Fusion Energy Sciences

Program Mission

The Fusion Energy Sciences program is a multi-purpose, scientific research effort, producing valuable scientific knowledge and technological benefits in the near term and providing the science base for a fusion energy option in the long term.

This is a time of important progress and scientific discovery in fusion research. By virtue of previous investments in facilities, sophisticated diagnostics, critical technologies, and modeling capabilities, the Fusion Energy Sciences program is making great progress in understanding the fundamental processes involved in confining fusion fuels, such as the turbulence responsible for loss of particles and energy across magnetic field lines. In addition, the program is exploring innovative approaches to fusion energy, including supporting advances in state-of-the-art enabling technology, in search of an optimized confinement system with an affordable development path.

Program Goal

During the next 50 years, the world population is expected to increase substantially, and energy usage will likely double. As oil and natural gas reserves are depleted, sustainable new energy sources will be needed. Both the President's Committee of Advisors on Science and Technology and the Secretary of Energy Advisory Board have recognized the potential of fusion energy and have recommended that fusion be a key component of the nation's long-term energy strategy. Accordingly, the long-range goal of the Fusion Energy Sciences program is to:

> *" Advance plasma science, fusion science, and fusion technology, and thereby establish the knowledge base for an economically and environmentally attractive fusion energy source."*

In pursuit of this goal, the program addresses a broad range of science and technology issues, resulting in spinoffs with many near-term applications.

Program Objectives

The objectives of the Fusion Energy Sciences program have been developed through extensive stakeholder meetings and were endorsed by the Fusion Energy Sciences Advisory Committee and the Secretary of Energy Advisory Board. They are summarized below.

- *Understand the science of plasmas, the fourth state of matter*. Plasmas comprise most of the observable universe, both stellar and interstellar, and have many practical applications. Progress in both plasma science and requisite supporting technology have contributed to the progress in fusion research and, conversely, fusion research has been the dominant driver of plasma science.
- *Identify and explore innovative and cost-effective development paths to fusion energy*. There are several approaches to fusion under investigation in the current program. They range from the advanced tokamak, which is the best understood magnetic confinement concept, and alternative magnetic configurations, to inertial confinement using particle beam or laser drivers.

- *Explore the science and technology of energy producing plasmas, the next frontier in fusion research, as a partner in an international effort*. Fusion research is a worldwide activity, with 80% of the research being conducted outside of the United States. International collaborations are a key strategic element of the U.S. fusion program, allowing us to leverage our funds by gaining access to facilities abroad needed to deal with scientific issues without having to use scarce resources to construct and operate them. Working from similar motivations, many scientists from abroad have participated in experiments on U.S. facilities as well. Interacting with highly qualified scientists from other countries and cultures provides an opportunity to see issues from new and different perspectives, allows solutions to arise from the diversity of the participants, and promotes both cooperation and friendly competition. In short, it provides an exciting and stimulating environment resulting in a synergistic effect that is good for science.

The Fusion Energy Sciences program is composed of three subprograms; Science, Facility Operations, and Enabling R&D. The Science subprogram includes research funds for general plasma science; for experiments on the physics of high temperature plasms in magnetic fields, in both tokamaks and other configurations; for the physics of heavy ion beam accelerators; and for theory and modeling of fusion plasmas. Funds for building, operating, upgrading and decommissioning of major facilities are in the Facility Operations subprogram. The Enabling R&D subprogram includes funds for key fusion technology research and innovations needed to advance fusion science and develop the knowledge base for an attractive fusion energy source. Many of the advances in fusion science that have occurred during the past 30 years have been enabled by technology innovations.

The Fusion Energy Sciences program today is focused primarily on the first two objectives above and the related enabling technology research. Only a small effort on burning plasma physics and related fusion technology, e.g. materials science and engineering research on energy conversion and tritium handling continues.

Scientific Facilities Utilization

The Fusion Energy Sciences request includes $95,000,000 to operate scientific user facilities. This investment will provide research time for about 500 scientists in universities, federally sponsored laboratories, and industry. It will also leverage both federally and internationally sponsored research, consistent with the Administration's strategy for enhancing the U.S. National science investment. The proposed funding will support operations at the Department's three major fusion energy physics facilities: the Doublet III-D tokamak at General Atomics, the Alcator C-Mod tokamak at the Massachusetts Institute of Technology, and the National Spherical Torus Experiment at the Princeton Plasma Physics Laboratory.

Performance Measures

The Fusion Energy Sciences program supports the Department's strategic goal of delivering the scientific and technological innovations critical to meeting the Nation's energy challenges. The performance measures of the Fusion Energy Sciences program fall into four areas: (1) excellence of the science, (2) relevance to the DOE mission and national needs, (3) stewardship of research capabilities, and (4) management of human resources. The ways in which the Fusion Energy Sciences program measures performance include merit-based peer review, charges to the Fusion Energy Sciences Advisory Committee (FESAC), and recognition of professional accomplishments of research performers. These measures have been an integral part of the program for many years. Each major research facility has a community based Program Advisory Committee (PAC) that sets priorities for the use of that facility. Proposals for new facilities or upgrades to existing facilities at laboratories receive both scientific and engineering/cost/schedule reviews.

For FY 2001, specific performance measures are:

- Initiate and meet schedules for dismantling, packaging, and offsite shipping of the Tokamak Fusion Test Reactor (TFTR) systems located in the basement of the TFTR building as described in the Decontamination and Decommissioning plan.
- Sustain partnerships that support fusion/plasma sciences, specifically through completion by June 2001 of a new NSF/DOE Partnership in Basic Plasma Science and Engineering to provide continuity after the present agreement ends, and by initiating a new element of the U.S.-Japan collaborative program by the end of FY 2001.
- Evaluate first physics results from the innovative Electric Tokamak (ET) at UCLA, where the long-range goals of this university-scale program (funded at about $2,000,000 per year) are to study fast plasma rotation and associated radial electric fields due to radiofrequency-drive, in order to enhance plasma pressure in sustained, stable plasmas.
- Improve nonlinear magneto-hydrodynamics codes to be capable of computing the effect of realistic resistive walls and plasma rotation on advanced tokamak pressure limits. (These codes may also be capable of modeling the startup of alternate configurations such as the spheromak.)
- Complete by June 2001 the 6 MW power upgrade of the DIII-D microwave system and initiate experiments with it to control and sustain plasma current profiles, with the goal of maintaining improved confinement of plasma energy for longer periods of time.
- Initiate a new phase of the U.S.-Japan collaborative program of research on enabling technologies, materials, and science for an attractive fusion energy source.
- Transfer the waste management and environmental monitoring activities at the Princeton Plasma Physics Laboratory (PPPL) from the Environmental Management program (EM) to the Fusion Energy Sciences program.
- Complete the DOE-Japan Atomic Energy Research Institute (JAERI) collaboration at the Tritium Systems Test Assembly (TSTA) facility at Los Alamos National Laboratory (LANL).

Significant Accomplishments and Program Shifts

There were six Performance Measures in the FY 1999 Fusion Energy Sciences budget narrative. Each of the six performance measures was either met or exceeded.

- The National Academy of Sciences is reviewing the quality of science in the Fusion Energy Sciences Program. An interim report was issued in August 1999, highlighting the contributions of fusion science to other fields of research. The full study, including strategic recommendations, will be completed in FY 2000.
- All three of the major fusion experiments have been operating as national facilities with research teams composed of participants from throughout the fusion science community. Program advisory committees assure scientific quality and program relevance of the research conducted at each facility.

- The National Spherical Torus Experiment (NSTX) project at the Princeton Plasma Physics Laboratory (PPPL) was completed in FY 1999, achieving its first major operational milestone ahead of schedule. A national research team was organized and the facility began experimental operations in FY 1999.
- Considerable progress has been made in areas such as the macroscopic equilibrium and stability of magnetically confined plasmas and turbulence and transport in tokamak plasmas. Software and hardware were developed that allow remote collaborations on a wide variety of fusion experiments in the United States and abroad.
- The fusion program continued exploring a wide range of confinement concepts other than the tokamak. Including the three new innovative confinement experiments that started operation in FY 1999, there are 13 exploratory level alternate magnetic concept experiments in the United States. In addition, there was increased effort on exploring the physics of a heavy ion accelerator for inertial fusion energy.
- The technology program subelement was restructured in FY 1999, and U.S. participation in the International Thermonuclear Experimental Reactor project was successfully completed.

Other significant accomplishments include:

- A major review of magnetic and inertial fusion energy options was carried out by a task force of the Secretary of Energy Advisory Board in response to congressional requests. The task force report was issued in August 1999. The report's Executive Summary states that "In the light of the promise of fusion and the risks arising from increasing worldwide energy demand and from eventually declining fossil energy supply, it is our view that we should pursue fusion aggressively." The task force also endorsed the revised focus of the magnetic fusion program to understand the science and technology of fusion and concluded that inertial fusion energy warranted continued exploration and development.
- At a two-week long workshop, 350 fusion researchers from the United States and abroad discussed virtually all of the key technical issues associated with fusion science. This workshop provided a very effective forum for enhanced interaction between magnetic fusion and inertial fusion approaches, between science and technology issues, and between basic understanding and energy applications of fusion. The community reaffirmed that the next frontier in magnetic fusion is the science of burning plasmas, and that the tokamak is technically ready for a high-gain burning plasma experiment.
- The Fusion Energy Sciences Advisory Committee (FESAC) led a community assessment of the restructured fusion program and provided a report, with specific recommendations on program priorities and balance, in September 1999.
- Preparation of a strategic plan for Fusion Energy Sciences was initiated in FY 1999. It will be completed early in 2000 incorporating the results of the Secretary of Energy Advisory Board and National Research Council reviews, the recommendations of the Fusion Energy Sciences Advisory Committee, and technical understandings that came from the 1999 Fusion Summer Study.
- DOE and NSF issued a joint announcement for new opportunities for funding in FY 2000 in September 1999 as part of the NSF/DOE Partnership in Basic Plasma Science and Engineering.

- In FY 1999, the general plasma science program was extended to include national laboratories with a solicitation for proposals on applications of plasma science. Proposals, many of which will have evolved from Laboratory Directed R&D programs, will be competitively peer reviewed.
- In late FY 1999 Los Alamos National Laboratory identified future operating cost increases for the Tritium System Test Assembly (TSTA) facility, which was built to study the fusion fuel cycle process. Following DOE and peer review, agreement was reached to complete the highly successful research program by mid-FY 2001. Research will cease then while operation to reduce the inventory of tritium fuel will continue, in preparation for transfer to EM for subsequent decontamination and decommissioning.

Science Accomplishments

During the past year, scientific accomplishments covered a wide range of activities ranging from improvements in the detailed understanding of fusion plasma confinement physics to theory and modeling advances that also contribute to fields outside of fusion science. Important examples include the following:

- *Magnetic Reconnection:* The tearing and reconnection of magnetic field lines is of fundamental importance in many areas of plasma physics, including fusion science. Newly developed laboratory experiments at the California Institute of Technology, Swarthmore, and the Princeton Plasma Physics Laboratory have led to significant advances in the understanding of this phenomenon, which is of particular importance in the eruptions of energetic bursts from the surface of the sun, which, in turn affect radio and satellite communications.
- *Understanding the Sharp Edge of the Plasma*: Tokamak plasmas spontaneously generate “transport barriers” that substantially reduce the loss of energy and result in high plasma confinement. When such a barrier forms, the steep pressure gradients that result can give rise to a variety of instabilities. While some instabilities are deleterious, others are benign or even beneficial, as in the regime recently discovered in the Alcator C-Mod tokamak at Massachusetts Institute of Technology, that combines favorable confinement of energetic particles with sufficient particle transport to maintain plasma purity. Installation of high-spatial-resolution diagnostics has enabled measurement, with unprecedented detail, of the plasma profiles in this transport barrier. These measurements are providing critical tests of predictions of stability theory.
- *Relating Plasma Turbulence to the Theory of Avalanches*: Plasma turbulence increases energy transport and thereby limits magnetic confinement. There have been recent attempts to compare plasma transport phenomena with avalanche or “sand pile” transport models. Although plasmas are fluids, Self-Organized Criticality (SOC) models that are used to simulate a wide variety of natural phenomena such as earthquakes, avalanches, etc. describe some nonlinear aspects of plasma turbulence. Measurements of electron temperature and density fluctuations in tokamaks are providing information about the size and frequency of transport events, thus improving comparisons with theoretical avalanche models.
- *Self-Acceleration of the Plasma*: Plasma flows are now known to be critical for improving particle and energy confinement in magnetic confinement configurations. Past experiments have shown that the force exerted on a plasma by injected beams of particles can generate flows through rotation. However, recent observations of rapid rotation in plasmas with radiowave heating rather than beam heating have led to speculation that radiowaves, which do not carry momentum, can also produce rotation. This indicates that it may be possible to use radiofrequency waves to control plasma flow and improve confinement. Focused experiments in Alcator C-Mod now show that even in plasmas

with no additional heating there can be substantial rotation. There is conjecture that this is an intriguing and unexpected effect of turbulent transport.

- *Exploring New Ways to Fuel Fusion Plasmas*: Injecting small pellets of frozen deuterium has long been a technique for fueling fusion plasmas. Usually pellets are launched from the outside, or low magnetic field side, of the tokamaks. But in large, high temperature and high density plasmas this requires extremely high velocity pellets in order to penetrate deep into the plasma core. Recently, pellets injected from the high magnetic field side of the DIII-D tokamak, that is from the center of the "doughnut," penetrated much deeper into the plasma. Analysis of these experiments has helped to uncover key physics missing from earlier pellet penetration codes.

- *New Methods for Starting up Plasmas*: The conventional method for initiating the current in a tokamak—magnetic induction—requires a large transformer winding (or magnet coil) through the center of the tokamak. Non-inductive startup could reduce the size and cost of future fusion devices. By combining edge current drive with the currents driven by radio frequency waves, neutral beam injection, and the bootstrap current generated by plasma pressure itself, calculations have shown that it should be possible to create plasmas in the National Spherical Torus Experiment with currents up to 500,000 amperes. Successful non-inductive startup would permit dispensing with the central magnet, thus simplifying the spherical torus concept enormously.

- *Resolving the Performance Projections for Future Experiments:* Future large-scale fusion devices will require an extrapolation from existing experiments. For several years one of the computer models used for predicting the performance of the International Thermonuclear Experimental Reactor indicated that its performance would be significantly below what empirical extrapolation from present experiments predicts. As a result of concentrated effort by the fusion theorists to understand this difference, it appears that this computer model did not accurately describe certain key physical phenomena. When an improved description of these key physics elements is included in the computer model, there is an increase in the performance projections for ITER, and other large-scale fusion devices, and the expected performance is in the range predicted by a logical empirical extension of present experimental work.

- *MFE Concept Development:* The fusion program is exploring a wide range of confinement concepts other than the tokamak. Three new experiments started operation in FY 1999—the Sustained Spheromak Physics Experiment (SSPX) at the Lawrence Livermore National Laboratory, the flow stabilized pinch experiment (ZAP) at the University of Washington, and the Helically Symmetric Stellarator Experiment (HSX) at the University of Wisconsin. During FY 2000, the Levitated Dipole Experiment at the Massachusetts Institute of Technology will begin operation. This will bring the total number of exploratory level alternate magnetic concept experiments in the United States to 13. This important new investment in the Fusion Energy Sciences program is expected to pay dividends in the form of enhanced understanding of the interaction of plasmas with electric and magnetic fields and lead to significantly better magnetic confinement concepts over the next decade.

- *IFE Concept Development:* There is also increased effort on heavy ion accelerator physics aimed at a driver for inertial fusion. Successful completion of experiments using modular systems would pave the way for the design of an Integrated Research Experiment, a proof-of-principle IFE facility using heavy ions.

Facility Operations Accomplishments

The Fusion Energy Sciences program operates three major facilities for producing high temperature plasmas hotter than the core of the sun: National Spherical Torus Experimental project (NSTX) at PPPL, DIII-D at General Atomics, and Alcator C-Mod at MIT. These facilities are equipped with extensive diagnostic instruments needed to connect experiments to theory and simulation codes. The scientific understanding developed from these facilities is contributing to the knowledge base for an attractive fusion energy source. Modifications and upgrades at these facilities proceeded on schedule and within cost during FY 1999. The combined average unscheduled downtime for these facilities was about 15% in FY 1999. Research on these facilities is augmented and extended through collaboration with international programs.

- The NSTX project at the Princeton Plasma Physics Laboratory (PPPL) was completed in FY 1999, achieving its first major operational milestone ahead of schedule. A national research team was organized and the facility began experimental operations in FY 1999. In FY 2000, one of the TFTR neutral beams will be installed and research operations will resume in mid-summer.
- Significant modifications to the divertor of the DIII-D facility were initiated in FY 1999 and will be completed in early FY 2000, providing capabilities required for experiments to extend the pulse duration of advanced toroidal operating modes later in the year. These important experiments should demonstrate the conditions necessary for long pulse operations.
- Conceptual design of a plasma heating and current drive system for Alcator C-Mod was completed and favorably reviewed in FY 1999. Design and fabrication will begin in FY 2000. Fabrication will continue in FY 2001. The system will be operational in 2002 and will provide significant enhancement of C-Mod plasma performance and duration.
- Preparations for the decontamination and decommissioning (D&D) of TFTR were initiated at PPPL in FY 1999. During FY 2000, PPPL will complete removal of all systems/components to be retained for future use in the program and will prepare the remaining systems/components for dismantling, removal, and shipment offsite. When D&D is completed, the TFTR test cell will be available for reuse by the Fusion Energy Sciences program.

Enabling R&D Accomplishments

- At the direction of Congress, U.S. participation in ITER was successfully completed. The Co-center in San Diego was closed and returned to the owner; U.S. secondees to the Joint Central Team returned; and the U.S. responsibilities in component R&D were discharged. Of particular note, the Central Solenoid Model Coil, the largest pulsed superconducting magnet ever built, was completed and shipped to Japan for testing.
- Bilateral and multilateral plasma technology activities on major scientific facilities abroad continued in order to access test conditions not available on domestic facilities.
- The low activation materials research program continued to focus on feasibility issues and to define and extend operating limits of candidate materials systems.
- All Enabling R&D program elements were fully integrated into a Virtual Laboratory for Technology, thus creating a coordinated national program.
- Research on systems with the potential for significantly increasing high heat flux component performance and lifetime was initiated. Such components will be needed for next generation experiments in several of the developing concepts.

- Research on the magnetic, heating, and fueling components that will enable domestic plasma experiments to achieve their full plasma science research objectives continued.

Awards

- The MIT Plasma Science and Fusion Center, in collaboration with PNNL, won a **1998 R&D 100 Award** for a device that measures smokestack emissions. The award winning work has its roots in fusion diagnostics and plasma physics.
- Five fusion researchers were elected **Fellows of the American Physical Society in 1999.**
- A University of Wisconsin researcher was awarded **the 1999 APS Award for Excellence in Plasma Physics.** This fusion scientist's work focused on the development and exploitation of a diagnostic to measure fluctuations and their relation to energy transport in hot, fusion-relevant plasmas.
- A University of Michigan faculty member received the **1999 IEEE Plasma Science and Application Award**. This fusion-supported researcher studies the scientific aspects of high power radio frequency tubes.
- The MIT Plasma Science and Fusion Center, developed a microplasmatron fuel converter that was selected as one of the **1999 Discover Award** finalists for technological innovation.
- A **U.S. Patent** was awarded to a LANL researcher and to the Regents of the University of California for a diagnostic that measures small temperature changes in fusion plasmas. The diagnostic is in use in Japan and is of interest to European researchers.

Funding of Contractor Security Clearances

In FY 1999, the Department divided the responsibility for obtaining and maintaining security clearances. The Office of Security Affairs, which was responsible for funding all Federal and contractor employee clearances, now pays only for clearances of Federal employees, both at headquarters and the field. Program organizations are now responsible for contractor clearances, using program funds. This change in policy enables program managers to make the decisions as to how many and what level clearances are necessary for effective program execution. In this way, it is hoped that any backlog of essential clearances that are impeding program success can be cleared up by those managers most directly involved. The Office of Science is budgeting $96,000 for estimated contractor security clearances in FY 2000 and FY 2001, within this decision unit.

Workforce Development

The Fusion Energy Sciences program is the Nation's primary sponsor of research in plasma physics and fusion science. The mission of the Fusion Energy Sciences program is to train future researchers not only for fusion research, but also for related areas such as plasma processing, space plasma physics, plasma electronics, and accelerator/beam physics. This program supported 365 graduate students and post doctoral investigators in FY 1999; 49 of these graduate students and post doctoral investigators conducted research at the FES user facilities.

Funding Profile

(dollars in thousands)

	FY 1999 Current Appropriation	FY 2000 Original Appropriation	FY 2000 Adjustments	FY 2000 Current Appropriation	FY 2001 Request
Fusion Energy Sciences					
Science	111,975	141,884	-3,395	138,489	136,202
Facility Operations	61,735	72,950	-1,405	71,545	77,440
Enabling R&D	43,538	35,166	-514	34,652	33,628
Subtotal, Fusion Energy Sciences	217,248	250,000	-5,314	244,686	247,270
Use of Prior Year Balances	-1,136[a]	0	0	0	0
General Reduction	0	-945	+945	0	0
Contractor Travel	0	-1,369	+1,369	0	0
Omnibus Rescission	0	-3,000	+3,000	0	0
Total, Fusion Energy Sciences	216,112[b]	244,686	0	244,686	247,270[c]

Public Law Authorization:

Public Law 95-91, “Department of Energy Organization Act”

Public Law 103-62, “Government Performance Results Act of 1993”

[a] Share of Science general reduction for use of prior year balances assigned to this program. The total general reduction is applied at the appropriation level.

[b] Excludes $5,083,000 which has been transferred to the SBIR program and $305,000 which has been transferred to the STTR program.

[c] Includes $3,157,000 for Waste Management activities at Princeton Plasma Physics Laboratory that was previously budgeted in FY 1999 and FY 2000 in the Environmental Management program.

Funding By Site

	(dollars in thousands)				
	FY 1999	FY 2000	FY 2001	$ Change	% Change
Albuquerque Operations Office					
Los Alamos National Laboratory	4,365	6,094	5,960	-134	-2.2%
Sandia National Laboratories	4,120	3,338	3,232	-106	-3.2%
Total, Albuquerque Operations Office	8,485	9,432	9,192	-240	-2.5%
Chicago Operations Office					
Argonne National Laboratory	2,604	2,339	2,270	-69	-2.9%
Princeton Plasma Physics Laboratory	52,129	62,970	70,219	+7,249	+11.5%
Chicago Operations Office	46,304	40,768	39,770	-998	-2.4%
Total, Chicago Operations Office	101,037	106,077	112,259	+6,182	+5.8%
Idaho Operations Office					
Idaho National Engineering and Environmental Laboratory	1,804	1,623	1,701	+78	+4.8%
Oakland Operations Office					
Lawrence Berkeley National Laboratory	4,971	7,877	7,655	-222	-2.8%
Lawrence Livermore National Laboratory	11,696	13,063	12,716	-347	-2.7%
Stanford Linear Accelerator Center	50	50	0	-50	-100.0%
Oakland Operations Office	67,342	67,858	64,453	-3,405	-5.0%
Total, Oakland Operations Office	84,059	88,848	84,824	-4,024	-4.5%
Oak Ridge Operations Office					
Oak Ridge Inst. for Science & Education	471	800	800	0	0.0%
Oak Ridge National Laboratory	18,093	17,550	17,621	+71	+0.4%
Oak Ridge Operations Office	89	87	70	-17	-19.5%
Total, Oak Ridge Operations Office	18,653	18,437	18,491	+54	+0.3%
Ohio Field Office	0	8	0	-8	-100.0%
Richland Operations Office					
Pacific Northwest National Laboratory	1,415	1,385	1,385	0	0.0%
Savannah River Operations					
Savannah River Tech Center	177	0	0	0	0.0%
Washington Headquarters	1,618	18,876	19,418	+542	+2.9%
Subtotal, Fusion Energy Sciences	217,248	244,686	247,270	+2,584	+1.1%
Use of Prior Year Balances	-1,136[a]	0	0	0	0.0%
Total, Fusion Energy Sciences	216,112[b]	244,686	247,270[c]	+2,584	+1.1%

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[a] Share of Science general reduction for use of prior year balances assigned to this program. The total general reduction is applied at the appropriation level.

[b] Excludes $5,083,000 which has been transferred to the SBIR program and $305,000 which has been transferred to the STTR program.

[c] Includes $3,157,000 for Waste Management activities at Princeton Plasma Physics Laboratory that was previously budgeted in FY 1999 and FY 2000 in the Environmental Management program.

Site Description

Argonne National Laboratory

Argonne National Laboratory (ANL) in Argonne, Illinois, is a Multiprogram Laboratory located on a 1,700 acre site in suburban Chicago. ANL has a satellite site located in Idaho Falls, Idaho. Argonne's Fusion Energy Sciences program contributes to a variety of fusion enabling R&D program activities in areas of modeling, analysis, and experimental research. Argonne has a lead role internationally in analytical models and experiments for liquid metal cooling in fusion devices, including the ALEX facility, that studies the interaction of flowing liquid metals with magnetic fields, and liquid lithium flow loop that studies corrosion in candidate structural alloy materials. Argonne's capabilities in the engineering design of fusion energy systems has contributed to the design of components such as blankets, tritium systems, and plasma-facing components, as well as to analysis supporting the ARIES studies of fusion power plant concepts. Argonne also contributes to low-activation materials research with its unique capabilities in vanadium alloy testing in fission reactors and post-irradiation examinations.

Idaho National Engineering and Environmental Laboratory

Idaho National Engineering and Environmental Laboratory (INEEL) is a Multiprogram Laboratory located on 572,000 acres in Idaho Falls, Idaho. Since 1978, INEEL has been the lead laboratory for fusion safety for the Fusion Energy Sciences program. As the lead laboratory, they have helped to develop the fusion safety data base that will demonstrate the environmental and safety characteristics of both nearer term fusion devices and future fusion power plants. They have focused their research on: (1) understanding the behavior of the sources of radioactive and hazardous materials in a fusion machine, (2) understanding the energy sources in a fusion machine that could mobilize these materials, and (3) developing the analytical tools that demonstrate the environmental and safety characteristics of a fusion machine. In FY 2001, fusion efforts at INEEL will be focused on safety research for magnetic and inertial concepts associated with both existing or planned domestic experimental facilities and the domestic research program. In addition, to develop further our domestic safety data base, INEEL will use existing collaborative arrangements to conduct work on existing international facilities.

Lawrence Berkeley National Laboratory

Lawrence Berkeley National Laboratory (LBNL) is a Multiprogram Laboratory located in Berkeley, California. The Laboratory is on a 200 acre site adjacent to the Berkeley campus of the University of California. One of LBNL's missions is to study and apply the physics of heavy ion beams and to advance related technologies for the U.S. Heavy-Ion Fusion (HIF) program. The HIF program centered at LBNL has the long-range goal of developing inertial fusion energy (IFE) as an economically and environmentally attractive source of electric power.

Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory (LLNL) is a Multiprogram Laboratory located on an 821 acre site in Livermore, California. LLNL is host for Defense Programs' National Ignition Facility, which will give the United States the first opportunity in the world to demonstrate inertial fusion ignition and energy gain in the laboratory. This goal will provide the IFE program with crucial results concerning target physics. This fusion energy mission is consistent with the NIF mission statement. Livermore partners with other Laboratories (LBNL, for example, in Heavy Ion Fusion) in fusion energy research. This program also includes collaborations on the DIII-D tokamak at General Atomics, construction of an innovative concept experiment, the Sustained Spheromak Physics Experiment (SSPX) at LLNL, and benchmarking of fusion physics computer models with experiments such as DIII-D. The SSPX started experimental operations in FY 1999. Definitive results on the feasibility of sustaining high temperature spheromak plasmas utilizing external electrode current drive are expected by the end of FY 2000.

Los Alamos National Laboratory

Los Alamos National Laboratory is a Multiprogram Laboratory located on a 27,000 acre site in Los Alamos, New Mexico. The FY 2001 budget will support the creation of computer codes for modeling the stability of plasmas, as well as work in diagnostics, innovative fusion plasma confinement concepts such as Magnetized Target Fusion, and the successful completion of the research operations of the Tritium Systems Test Assembly (TSTA) facility.

Oak Ridge Institute for Science and Education

Oak Ridge Institute for Science and Education (ORISE) is located on a 150 acre site in Oak Ridge, Tennessee. ORISE was established by DOE to undertake national and international programs in education, training, health, and the environment. ORISE and its programs are operated by Oak Ridge Associated Universities (ORAU) through a management and operating contract with DOE. Established in 1946, ORAU is a consortium of 88 colleges and universities. For the Fusion Energy Sciences (FES) program, ORISE acts as an independent and unbiased agent to administer the Fusion Energy Sciences Graduate and Postgraduate Fellowship Programs, in conjunction with FES, the Oak Ridge Operations Office (ORO), participating universities, DOE laboratories, and industries.

Oak Ridge National Laboratory

Oak Ridge National Laboratory (ORNL) is a Multiprogram Laboratory located on a 24,000 acre site in Oak Ridge, Tennessee. ORNL develops a broad range of components that are critical for improving the research capability of fusion plasma experiments located at other institutions and that are essential for developing fusion as an environmentally acceptable energy source. The laboratory is a leader in the theory of heating of plasmas by electromagnetic waves, antenna design, and design and modeling of pellet injectors to fuel the plasma and control the density of plasma particles. Research is also done in the area of turbulence and its effect on transport of heat through a plasma. Codes developed at the laboratory are also used to model plasma processing in industry. While some ORNL scientists are located full-time at off-site locations, others carry out their collaborations with short visits to the host institutions, followed by extensive computer communications from ORNL for data analysis and interpretation, and theoretical studies. ORNL leads the advanced materials program, contributes to research on all materials systems of fusion interest, coordinates experimental collaborations for two U.S.-Japan programs, and coordinates materials activities for the Virtual Laboratory for Technology.

Pacific Northwest National Laboratory

Pacific Northwest National Laboratory (PNNL) is a Multiprogram Laboratory located on 640 acres at the Department's Hanford site in Richland, Washington. The Fusion Energy Sciences program at PNNL is focused on research on materials that can survive in a fusion neutron environment. The available facilities used for this research include mechanical testing and analytical equipment, including state-of-the-art electron microscopes, that are either located in radiation shielded hot cells or have been adapted for use in evaluation of radioactive materials after exposure in fission test reactors. Experienced scientists and engineers at PNNL provide leadership in the evaluation of ceramic matrix composites for fusion applications and support work on vanadium, copper and ferritic steels as part of the U.S. fusion materials team. PNNL also plays a leadership role in a fusion materials collaboration with Japan, with Japanese owned test and analytical equipment located in PNNL facilities and used by both PNNL staff and up to ten Japanese visiting scientists per year.

Princeton Plasma Physics Laboratory

Princeton Plasma Physics Laboratory (PPPL) is a program-dedicated laboratory (Fusion Energy Sciences) located on 72 acres in Princeton, New Jersey. PPPL is the only U.S. Department of Energy (DOE) laboratory devoted primarily to plasma and fusion science. It hosts experimental facilities used by multi-institutional teams and also sends researchers and specialized equipment to other fusion facilities in the United States and abroad. PPPL is the host for the National Spherical Torus Experiment (NSTX), which is an innovative toroidal confinement device closely related to the tokamak, and is currently working on the conceptual design of another innovative toroidal concept, the compact stellarator. PPPL scientists and engineers have significant involvement in the DIII-D and Alcator C-Mod tokamaks in the U.S. and the large JET (Europe) and JT-60U (Japan) tokamaks abroad. This work is focused on developing the scientific understanding and innovations required for an attractive fusion energy source. PPPL scientists are also involved in several basic plasma science experiments, ranging from magnetic reconnection to plasma processing. PPPL, through its association with Princeton University, provides high quality education in fusion-related sciences, having produced more than 175 Ph.D. graduates since its founding in 1951.

Sandia National Laboratory

Sandia National Laboratory is a Multiprogram Laboratory, with a total of 3,700 acres, located in Albuquerque, New Mexico, with other sites in Livermore, California, and Tonapah, Nevada. Sandia's Fusion Energy Sciences program plays a lead role in developing plasma-facing components for fusion devices through the study of plasma interactions with materials, the behavior of materials exposed to high heat fluxes, and the interface of plasmas and fusion device first walls. Sandia selects, specifies, and develops materials for components exposed to high heat and particles fluxes and conducts extensive analysis of prototypes to qualify components before their use in fusion devices. Materials samples and prototypes are tested in Sandia's Plasma Materials Test Facility, which uses high-power electron beams to simulate the high heat fluxes expected in fusion environments. Materials and components are exposed to tritium-containing plasmas in the Tritium Plasma Experiment. Tested materials are characterized using Sandia's accelerator facilities for ion beam analysis. Sandia supports a wide variety of domestic and international fusion experiments in areas of tritium inventory removal, materials postmortem analysis, diagnostics development, and component design and testing.

Stanford Linear Accelerator Center

Stanford Linear Accelerator Center (SLAC) is a program-dedicated laboratory (High Energy Physics) located on 426 acres in Menlo Park, California. SLAC is operated for the United States Department of Energy by Stanford University. The main interest in fusion at SLAC is the possibility of adapting the accelerator science and technology from elementary particle physics to the production of fusion power from the implosion of inertial fusion targets driven by beams of high energy, heavy ions. A member of the accelerator research department at SLAC has been involved with the heavy ion fusion program since its inception.

All Other Sites

The Fusion Energy Sciences program funds research at 54 colleges/universities located in 28 states. Also included are funds for DIII-D and related programs at General Atomics and funding of research grants awaiting distribution pending completion of review results or program office detailed planning.

Science

Mission Supporting Goals and Objectives

The goals of the Science subprogram are to advance our understanding of the plasma state and to develop innovative approaches for confining a fusion plasma. These goals are accomplished through a modest program in basic plasma science; active research programs in toroidal concept innovations and non-toroidal concept explorations; strong theory and modeling programs; and the development of improved diagnostics that make possible a rigorous testing of the scientific principles of fusion. A companion objective of the Science subprogram is to broaden the intellectual and institutional base in fundamental plasma physics. Two activities, development activities for junior faculty in plasma physics and an NSF/DOE partnership in plasma physics and engineering, are the major contributors to this objective.

Plasma science is the study of ionized matter, ranging from neon lights to stars, that makes up 99 percent of the observable universe. It includes not only plasma physics but also other physical phenomena in ionized matter, such as atomic, molecular, radiation-transport, excitation, and ionization processes. 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 national science and technology, including astrophysics, industrial processing, and national security.

Fusion science is focused primarily on describing the fundamental processes in high temperature plasmas (greater than 100,000,000 degrees Celsius) with a confinement parameter (density multiplied by energy confinement time) larger than 10^{20} seconds per cubic meter. Nevertheless, fusion science shares many scientific issues with other topical areas of plasma science. These scientific issues include: 1) wave-particle interaction and plasma heating; 2) chaos, turbulence, and transport; 3) sheaths and boundary layers; and 4) stability, magnetic reconnection, and dynamos. Progress in all of these research issues will be required for ultimate success in achieving a practical fusion energy source.

The largest component of the Science subprogram is the tokamak research activity, that focuses on gaining a predictive understanding of the behavior of high temperature, high density plasmas required for fusion energy applications. All of the major scientific issues of fusion science will be studied in an integrated program on the two major U.S. tokamaks, DIII-D at General Atomics and Alcator C-Mod at the Massachusetts Institute of Technology. DIII-D has been a major contributor to the world fusion program over the past decade in the areas of turbulence and transport, boundary layer/divertor physics, and stability. DIII-D has an extensive set of diagnostics and is focused on developing “advanced toroidal” modes of operation using the flexibility of its plasma shaping and computer control systems. Alcator C-Mod uses intense magnetic fields to explore high temperature and high density plasmas in a unique, compact tokamak facility. Alcator C-Mod has been a major contributor to the world fusion program in the areas of wave-particle interaction/plasma heating and boundary layer/divertor physics.

In addition, advanced tokamak research is carried out by U.S. researchers working on international facilities. The Fusion Energy Sciences program has long followed a policy of not duplicating facilities that exist abroad. More recently, the Fusion Energy Sciences Advisory Committee has recommended that the United States increase collaboration on a number of these unique, state-of-the-art foreign facilities. These include the world’s highest performance tokamaks (JET in England and JT-60 in Japan), a new 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 a 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.

Research on alternative confinement concepts, both magnetic and inertial, is aimed at identifying approaches that will extend fusion science and that may improve the economical and environmental attractiveness of fusion energy sources. Since this research is exploratory in nature, much of it is carried out on small "concept exploration" experiments; however, a few concepts are sufficiently advanced for medium-size "proof-of-principle" experiments.

Concept exploration experiments typically focus on energy transport and/or plasma stability. These two issues are critical for improved economic attractiveness. Proof-of-principle experiments continue to study these two issues; however, they also begin to focus on wave-plasma interaction, plasma heating, and boundary layer physics.

The first alternate concept proof-of-principle experiment, the new National Spherical Torus Experiment (NSTX) facility at the Princeton Plasma Physics Laboratory (PPPL), began its first full year of operation in FY 2000, with a goal of demonstrating improved plasma stability and confinement in a very compact structure. The Madison Symmetric Torus (MST) at the University of Wisconsin was favorably reviewed by the Fusion Energy Sciences Advisory Committee, and is being upgraded to the proof-of-principle level. A number of concept exploration experiments are in operation or nearly ready to begin operation at various laboratories and universities around the country.

The Inertial Fusion Energy (IFE) activity is exploring an alternate path for fusion energy that would capitalize on the major R&D effort in inertial confinement fusion (ICF) carried out for stockpile stewardship purposes within the Office of Defense Programs. The IFE program depends on the ICF program for experimental research into the physics of target ignition that will be tested in the National Ignition Facility at LLNL. Efforts in IFE focus on understanding the physics of systems or techniques that will be needed to produce a viable inertial fusion energy source. These include the heavy ion beam systems for heating and compressing a target pellet to fusion conditions, the experimental and theoretical scientific basis for modeling target chamber responses, and high-gain target design.

Theory and modeling are essential to progress in fusion and plasma science because they provide the central organizing concepts of the field. They also provide the capability to analyze existing experiments, produce new ideas to improve performance, and provide a scientific assessment of new ideas. An important component of the theory program is the development and use of advanced computational tools to model the complex physical phenomena that govern confinement of high temperature plasmas. Such tools will be necessary to provide a predictive understanding of complex, highly nonlinear fusion systems.

Similarly, the development and improvement of diagnostic tools for analyzing plasma behavior continues to provide new insights into fusion plasmas and enables the detailed comparison of fusion theory and experiments.

Performance Measures

- Sustain partnerships that support fusion/plasma sciences, specifically through completion by June 2001 of a new NSF/DOE Partnership in Basic Plasma Science and Engineering to provide continuity after the present agreement ends, and by initiating a new element of the U.S.-Japan collaborative program by the end of FY 2001.

Funding Schedule

(dollars in thousands)

	FY 1999	FY 2000	FY 2001	$ Change	% Change
Tokamak Experimental Research	45,824	47,561	44,456	-3,105	-6.5%
Alternative Concept Experimental Research	37,263	53,243	50,299	-2,944	-5.5%
Theory	22,666	24,536	27,536	+3,000	+12.2%
General Plasma Science	6,222	7,964	8,450	+486	+6.1%
SBIR/STTR	0[a]	5,185	5,461	+276	+5.3%
Total, Science	111,975	138,489	136,202	-2,287	-1.7%

Detailed Program Justification

(dollars in thousands)

	FY 1999	FY 2000	FY 2001

Tokamak Experimental Research

- **DIII-D Research:** The DIII-D facility at General Atomics is directed towards the investigation of the physics of Advanced Tokamak concepts. Since the early 1990s, the experimental results from DIII-D and other tokamaks worldwide have shown that the use of detailed plasma control techniques such as selective heating, fueling, and current drive impacts the performance of tokamak plasmas considerably. The underlying physical processes that affect tokamak performance are complex and require extensive diagnostics and theoretical support to understand them. DIII-D, the largest U.S. fusion experiment, is extensively equipped with diagnostics to investigate these challenging scientific issues with a large group of collaborators from the many U.S. and international fusion groups. In FY 2001, initial results will be obtained on Advanced Tokamak integration (optimizing transport, power exhaust, profile control simultaneously) using the upgraded current drive and

[a] Excludes $4,020,000 which has been transferred to the SBIR program and $241,000 which has been transferred to the STTR program.

	(dollars in thousands)		
	FY 1999	FY 2000	FY 2001
power exhaust systems and a wide range of diagnostics. These results will be analyzed using the latest theory and modeling to evaluate the future scientific path for Advanced Tokamaks..	21,931	23,025	21,617
■ **Alcator C-Mod Research:** The Alcator C-Mod facility, by virtue of its very high magnetic field, is particularly well suited to operate in plasma regimes which are relevant to future much larger fusion tokamaks as well as compact, high field ignition tokamaks. The approach to ignition and sustained burn of a plasma is an important scientific issue for fusion. In FY 2001, Alcator C-Mod will address issues relevant to the confinement and heating of ignition tokamaks. It will also examine the physics of the plasma edge, power and particle exhaust from the plasma, mechanisms of self-generation of flows in the plasma, and improved confinement modes with currents driven by radio waves. New diagnostics made possible by the commissioning of a new diagnostic neutral beam in FY 2000 will be available in FY 2001. These new diagnostics will allow for improved comparisons between theory and experimental results.	7,775	7,870	7,367
■ **International Collaborations and Education:** International collaboration at the level of $4,329,000 provides the opportunity for U.S. scientists to work with their colleagues on unique foreign tokamaks (JET, Tore Supra, TEXTOR, and ASDEX-UG in Europe, JT-60U in Japan, and K-STAR in Korea). These collaborations produce complementary and comparative data to those obtained on the U.S. tokamaks to further the scientific understanding of fusion physics and enhance the pace of fusion energy development. In FY 2001, the collaboration with these programs will focus on the physics of Advanced Tokamaks, Burning Plasmas, and long pulse physics issues. The remaining $4,118,000 is required primarily for graduate and postgraduate fellowships in fusion science and technology, summer internships for undergraduates, general science literacy programs with teachers and students, support for historically black colleges and universities, and similar broad outreach efforts related to fusion science and technology.	8,495	9,181	8,447
■ **Experimental Plasma Research (Tokamaks):** Several unique, innovative tokamak experiments are supported at leading universities. These focus on various topics, including advanced toroidal operating modes and plasma stability and control. The Electric Tokamak at UCLA will begin research			

	(dollars in thousands)		
	FY 1999	FY 2000	FY 2001
operation. This program also develops unique diagnostic probes that provide an understanding of the plasma behavior in fusion research devices, supplying the necessary information for analysis codes and theoretical interpretation. Some key areas of diagnostic research include: 1) techniques to measure temperature and density profiles and fluctuations in these profiles to provide a better understanding of transport and 2) methods to measure the production and confinement of alpha particles to prepare for future burning plasma experiments. The requested funding level in FY 2001 supports the core diagnostic development research, as well as the work begun as a result of an FY 1999 competitive initiative to develop new diagnostic techniques........................	7,623	7,485	7,025
Total, Tokamak Experimental Research..	45,824	47,561	44,456
Alternative Concept Experimental Research			
■ **NSTX Research:** The NSTX at PPPL will complete the first year of scientific research in FY 2000. The research program, that is carried out by a national team made up of PPPL and other laboratory and university researchers, includes plasma formation, methods of controlled startup, plasma heating by radiofrequency waves and diagnostic implementation. Research in FY 2001 will pursue noninductive assisted startup at high currents and test stability properties of the spherical torus configuration...	9,906	12,874	12,250
▪ **Experimental Plasma Research (Alternates):** This budget category includes most of the experimental research on plasma confinement configurations outside of the three large fusion facilities described elsewhere. It consists of twelve smaller experiments (concept exploration level [CE]), one intermediate level experiment (proof-of-principle [PoP]) and one large study program that is focused on obtaining a design for another Proof-of-Principle experiment – a compact stellarator.			
The majority of the research is directed toward toroidal configuration with nested magnetic surfaces. For configurations with a large toroidal magnetic field, the research is focused on stellarators with special symmetry properties. The Helically Symmetric Torus, now operating at the University of Wisconsin, is the world's first stellarator designed using these symmetry principles. There is also another large effort underway, that is studying the design of a			

	(dollars in thousands)	
FY 1999	FY 2000	FY 2001

Proof of Principle level stellarator with symmetry properties similar to those of the tokamak but without externally driven plasma current. Also, in this category are two very low aspect ratio concept exploration level spherical tokamak experiments (Helicity Injection Tokamak at the University of Washington and the Pegasus Experiment at the University of Wisconsin), which will study the physics of toruses with only a very small hole in the middle. Such configurations stretch conventional stability theory into unexplored regimes.

Research on configurations where the toroidal field is less than the poloidal field concentrates on magnetic turbulence and reconnection. This program includes Madison Symmetric Torus (University of Wisconsin), a concept exploration level experiment at LLNL, and a small experiment at California Institute of Technology designed to study basic physics of the reconnection process itself.

Research on toroidal systems with closed magnetic field lines concentrates on systems where the lines close upon themselves the short way around (poloidally) the torus. The field reversed configuration (FRC) experiment at the University of Washington, the world's most advanced experiment of this type, focuses on stability issues. The ion ring experiment at Cornell University seeks gross stabilization of the FRC through the use of large ion orbits. The levitated dipole experiment (LDX) at MIT studies a variant where the confining poloidal magnetic fields are generated by a superconducting magnetic ring located within the plasma itself. Dipole confinement is of great importance in many solar and astrophysical systems.

	FY 1999	FY 2000	FY 2001
The magnetized target fusion program (funded by the FES program) at LANL and the Air Force Research Laboratory will study the possibility that a FRC can be compressed to multi-keV temperatures using fast liner technology developed by the defense programs.	18,980	25,088	23,665

- **Inertial Fusion Energy Experiments:** The inertial fusion energy program has research components that encompass many of the scientific and technical elements that form the basis of an inertial fusion energy system. Heavy ion accelerators continue to be the leading candidate driver. Understanding the physics of the heavy ion beam, that is a non-neutral plasma, is one of the outstanding scientific issues. Considerable progress has been made on developing a

	(dollars in thousands)		
	FY 1999	FY 2000	FY 2001
model for the accelerator, with the goal of providing a predictive "end-to-end" capability. The elements of this model must be compared to experimental results, and this effort will continue. Technical elements of the program include the continuing development of experimental systems to study beam formation, acceleration and focussing. The design of fusion energy targets will continue, benefiting from presently available high energy density physics data. Physics experiments to be carried out on Defense Programs' National Ignition Facility will ultimately provide validation of target design. Emphasis will be maintained on critical scientific research topics that, even with reduced efforts, will allow modest progress to be made in developing the scientific and technical foundations of inertial fusion energy.	8,377	15,281	14,384
Total, Alternative Concept Experimental Research..........................	37,263	53,243	50,299

Theory

- The theoretical problems in plasma science are formidable. The goal of the theory and computation program is to achieve a quantitative understanding of the behavior of fusion plasmas. Considerable progress has been made in areas such as the macroscopic equilibrium and stability of magnetically confined plasmas and turbulence and transport in tokamak plasmas. The theory and computing program is a broad-based program with researchers located at national laboratories, universities, and industry. There is an increased program emphasis on advanced computing, including the development of improved modeling codes and a code library for use by all fusion researchers. Work in tokamak theory includes not only efforts to support analysis of experiments, but also includes the development of many new theories and tools that model plasma behavior in advanced tokamaks. These tools will later be extended to innovative confinement geometries. The majority of the work in toroidal theory is aimed at developing a predictive understanding of advanced tokamak operating modes. In alternate concept theory, the emphasis will be on understanding the fundamental processes determining equilibrium, stability, and confinement in each concept. Generic theory supports the development of basic plasma theory and atomic physics theory that is applicable not only to fusion research, but also to basic plasma science. The objective of the advanced computing activity is to improve computational simulation

	(dollars in thousands)		
	FY 1999	FY 2000	FY 2001
and modeling capabilities in order to obtain a quantitative understanding of plasma behavior in fusion experiments. This will ensure optimum use of a set of innovative national experiments and fruitful collaboration on major international facilities.			
In FY 2001, funds will be used to develop improved models of equilibrium and stability and turbulence and energy transport in toroidal magnetic confinement systems and to improve the fidelity of heavy ion accelerator models. The Fusion Energy Sciences program will select the research projects on advanced simulation and modeling of fusion plasma systems using a competitive peer review process..........	22,666	24,536	27,536
General Plasma Science			
■ The plasma science program focuses on basic plasma science and, engineering research. This research is carried out primarily by the University community, but DOE laboratories are expected to make contributions as well. Advances in basic plasma physics contribute to the foundation of the Fusion Energy Sciences program as well as other important areas of science and technology. This program provides a strong contribution to the education of plasma physicists. The Plasma Science Junior Faculty Development Program will continue at FY 2000 levels. Collaborative efforts such as the NSF/DOE plasma science and engineering program will continue. In FY 2000 opportunities were made available to DOE laboratory plasma scientists to compete for funding for basic and applied plasma physics research. Laboratory scientists form an important component of the general plasma science community. They also operate unique user facilities such as the Magnetic Reconnection Experiment (MRX) at PPPL. In FY 2001, laboratory activities will be maintained at a constant level. The program will also continue to collect and distribute atomic physics data for fusion.	6,222	7,964	8,450
SBIR/STTR			
■ In FY 1999, $4,020,000 and $241,000 were transferred to the SBIR and STTR programs, respectively. The FY 2000 and FY 2001 amounts are the estimated requirement for the continuation of the SBIR and STTR programs.	0	5,185	5,461
Total, Science...	111,975	138,489	136,202

Explanation of Funding Changes from FY 2000 to FY 2001

	FY 2001 vs. FY 2000 ($000)
Tokamak Experimental Research	
■ The level of participation by the collaborators and on site staff in physics research and data analysis will decrease on DIII-D.	-1,408
■ Participation of offsite collaborators and development of diagnostics will decrease on Alcator C-Mod	-503
■ There is a decrease in diagnostic development within Tokamak Experimental Plasma Research.	-460
■ This decrease primarily results from decreased effort in international collaboration on medium-size tokamaks.	-734
Total, Tokamak Experimental Research	-3,105
Alternative Concept Experimental Research	
■ The decrease in support for NSTX research will impact data collection and analysis, and funds for enhancement of existing research collaborations and preparation of advanced diagnostics	-624
■ Funding for alternate concepts experiments is reduced.	-1,423
■ The IFE program is reduced to fund other fusion program priorities. Programmatic emphasis will be placed on scientific areas which will enable progress to be made in the development of the scientific and technical foundations of inertial fusion energy.	-897
Total, Alternative Concept Experimental Research	-2,944
Theory	
■ The theory program will include increased effort on advanced computational simulation and modeling of complex fusion systems.	+3,000
Basic Plasma Science	
■ Increased funding in basic plasma science will be directed to the support of user facilities in basic plasma science	+486
SBIR/STTR	
■ Support for SBIR/STTR is mandated at 2.65 percent. These grants will support plasma and fusion science.	+276
Total Funding Change, Science	-2,287

Facility Operations

Mission Supporting Goals and Objectives

This activity provides for the operation and maintenance of major fusion research facilities; namely, DIII-D at GA, Alcator C-Mod at MIT, and NSTX at PPPL. These user facilities enable U.S. scientists from universities, industry, and laboratories, as well as visiting foreign scientists, to conduct world-class research on the behavior of fusion plasmas. 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. This activity includes the cost of operating and maintenance personnel, electric power (about 3% of the total operating cost at a research facility), expendable supplies, replacement parts, subsystem modifications and enhancements, and inventories. In the case of PPPL, funding is provided for continuing the decontamination and decommissioning of the Tokamak Fusion Test Reactor, which was shut down in FY 1997; ongoing caretaking for the tritium systems and radioactive elements is also required during this process. In addition, in FY 2001, the Fusion Energy Sciences program will take over waste management activities from the Environmental Management (EM) program for the PPPL site. General plant projects (GPP) funding for PPPL supports minor facility renovations and other capital alterations and additions for buildings and utility systems. Capital equipment funding for upgrading the research capability of DIII-D and C-Mod is also included to further enhance the facilities.

The principal objective of the Facility Operations subprogram is to maximize the quantity and quality of data collected at the major fusion energy science facilities while complying with all applicable safety and environmental requirements and cultivating an environment of operational excellence.

The following table summarizes the scheduled weeks of operations for DIII-D, C-Mod, and NSTX.

Performance Measures

- Complete by June 2001 the 6 MW power upgrade of the DIII-D microwave system and initiate experiments with it to control and sustain plasma current profiles, with the goal of maintaining improved confinement of plasma energy for longer periods of time.
- Initiate and meet schedules for dismantling, packaging, and offsite shipping of the Tokamak Fusion Test Reactor (TFTR) systems.

Facility Utilization

(Weeks of Operations)

	FY 1999	FY 2000	FY 2001
DIII-D	14	14	17
Alcator C-Mod	12	18	14
NSTX	6	14	17

Funding Schedule

	(dollars in thousands)				
	FY 1999	FY 2000	FY 2001	$ Change	% Change
TFTR	3,949	13,422	19,600	+6,178	+46.0%
DIII-D	29,065	31,098	29,255	-1,843	-5.9%
Alcator C-Mod	10,223	10,657	10,042	-615	-5.8%
NSTX	17,022	15,406	14,469	-937	-6.1%
General Plant Projects/Other	1,476	962	917	-45	-4.7%
Waste Management	0	0	3,157	+3,157	+100.0%
Total, Facility Operations	61,735	71,545	77,440	+5,895	+8.2%

Detailed Program Justification

	(dollars in thousands)		
	FY 1999	FY 2000	FY 2001
TFTR			
■ Continue the decontamination and decommissioning (D&D) of TFTR ($16,000,000). This activity will provide for the removal and disposal of the tokamak and remaining radioactive components from the test cell and the basement. In addition, during the D&D, $3,600,000 is necessary to maintain and keep the facility safe.	3,949	13,422	19,600
DIII-D			
■ Provide support for operation, maintenance, and improvement of the DIII-D facility and its auxiliary systems, such as the Electron Cyclotron Heating (ECH) systems, developed by the Enabling R&D subprogram. In FY 2001, these funds support 17 weeks of plasma operation during which time fusion research experiments will be conducted. The fabrication and installation of the 6 megawatt, 110 GHz ECH system will be completed in FY 2001.	29,065	31,098	29,255

	(dollars in thousands)		
	FY 1999	FY 2000	FY 2001
Alcator C-Mod			
■ Provide support for operation, maintenance and minor machine improvements. In FY 2001, these funds support 14 weeks of plasma operation during which time fusion research experiments will be conducted. Design and construction of the Lower Hybrid Current Drive System will continue. This is a Major Item of Equipment with a TEC of $4,200,000 that will be initiated in FY 2000	10,223	10,657	10,042
NSTX			
■ Provide continuation of operational activity on the NSTX experiment and installation of planned diagnostic upgrades. These funds support 17 weeks of plasma operation during which time fusion research experiments will be conducted	8,122	12,906	14,469
■ **NSTX Project:** Project completed in FY 1999 and facility begins operations.	5,450	0	0
■ **NSTX Neutral Beam:** The NSTX neutral beam modification will be completed in FY 2000 and will be integrated into the NSTX research facility for use in FY 2001 research programs.	3,450	2,500	0
Total, NSTX	17,022	15,406	14,469
General Plant Projects/Other			
■ These funds provide primarily for general infrastructure repairs and upgrades for the PPPL site	1,476	962	917
Waste Management			
■ These funds provide the support necessary to handle all waste management activities at the PPPL site	0	0	3,157
Total, Facility Operations	61,735	71,545	77,440

Explanation of Funding Changes from FY 2000 to FY 2001

	FY 2001 vs. FY 2000 ($000)
TFTR	
■ Decommissioning of TFTR proceeds on schedule for completion in 2002	+6,178
DIII-D	
■ Operating time of DIII-D is increased by 3 weeks and modest refurbishments are carried out	+3,050
■ The heating system upgrade modification to DIII-D is completed in FY 2001	-4,893
Total, DIII-D	-1,843
Alcator C-Mod	
■ Modifications to the device's heating system will be delayed and operating time decreased by 4 weeks.	-615
NSTX	
■ Support for operating the heating systems on NSTX is increased and operating time is increased by 3 weeks.	+1,563
■ Decrease due to completion of NSTX neutral beam heating system fabrication project in FY 2000	-2,500
Total, NSTX	-937
GPP/Other	
■ Completion of ongoing repairs will continue at essentially the FY 2000 level	-45
Waste Management	
■ Responsibility for waste management activities at the PPPL site has been transferred to the Fusion Energy Sciences program from the Environmental Management program in FY 2001. These funds are being transferred to the program in order to provide an incentive for the laboratory to minimize the amount of waste they produce.	+3,157
Total Funding Change, Facility Operations	+5,895

Enabling R&D

Mission Supporting Goals and Objectives

For sustained progress toward ultimate research goals, science-oriented programs that push the frontiers of human knowledge, such as fusion, require intellectual resources, experimental facilities with state-of-the-art technological capabilities, and continuing technology innovations. The Enabling R&D subprogram provides for such progress in both magnetic and inertial fusion energy research. This subprogram is divided into two elements: Engineering Research and Materials Research.

The Engineering Research element underwent a major restructuring in FY 1999 when the U.S. stopped participating in the International Thermonuclear Experimental Reactor project. The scope of activities has been substantially broadened to address more fully the diversity of domestic interests in enabling R&D for both magnetic and inertial fusion energy systems. These activities now focus on critical technology needs for enabling U.S. plasma experiments to achieve their full performance capability. Also, international technology collaborations allow the U.S. to access plasma experimental conditions not available domestically. These activities also include investigation of the scientific foundations of innovative technology concepts for future experiments. Another activity is advanced design of the most scientifically challenging systems for next step fusion research facilities, i.e. facilities that may be needed in the immediate 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 power plant applications. Major FY 1999/2000 accomplishments include: completed fabrication of the world's largest pulsed superconducting magnet coil, and shipped it for testing in a Japanese facility; completed fabrication and testing of both a prototype actively cooled, high surface heat flux divertor system and a robotic vacuum vessel welding system; and demonstrated world record performance levels for a plasma heating microwave power tube.

The Materials Research element continues to focus its scientific research on low-activation materials, that have high performance capability and can withstand long-term exposure to the energetic particles and electromagnetic radiation expected from energy-producing plasmas. Efforts continued on mapping of irradiation effects on candidate low-activation alloys, that will be used to set priorities for future research. Recommendations provided in an FY 1998 FESAC review were followed by strengthening the modeling and theory component of materials research, by greater integration with other fusion program elements, and by expansion to include conditions and materials of interest to both magnetic and inertial fusion energy systems.

Funding Schedule

	(dollars in thousands)				
	FY 1999	FY 2000	FY 2001	$ Change	% Change
Engineering Research	36,698	26,578	25,943	-635	-2.4%
Materials Research	6,840	7,167	6,804	-363	-5.1%
SBIR/STTR	0[a]	907	881	-26	-2.9%
Total, Enabling R&D	43,538	34,652	33,628	-1,024	-3.0%

Detailed Justification

	(dollars in thousands)		
	FY 1999	FY 2000	FY 2001
Engineering Research			
■ Plasma Technology efforts will be focused on critical needs of domestic plasma experiments and on the scientific foundations of innovative technology concepts for use in both future magnetic and inertial fusion experiments and attractive fusion energy sources. Nearer-term experiment support efforts will be oriented toward plasma facing components and plasma heating and fueling technologies. Longer-term efforts will be oriented toward superconducting magnet research to reduce magnet costs and improve their reliability	19,475	12,085	11,664
■ Fusion Technology will be focused on technology innovations and model improvements needed to resolve critical issues faced by inertial fusion concepts and possibly magnetic concepts as well. These issues include the vacuum chamber as well as tritium and safety research that are critical to the safety and environmental attractiveness of all fusion systems. In the tritium area, TSTA will complete its mission in FY 2001 and research will cease, while tritium inventory reduction will continue in preparation for decommissioning. Management of all of the diverse collection of fusion technologies will be accomplished through a Virtual Laboratory for Technology whereby community-based coordination and communication of plans, progress, and results will be accomplished through the use of modern information technology.	8,096	9,222	9,373

[a] Excludes $1,063,000 which has been transferred to the SBIR program and $64,000 which has been transferred to the STTR program.

	FY 1999	FY 2000	FY 2001
	(dollars in thousands)		
■ Advanced Design and Analysis will be modestly reduced and redirected to include design of the most critical systems for fusion research facilities that may be needed in the near future, and analysis of cost-effective research pathways.	9,127	5,271	4,906
Total, Engineering Research..	36,698	26,578	25,943
Materials Research			
■ Materials research remains a key element in developing a safe, reliable, and environmentally attractive fusion energy system. Scientific understanding and the development, research, and testing of vanadium alloys, silicon carbide composite materials, and advanced ferritic steels for structural service in the high power zones for fusion energy sources will continue. Priorities for this work, including innovative approaches to evaluating materials and improved modeling of materials behavior, are guided by the results of a Fusion Energy Sciences Advisory Committee review conducted during 1998 and include materials and conditions relevant to inertial fusion systems as well as magnetic systems...	6,840	7,167	6,804
SBIR/STTR			
■ In FY 1999, $1,063,000 and $64,000 were transferred to the SBIR and STTR programs, respectively. The FY 2000 and FY 2001 amounts are the estimated requirement for the continuation of the SBIR and STTR programs.	0	907	881
Total, Enabling R&D...	43,538	34,652	33,628

Explanation of Funding Changes from FY 2000 to FY 2001

	FY 2001 vs. FY 2000 ($000)
Engineering Research	
■ Plasma Technology is decreased in the areas of magnetics and plasma facing components.	-421
■ Fusion Technology is increased to include additional efforts on inertial fusion tasks.	+151
■ Advanced Design and Analysis effort is reduced and will be focused on selected critical topics.	-365
Total Engineering Research	-635
Materials Research	
■ Research on modeling of materials will be reduced.	-363
SBIR/STTR	
■ Requirements reduced as Enabling R&D is decreased.	-26
Total Funding Change, Enabling R&D	-1,024

Capital Operating Expenses & Construction Summary

Capital Operating Expenses

(dollars in thousands)

	FY 1999	FY 2000	FY 2001	$ Change	% Change
General Plant Projects	1,165	862	822	-40	-4.6%
Capital Equipment	17,475	13,946	7,115	-6,831	-49.0%
Total, Capital Operating Expenses	18,640	14,808	7,937	-6,871	-46.4%

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

(dollars in thousands)

	Total Estimated Cost (TEC)	Prior Year Approp-riations	FY 1999	FY 2000	FY 2001	Accept-ance Date
DIII-D Upgrade	27,367	17,437	4,023	5,400	507	FY 2001
NSTX	21,100	15,650	5,450	0	0	FY 1999
NSTX – Neutral Beam	5,950	0	3,450	2,500	0	FY 2000
Alcator C-Mod LH Modification	4,200	0	0	1,120	1,864	FY 2002
Total, Major Items of Equipment		33,087	12,923	9,020	2,371	