NCSX) Major Item of Equipment project at PPPL. In FY 2005, the project will be in its third year, following the FY 2003 project start, and FY 2004 funding will support the final design activities and initial hardware procurements.

Funding is also provided for ITER transitional activities, in which U.S. scientists and engineers will be involved in various technical activities that support both ITER negotiations for a construction project as well as preparations for eventual project construction. These activities will be managed from a U.S. ITER Project Office, to be selected in FY 2004, in preparation for ITER construction starting in FY 2006.

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 third of four years to support the move of ORNL fusion personnel and facilities to a new location at ORNL.

Facility Operations Accomplishments

In FY 2003, 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:

- Princeton Plasma Physics Laboratory (PPPL) has awarded contracts, for $600,000 each, to two industrial teams for manufacturing development of the National Compact Stellarator Experiment (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 is to develop the manufacturing processes for the forms through fabrication of full-scale prototypes. The project plans to award a follow-on contract for the production order to one of these teams next year.

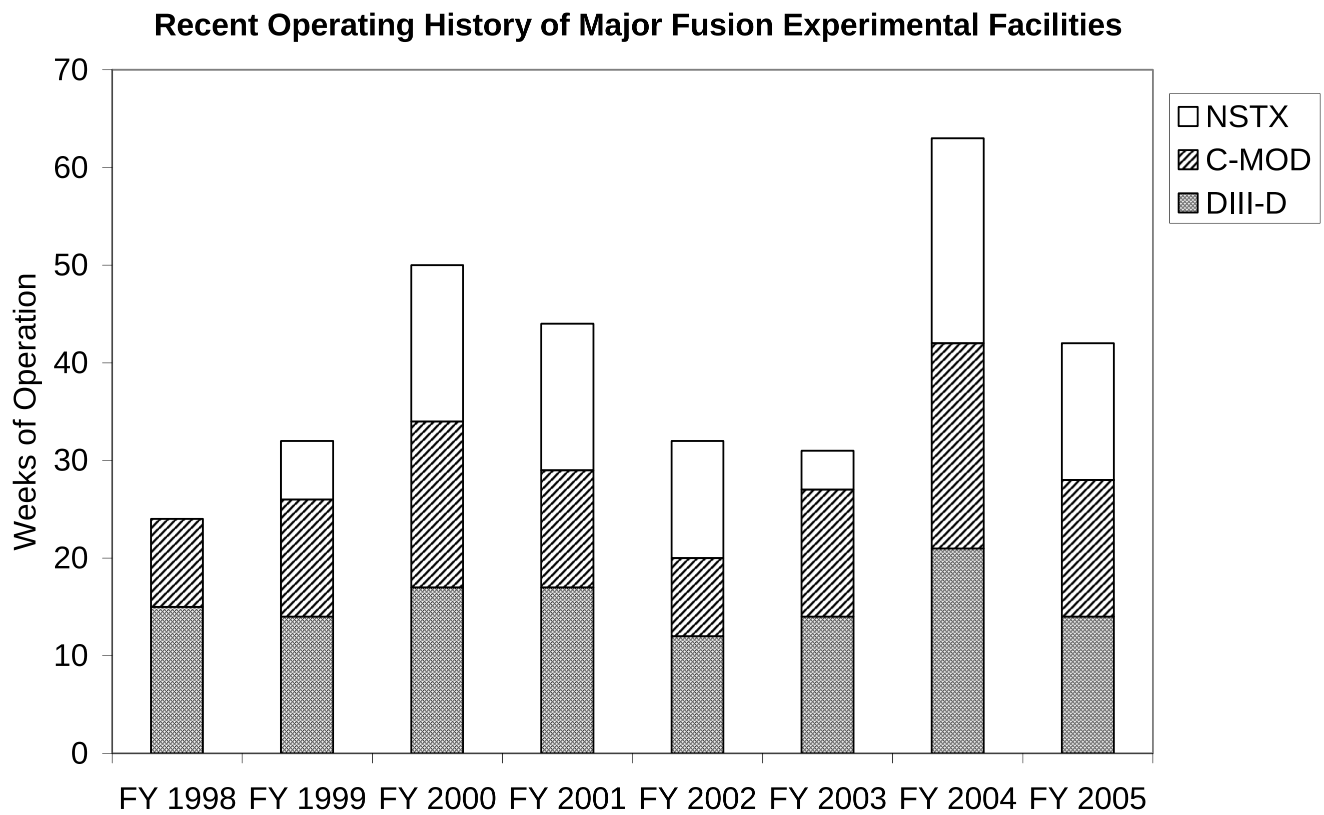
  In addition, PPPL has awarded contracts, for $400,000 each, to two industrial suppliers for manufacturing development of the NCSX vacuum vessel. The vacuum vessel is a highly shaped structure with stringent requirements on vacuum quality and magnetic permeability. The purpose of these contracts is to 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 plans to award a follow-on contract for the production order to one of these suppliers next year.

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

Weeks of Fusion Facility Operation

(Weeks of Operations)

	FY 2003 Results	FY 2004 Target	FY 2005 Target
DIII-D	14	18	14
Alcator C-Mod	13	18	14
NSTX	4	18	14
Total	31	54	42



The specific FY 2005 goal leading toward the long-term performance measures for Fusion Energy Sciences is:

NCSX Fabrication

- Award, through a competitive process, production contracts for the following major NCSX systems: Modular Coil Winding Forms and Conductor, and Vacuum Vessel. Complete winding of the first modular coil.

Detailed Justification

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005
DIII-D	**27,474**	**30,427**	**29,074**

Provide support for operation, maintenance, and improvement of the DIII-D facility and its auxiliary systems. In FY 2005, these funds support 14 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 sequentially upgrading the oldest gyrotrons used in the electron cyclotron heating system to provide a uniform 10 second pulse length capability.

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005
Alcator C-Mod	**12,039**	**13,764**	**13,000**

Provide support for operation, maintenance, and improvement of the Alcator C-Mod facility and its auxiliary systems. In FY 2005, these funds support 14 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)	**16,367**	**18,427**	**17,300**

Provide support for operation, maintenance, and minor upgrades, such as error field coils and antenna upgrades. In FY 2005, these funds support 14 weeks of single shift plasma operation to carry out the research described in the Science subprogram.

National Compact Stellarator Experiment (NCSX)	**7,897**	**15,921**	**15,921**

Funding in the amount of $15,921,000 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 total estimated cost (TEC) of NCSX is in the range of $87,000,000-$89,000,000, with completion expected to be in the late FY 2008/early FY 2009 time frame. After the preliminary design is completed at the end of CY 2003, the cost and schedule baseline for this project will be established in early CY 2004.

ITER	**0**	**3,000**	**7,000**

Funding in the amount of $7,000,000 is provided to continue with ITER transitional activities such as safety, licensing, project management, preparation of final specifications and system integration. U.S. personnel will participate in these activities in preparation for eventual project construction. In addition, preparations will be made to qualify U.S. vendors to supply hardware and components for the project when the need arises.

General Plant Projects/General Purpose Equipment/Other	**2,421**	**2,993**	**3,200**

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	**66,198**	**84,532**	**85,495**

Explanation of Funding Changes

	FY 2005 vs. FY 2004 ($000)
DIII-D	
▪ Funding is reduced to support higher priority activities such as ITER preparation. The number of weeks of operation, 14, is a decrease of 4 weeks from the FY 2004 planned operation..	-1,353
Alcator C-Mod	
▪ Funding is reduced to support higher priority activities such as ITER preparation. The number of weeks of operation, 14, is a decrease of 4 weeks from the FY 2004 planned operation..	-764
NSTX	
▪ Funding is reduced to support higher priority activities such as ITER preparation. The number of weeks of operation, 14, is a decrease of 4 weeks from the FY 2004 planned operation.	-1,127
ITER	
▪ Funding for direct ITER support is increased to $7M to support additional U.S. preparation for ITER construction, primarily for sending additional U.S. personnel to the interim ITER team, for broader qualification of potential U.S. suppliers of hardware, for expanded R&D preparations, and expanded project preparations in the United States.	+4,000
GPP/GPE/Other	
▪ Funding is increased to provide necessary improvements in the PPPL infrastructure and to move ORNL fusion personnel and facilities to a new location at ORNL.	+207
Total Funding Change, Facility Operations	**+963**

Technology

Funding Schedule by Activity

	(dollars in thousands)				
	FY 2003	FY 2004	FY 2005	$ Change	% Change
Technology					
Engineering Research	30,558	19,763	20,421	+658	+3.3%
Materials Research	7,741	7,600	7,379	-221	-2.9%
Total, Technology	38,299	27,363	27,800	+437	+1.6%

Description

The mission of the Technology 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 technology 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 Technology 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 advances in fusion technology 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 technology R&D for magnetic fusion systems as well as international collaborations that support the mission and objectives of the Fusion Energy Sciences 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 burning plasma experiments, especially ITER. Technology 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 United States 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 of 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 to fusion.

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

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

Technology Accomplishments

A number of technological advances were made in FY 2003. Examples include:

- Los Alamos National Laboratory (LANL) completed all characterization and stabilization activities of the Tritium Systems Test Assembly **(**TSTA) Facility and as per the Memorandum of Agreement signed by the Office of Science, Office of Environmental Management (EM), and the Office of Defense Programs in the National Nuclear Security Administration, overall management and financial responsibilities were transferred to EM on August 1. EM will now be responsible for conducting the surveillance and maintenance and eventually, the decontamination and decommissioning.

  The TSTA Facility was built to develop and demonstrate the deuterium-tritium fuel cycle technology for next step fusion devices as well as conduct tritium testing of different fusion components and systems. TSTA successfully and safely demonstrated the capability of processing over 1 kilogram of tritium per day which is approximately one tenth the rate of the ITER Tritium Plant. The data base from its operation was critical to the design of the ITER Tritium Plant.

- The Oak Ridge National Laboratory has completed the installation and testing of the Joint European Torus (JET) high power prototype antenna. This new antenna should enhance the heating of the plasma during experiments. The JET antenna was designed, fabricated and tested on schedule. As planned, the results of this collaborative program were used by JET scientists to design their production antenna.

Detailed Justification

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005
Engineering Research	**30,558**	**19,763**	**20,421**
▪ **Plasma Technology**	**13,517**	**13,635**	**17,840**

Engineering research efforts will continue on critical needs of domestic plasma experiments and on the scientific foundations of innovative technology concepts for use and testing in ITER. Nearer-term experiment support efforts will be oriented toward plasma facing components and plasma heating and fueling technologies. Additional funds and redirected effort will be provided for technology R&D supporting U.S. responsibilities for ITER procurement packages. Fabrication started in FY 2004 of a 110 gigahertz, 1.5 megawatt industrial prototype gyrotron microwave generator that will be the most powerful of its kind for electron cyclotron heating of plasmas. Completion of the prototype and the beginning of testing will be accomplished in FY 2005. Testing will also begin in FY 2005 of a high speed, compact vertical pellet injector system relevant to the fueling requirements of burning plasma experiments. Based on the experimental research and initial designs during FY 2004 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 design of a lithium module for future deployment in NSTX will be initiated in FY 2005. During FY 2005, studies will continue in the Plasma Interactive Surface Component Experimental Station (PISCES) at the University of California at San Diego, and the Tritium Plasma Experiment at INEEL, of tungsten-carbon-beryllium mixed materials layer formation and redeposition with attached hydrogen isotopes, and results will be applied to evaluate tritium accumulation in ITER plasma facing components. Following initiation in FY 2004 of full-scale tritium operations in the Safety and Tritium Applied Research (STAR) facility at INEEL, preliminary results will be obtained in FY 2005 from material science experiments in STAR performed 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 ITER nuclear and safety design and analysis, as well as for research on safety, power extraction and tritium technologies for blanket concepts that will be tested in. Funds will be provided to continue superconducting magnet research, 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**	**11,023**	**3,038**	**0**

Following close out of Fusion Technology efforts in FY 2004 in order to focus on research relevant to ITER, no activities are planned for FY 2005.

▪ **Advanced Design**	**6,018**	**3,090**	**2,581**

Funding for this effort will 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.

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005
Materials Research	**7,741**	**7,600**	**7,379**

Materials Research remains a key element in establishing the scientific foundations for safe and environmentally attractive uses of fusion. Through a wide variety of modeling and experimental activities aimed at the science of materials behavior in fusion environments, research on candidate materials for the structural elements of fusion chambers will continue. Priorities for this work are based on the innovative approaches to evaluating materials and improved models of materials behavior that were adopted from recommendations of earlier FESAC reviews. Building on successes during FY 2004 in the first phase of a cost-shared collaborative program with Japan for irradiation testing of fusion materials in a U.S. fission reactor (High Flux Isotope Reactor), which provides key data to evaluate the effects of neutron bombardment on the microstructural evolution, damage accumulation, and property changes of fusion materials that could be used in next step devices, preliminary investigations will be completed in FY 2005 of nanocomposited ferritic steels with alloy compositions and fabrication techniques designed through nanoscience methods to operate at high temperatures without significant deformation by creep mechanisms. Investigations during FY 2005 will focus on thermodynamics, interface structure, irradiation stability, and helium trapping efficiency of the nanometer sized yttrium-titanium based oxide dispersoids in nano-composited ferritic alloys. In addition, an assessment will be made during FY 2005 of the effects of helium additions on the low temperature radiation embrittlement of ferritic steels.

	FY 2003	FY 2004	FY 2005
Total, Technology	**38,299**	**27,363**	**27,800**

Explanation of Funding Changes

	FY 2005 vs. FY 2004 ($000)
Engineering Research	
Plasma Technology	
▪ Additional funds will be provided for ITER nuclear and safety design and analysis for research on power handling and tritium technology concepts that will be tested in ITER for extracting heat from burning plasmas and for producing sufficient amounts of tritium to achieve self-sufficiency and for technology R&D supporting U.S. responsibilities for ITER procurement packages.	+4,205
Fusion Technology	
▪ Fusion Technology, which generally consists of longer range technology activities, will be closed out in FY 2004 and no activities are planned in FY 2005. This action will provide additional resources for technology development that enables existing and near term facilities like ITER to achieve their full performance capability.	-3,038

	FY 2005 vs. FY 2004 ($000)
Advanced Design	
▪ Advanced Design funding is decreased due to the closeout of the next-step option.	-509
Total, Engineering Research	**+658**
Materials Research	
▪ Funding for research on vanadium alloys is reduced due to closeout of tasks that did not yield promising results.	-221
Total Funding Change, Technology	**+437**

Capital Operating Expenses & Construction Summary

Capital Operating Expenses

(dollars in thousands)

	FY 2003	FY 2004	FY 2005	$ Change	% Change
General Plant Projects	1,300	1,415	1,643	+228	+16.1%
Capital Equipment	12,448	20,206	19,998	-208	-1.0%
Total, Capital Operating Expenses	13,748	21,621	21,641	+20	+0.1%

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

(dollars in thousands)

	Total Estimated Cost (TEC)	Prior Year Approp-riations	FY 2003	FY 2004	FY 2005	Accept-ance Date
Alcator C-Mod LH Modification	5,180	4,471	709	0	0	FY 2003
NCSX	87,000-89,000[a]	0	7,897	15,921	15,921	FY 2008-FY 2009
Total, Major Items of Equipment		4,471	8,606	15,921	15,921	

[a] The preliminary TEC increased from $69,000,000 to $73,500,000 with completion in FY 2007, based on the completed conceptual design activities that demonstrated more contingency funds were needed for fabricating the highest risk components. However, because of a delayed start (April 2003) of the project attributable to delayed FY 2003 Congressional appropriations, more detailed information on the design and cost of NCSX components/systems, recommendations from three different review committees and revised funding profile, the NCSX TEC is now expected to be in the range of $87,000,000-$89,000,000 with completion expected to be in the late FY 2008/early FY 2009 time frame. After preliminary design is completed at the end of CY 2003, the cost and schedule baseline for the NCSX project will be established in early CY 2004. The NCSX MIE project will be completed when first plasma is attained during cryogenic operation.