Fusion Energy Sciences

Funding Profile by Subprogram

(dollars in thousands)

	FY 2007 Current Appropriation	FY 2008 Original Appropriation	FY 2008 Adjustments	FY 2008 Current Appropriation	FY 2009 Request
Fusion Energy Sciences					
Science	144,572	162,910	+994[ab]	163,904	168,435
Facility Operations	146,338[c]	93,504	+7,349[abc]	100,853	301,900
Enabling R&D	20,754[c]	32,766	-10,975[abc]	21,791	22,715
Total, Fusion Energy Sciences	311,664[d]	289,180	-2,632[a]	286,548	493,050

Public Law Authorizations:
Public Law 95–91, "Department of Energy Organization Act", 1977
Public Law 109–58, "Energy Policy Act of 2005"
Public Law 110–69, "America COMPETES Act of 2007"

Mission

The mission of the Fusion Energy Sciences (FES) program is to support fundamental research to develop the knowledge base for a new energy source based on the power of the stars, and to expand the underlying scientific foundations of matter at very high temperatures and densities for applications of societal benefit. Research supported by this program concentrates on establishing the knowledge base for future fusion energy sources, plus developing the underlying sciences of plasma physics and high energy density physics. Related work contributes to understanding astrophysics, geosciences, industrial plasma processing, turbulence, and complex self-organizing systems.

Description

Fusion energy systems offer the promise of a fundamentally new and attractive energy source based upon the nuclear fusion process. The Fusion Energy Sciences program is oriented towards developing the scientific underpinnings of potential fusion energy systems. The program also is a steward of the fundamental field of plasma physics, the study of the fourth state of matter, which is a central component of a magnetically confined fusion plasma system. More recently, the program is enhancing its stewardship of the related field of high energy density physics, which underpins inertially confined fusion concepts.

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[a] Reflects a reduction for the 0.91% rescission in P.L. 110–161, the Energy and Water Development and Related Agencies Appropriations Act, 2008, as follows: Science ($-1,483,000), Facility Operations ($-851,000), and Enabling R&D ($-298,000).
[b] Reflects a reallocation of funding in accordance with P.L. 110–161, the Energy and Water Development and Related Agencies Appropriations Act, 2008, as follows: Science ($+2,477,000), Facility Operations ($-2,426,000), and Enabling R&D ($-51,000).
[c] For the FY 2009 Request to Congress, ITER funding is consolidated within the Facility Operations subprogram. Previous years' budgets reflected ITER operating expense (Other Project Costs or OPC) funding within the Enabling R&D subprogram; while capital equipment (Total Estimated Cost or TEC) funding was within the Facility Operations subprogram. FY 2007 and FY 2008 amounts in this budget reflect this change ($18,000,000 in FY 2007 and $10,626,000 in FY 2008 is moved from Enabling R&D to Facility Operations).
[d] Total is reduced by $7,286,000: $6,505,000 of which was transferred to the SBIR program and $781,000 of which was transferred to the STTR program.

A defining feature of the FES program is its emphasis on developing the underlying science of potential fusion energy systems. This effort consists of campaigns to develop the requisite understanding of several critical issues, including:

- Integrated Burning Plasma properties;
- Macroscopic equilibrium and stability of plasmas;
- Multi-scale transport of energy and particles;
- Plasma boundary interfaces between a hot plasma and the surrounding material surfaces;
- Interaction of electromagnetic waves and plasma electrons and ions;
- High energy density implosion physics; and
- Fusion engineering science.

These studies have led to a wide range of advances in fusion and plasma related sciences. Some representative advances include:

- Achieved an increase in fusion power output in laboratory experiments by 12 orders of magnitude over the past 3 decades, faster growth than that obtained for computer chip speed.
- Developed the understanding of the tokamak confinement concept needed to support the first demonstration of a burning plasma with significant fusion energy output in the next decade.
- Learned how to control macroscopic plasma equilibrium in magnetic confinement geometries.
- Developed an understanding of nonlinear and resistive macroscopic plasma instabilities, allowing control of high-performance confined plasmas.
- Continued development of a model for plasma turbulence, which will help us to control it as well as energy transport, to improve the prospects for developing a fusion energy system.
- Provided major impetus to establish the scientific field of plasma physics, which underlies a wide range of industrial and scientific applications, including computer chip fabrication, satellite thrusters, materials processing, and clean engines.
- Achieved a deeper understanding of magnetic reconnection and self-organization of magnetized plasmas, with relevance to understanding solar structures to unique confinement configurations for laboratory fusion.
- Discovered complex, three-dimensional magnetic field systems that lead to magnetized plasmas with internal symmetries that may offer attractive energy systems.
- Partnered in developing the emerging new area of physical science of matter at very high energy density, with applications from inertial confinement fusion energy to understanding stellar and astrophysical phenomena.
- Advanced our understanding of the complex interactions of currents and flows that give rise to spontaneous generation of magnetic fields in nature, from the Earth's magnetic field to astrophysical fields, with applications to simplified plasma confinement systems.

The magnetic fusion energy program is now moving into the burning plasma regime through its participation in the ITER program. The achievement of a burning plasma regime in ITER, wherein much more fusion energy is released than that used to heat the plasma fuel, will provide a fundamental demonstration of the viability of magnetic fusion as a potential new energy source. This will address, for the first time, the strongly nonlinear interactions inherent in the self-heated fusion plasma state. As that regime is approached, the emphasis of the science will necessarily expand from considerations of the hot plasma core regimes to more fully include the multiphase plasma-material phenomena that non-linearly couple to the fusing system.

FES supports research activities in theory, modeling, and experiment across a wide range of scales and capabilities. These range from single-investigator research programs to large-scale national and international collaborative efforts. The FES program funds activities involving over 1,100 researchers and students at approximately 67 universities, 10 industrial firms, 11 national laboratories, and 2 Federal laboratories, all of which are located in 31 states. At the largest scale, the program supports world-class magnetic confinement facilities that are shared by national teams of researchers to advance fusion energy sciences at the frontiers of near-energy producing plasma conditions. Each of the major facilities offers world-leading capabilities for the study of fusion-grade plasmas and their interactions with the surrounding systems. The three major facilities are operated by the hosting institutions but are configured with national research teams made up of local scientists and engineers, researchers from other institutions and universities, and foreign collaborators

While pursuing the long-term development of the required fusion energy knowledge base, this research program also provides tools for understanding fundamental properties of the universe and supports the economic prosperity and national security of the country in the near-term. Research in plasma sciences has improved fabrication techniques for semiconductors and computer chips, material hardening for industrial and biological uses, waste management techniques, and lighting and display techniques. The extreme states of matter studied in high energy density laboratory plasmas that are encountered in inertial confinement fusion studies may offer an alternate path to a fusion energy source. This research is related to the National Nuclear Security Administration (NNSA) stockpile stewardship program and, hence, indirectly supports the national security program of DOE. Related areas of science addressed in these research programs include turbulence and complex systems, multiphase interactions and plasma-material interactions, self-organization of complex systems, astrophysics, geodynamics, and fluids.

Some of the major components of the FES program and their status in the FY 2009 budget year are noted:

- The United States participation in the international ITER project continues in FY 2009, but the U.S. ITER Major Item of Equipment (MIE) project is not fully funded due to FY 2008 Appropriations, which reduced funding from the requested $160,000,000 to $10,626,000. As a result, the United States will be forced to default on most of its 2008 commitments to the ITER Organization. The funding delay will impact the international schedule and will increase U.S. costs; the extent of the cost and schedule impacts is still being assessed.
- The major experimental facilities in the FES program include the DIII-D tokamak at General Atomics (GA) in San Diego, California, the Alcator C-Mod tokamak at the Massachusetts Institute of Technology (MIT) in Cambridge, Massachusetts, and the National Spherical Torus Experiment (NSTX) at Princeton Plasma Physics Laboratory (PPPL) in Princeton, New Jersey. Experiments on major facilities and theory and computer modeling activities, will emphasize developing an understanding of toroidal confinement systems and burning plasma research in support of preparations for the ITER scientific program. In particular, operations and research on existing major tokamak facilities will support final design decisions for ITER and assist in developing operating scenarios for the ITER research program
- The centerpiece of the stellarator program, the National Compact Stellarator Experiment (NCSX) MIE project, is being fabricated at PPPL. The Department of Energy (DOE) and PPPL have recognized that the project cannot be completed within the approved cost. The total project cost for

the NCSX has increased 39 percent over its approved CD-2 baseline, with a greater than 2 year delay in completion. Addressing a charge from the Office of Science, the Fusion Energy Sciences Advisory Committee conducted a scientific and programmatic review of NCSX and the stellarator program and concluded that the NCSX should be completed to maintain U.S. interests in this field. This review plus technical reviews by the Office of Science and Princeton University have provided the necessary input to allow the Department to make the decision to either rebaseline the project or cancel it. Pending this decision in the first half of FY 2008 and a project cost validation, the budget assumes the rebaselining and continued construction of the NCSX project.

- A Fusion Simulation Project (FSP) will be started in FY 2009, taking advantage of the many recent improvements in computational and computing capabilities, as well as a significant amount of preparatory work that has already been done by FES's Scientific Discovery through Advanced Computing (SciDAC) activities. The FSP will be directed at developing a world-leading predictive integrated plasma simulation capability that can be applied to burning plasmas of the type that will be necessary for fusion energy producing power plants. As such, the FSP will represent the embodiment of the goal of developing the knowledge base for a fusion energy system. The FSP will start in FY 2009 and is expected to be completed by FY 2024—with key deliverables targeted at the end of five, ten, and fifteen years
- FES continues to support both the general plasma sciences program that is part of stewarding the field of plasma science and the joint program of research with the NNSA in High Energy Density Laboratory Plasmas (HEDLP) that was started in FY 2008. HEDLP activity within the FES program will be expanded to $24,636,000 in FY 2009.

Finally, it is noted that the research pursued here is one of the nation's main sources of a scientific workforce educated in plasma sciences, and as such provides trained personnel for a wide range of research and development activities in national laboratories, academia, and industry.

Strategic and GPRA Unit Program Goals

The Department's Strategic Plan identifies five Strategic Themes (one each for nuclear, energy, science, environmental, and management aspects of the DOE mission) plus 16 Strategic Goals that tie to the Strategic Themes. The FES program supports the following goals:

Strategic Theme 3, Scientific Discovery & Innovation

- Strategic Goal 3.1, Scientific Breakthroughs: Achieve the major scientific discoveries that will drive U.S. competitiveness; inspire America; and revolutionize our approaches to the Nation's energy, national security, and environmental quality challenges.
- Strategic Goal 3.2, Foundations of Science: Deliver the scientific facilities, train the next generation of scientists and engineers, and provide the laboratory capabilities and infrastructure required for U.S. scientific primacy.

The FES program has one GPRA Unit Program goal which contributes to Strategic Goal 3.1 and 3.2 in the "goal cascade":

- GPRA Unit Program Goal 3.1/2.49.00: Bring the Power of the Stars to Earth—Answer the key scientific questions and overcome enormous technical challenges to harness the power that fuels our Sun.

Contribution to GPRA Unit Program Goal 3.1/2.49.00, Bring the Power of the Stars to Earth

The FES program contributes to this goal by managing a program of fundamental research into the nature of fusion plasmas and the means for confining plasma to yield energy. This program includes:

(1) exploring basic issues in plasma science; (2) developing the scientific basis and computational tools to predict the behavior of magnetically confined plasmas; (3) using the advances in tokamak research to enable the initiation of the burning plasma physics phase of the FES program; (4) exploring innovative confinement options that offer the potential to increase the scientific understanding and to improve the confinement of plasmas in various configurations; (5) investigation of non-neutral plasmas and high energy density physics; and (6) developing the cutting edge technologies that enable fusion facilities to achieve their scientific goals.

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

The specific long term (10 year) goals for scientific advancement to which the FES program is committed and against which progress can be measured are:

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

Funding by Strategic and GPRA Unit Program Goal

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Strategic Goals 3.1, Scientific Breakthroughs and 3.2, Foundations of Science			
GPRA Unit Program Goal 3.1/2.49.00, Bring the Power of the Stars to Earth			
Fusion Energy Sciences	311,664	286,548	493,050

Annual Performance Results and Targets

FY 2004 Results	FY 2005 Results	FY 2006 Results	FY 2007 Results	FY 2008 Targets	FY 2009 Targets
GPRA Unit Program Goal 3.1/2.49.00 (Bring the Power of the Stars to Earth)					
Science					
N/A	Conduct experiments on the major fusion facilities (DIII-D, Alcator C-Mod and NSTX) leading toward the predictive capability for burning plasmas and configuration optimization. In FY 2005, FES measured plasma behavior in Alcator C-Mod with high-Z antenna guards and input power greater than 3.5 MW. [Met Goal]	Conduct experiments on the major fusion facilities (DIII-D, Alcator C-Mod, and NSTX) leading toward the predictive capability for burning plasmas and configuration optimization. In FY 2006, FES injected 2 MW of neutral power in the counter direction on DIII-D and began physics experiments. [Met Goal]	Conduct experiments on major fusion facilities leading toward the predictive capability for burning plasmas and configuration optimization. In FY 2007, FES measured and identified magnetic modes on NSTX that were driven by energetic ions traveling faster than the speed of magnetic perturbations (Alfvén speed); such modes are expected in burning plasmas such as ITER. [Met Goal]	Conduct experiments on major fusion facilities leading toward the predictive capability for burning plasmas and configuration optimization. In FY 2008, FES will evaluate the generation of plasma rotation and momentum transport, and assess the impact of plasma rotation on stability and confinement. Alcator C-Mod will investigate rotation without external momentum input, NSTX will examine very high rotation speeds, and DIII-D will vary rotation speeds with neutral beams. The results achieved at the major facilities will provide important new data for estimating the magnitude of and assessing the impact of rotation on ITER plasmas.	Conduct experiments on major fusion facilities to develop understanding of particle control and hydrogenic fuel retention in tokamaks. In FY09, FES will identify the fundamental processes governing particle balance by systematically investigating a combination of divertor geometries, particle exhaust capabilities, and wall materials. Alcator C-mod operates with high-Z metal walls, NSTX is pursuing the use of lithium surfaces in the divertor, and DIII-D continues operating with all graphite walls. Edge diagnostics measuring the heat and particle flux to walls and divertor surfaces, coupled with plasma profile data and material surface analysis, will provide input for validating simulation codes. The results achieved will be used to improve extrapolations to planned ITER operation.

FY 2004 Results	FY 2005 Results	FY 2006 Results	FY 2007 Results	FY 2008 Targets	FY 2009 Targets
N/A	Increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. In FY 2005, FES simulated nonlinear plasma edge phenomena using extended MHD codes with a resolution of 20 toroidal modes. [Met Goal]	Increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. In FY 2006, FES simulated nonlinear plasma edge phenomena using extended MHD codes with a resolution of 40 toroidal modes. [Met Goal]	Increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. In FY 2007, FES improved the simulation resolution of linear stability properties of Toroidal Alfvén Eigenmodes driven by energetic particles and neutral beams in ITER by increasing the number of toroidal modes used to 15. [Met Goal]	Increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. In FY 2008, improve the simulation resolution of ITER-relevant modeling of lower hybrid current drive experiments on Alcator C-Mod by increasing the number of poloidal modes used to 2,000 and the number of radial elements used to 1,000 using the leadership class computers at ORNL.	Continue to increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. In FY 2009, gyrokinetic edge electrostatic turbulence simulations will be carried out across the divertor separatrix with enhanced resolution down to the ion gyroradius scale.
Facility Operations					
<u>Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%.[Met Goal]</u>	<u>Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%. [Met Goal]</u>	<u>Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%. [Met Goal]</u>	<u>Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%. [Met Goal]</u>	<u>Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%.</u>	<u>Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%.</u>
<u>Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%. [Met Goal]</u>	<u>Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%. [Met Goal]</u>	<u>Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%. [Met Goal]</u>	<u>Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%. The NCSX team has concluded that the project cannot be completed within the cost and schedule baseline. [Goal Not Met]</u>	<u>Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%.</u>	<u>Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%.</u>

Means and Strategies

FES supports a range of small-scale local and mid-scale national facilities to explore both low and high temperature plasmas. The largest of these facilities are three unique mid-sized toroidal confinement experiments, which are operated as collaborative programs for the national fusion research community. Joint experiments among tokamaks around the world are coordinated by the International Tokamak Physics Activity (ITPA).

To develop the knowledge base for a fusion energy system, FES supports a combined experiment, theory and computational modeling research program with two main thrust areas:

- preparation for and execution of studies of burning plasmas in the ITER experiment to develop verified models of this highly nonlinear, self-heated system; and
- resolution of questions that are outside the scope of the ITER program but must be confronted to establish the knowledge base for a first-generation fusion energy power plant on the timescale of the ITER program.

The Fusion Simulation Project (FSP), which will employ world-leading computational capabilities to construct integrated models of the burning plasma state, will codify the understanding developed in the first thrust area. The second thrust area includes studies of plasma confinement concepts for future optimization and studies of the plasma and materials issues encountered in the unique nuclear fusion environment.

Non-fusion general plasma science is studied principally through individual investigator grants that concentrate on theory and/or experimental studies of specific issues of interest. Areas covered include, among others, turbulence, multiphase plasma interactions, generation and destruction of magnetic fields, and waves and instabilities.

The emerging field of high energy density laboratory science is pursued by theory and experiments over a wide range of scales, from individual and small groups to experiments on large national facilities supported by the NNSA. The FES research program will complement the planned high-gain fusion demonstration in NIF by supporting research on energy-related high energy density physics issues that focus on improved efficiency and non-laser approaches.

External factors that affect the level of performance include:

- changing mission needs as described by the DOE and SC mission statements and strategic plans;
- scientific opportunities as determined, in part, by new discoveries, proposal pressure, and scientific workshops;
- results of external program reviews and international benchmarking activities of entire fields or subfields, such as those performed by the National Academy of Sciences (NAS);
- unanticipated failures in critical components of scientific facilities that cannot be mitigated in a timely manner; and
- 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)

The Department has implemented a tool, the PART Assessment, to evaluate selected programs. PART was developed by the Office of Management and Budget (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. FES has incorporated feedback from OMB and has taken or will take the necessary steps to continue to improve performance.

In the FY 2003 PART review for the FY 2005 Budget, OMB gave the FES program a score of 82% overall which corresponds to a rating of "Moderately Effective." The assessment found that FES has developed a limited number of adequate performance measures which are continued for FY 2009. These measures have been incorporated into this budget request, FES grant solicitations, and the performance plans of senior managers. As appropriate, they will be incorporated into the performance based contracts of Management and Operating (M&O) contractors. Roadmaps, developed in consultation with the Fusion Energy Sciences Committee (FESAC), will guide triennial FESAC reviews of progress toward achieving the long-term Performance Measures. The Annual Performance Targets are tracked through the Department's Joule system and reported in the Department's Annual Performance and Accountability Report.

OMB has provided FES with three recommendations to further improve performance:

- Develop strategic and implementation plans in response to multiple Congressional requirements.
- Implement the recommendations of expert review panels, especially two major NAS studies, as appropriate.
- Re-engage the advisory committee in a study of how the program could best evolve over the coming decade, including taking into account new and upgraded international facilities.

In response to previous OMB recommendations FES has:

- In accordance with the Energy Policy Act of 2005, prepared several reports which were submitted to Congress in FY 2006.[a]
- Formally charged the FESAC to assess progress toward the long term goals of the FES program.
- Tasked FESAC to prepare a report that identified and prioritized scientific issues and respective campaign strategies. The final report was completed in April 2005, and formed the basis of the September 2005 FES strategic plan.
- Established a Committee of Visitors (COV) process to provide outside expert validation of the program's merit-based review processes for impact on quality, relevance, and performance. The COV reports are available on the web at http://www.science.doe.gov/ofes/fesac.shtml.

During the past three years, COV committees have examined all elements of the FES program in the following order: (1) theory and computation, (2) innovative confinement concepts, high energy density physics, and general plasma science, and (3) tokamak research and enabling R&D. The three COV reports and the FES response to these reports are available at:

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[a] (1) A 'Plan for U.S. Scientific Participation in ITER'; (2) A report describing the management structure of the ITER and estimate of the cost of U.S. participation; and (3) A report describing how U.S. participation in ITER will be funded without a funding reduction in other SC programs.

http://www.ofes.fusion.doe.gov/more_html/fesac/committeeofvisitors.pdf,
http://www.ofes.fusion.doe.gov/more_html/fesac/covlettertohazeltine.pdf,
http://www.ofes.fusion.doe.gov/more_html/fesac/cov_final.pdf, and
http://www.ofes.fusion.doe.gov/more_html/fesac/ofesresponseto2ndcov.pdf.

To improve public access to PART assessments and follow up actions, OMB has created the ExpectMore.gov web site. Information concerning FES PART assessments and current follow up actions can be found by searching on "fusion energy sciences" at http://ExpectMore.gov.

Basic and Applied R&D Coordination

Since 2004, projects sponsored previously by FES in inertial fusion energy (IFE) have been re-directed towards research in high energy density physics (HEDP). Existing, on-going projects in the FES HEDP program include fast ignition, laser-plasma interaction, magnetized high energy density plasmas including plasma jets, and heavy-ion-beam driven warm dense matter. These research areas have been identified by the interagency Task Force on HEDP as belonging to the research category of HEDLP, specifically energy-related research areas of HEDLP. This research overlaps with other areas of HEDLP that have been funded by the NNSA; basic scientific research that is important to nuclear stockpile stewardship including compressible and radiative hydrodynamics, laser-plasma interactions, material properties under extreme conditions, and laboratory astrophysics. NNSA funds these projects under the Stockpile Stewardship Academic Alliance (SSAA) program in the Science Campaign and the National Laser User Facilities program in the Inertial Confinement Fusion program.

The research activities of FES and NNSA in HEDLP will be coordinated under a joint program in HEDLP, with coordinated solicitations, peer reviews, scientific workshops, and Federal advisory functions. The benefits of this coordination is that it will: avoid duplication of effort; include the NNSA funded activities in the SC peer review process; provide better leverage for the FES HEDP projects of the NNSA high energy density (HED) facilities; and stimulate synergies between the two programs. This is in line with the recommendation of the interagency Task Force on HEDP for DOE to provide improved stewardship of the field of HEDLP, while maintaining the interdisciplinary nature of this area of science, by tying the basic scientific research to its roots in application. Thus, the FES funding will be focused mainly on stewarding energy-related areas of basic research in HEDLP, while NNSA's funding will be focused mainly on stewarding the basic research areas of HEDLP that are related to stockpile stewardship.

In May 2007, through the Under Secretary for Science, SC and NNSA jointly sponsored a Workshop in HEDLP held at Argonne National Laboratory to update the scientific research agenda for HEDLP. Three scientific themes emerged from the Workshop: enabling the grand challenge of fusion energy by high energy density laboratory plasmas; creating, probing and controlling new states of high energy densities; and, catching reactions in the act by ultra-fast dynamics. The Workshop participants recommended an expansion of the existing HEDLP research activities which is reflected in the FES request to increase funding in FY 2009 by $8,694,000 over FY 2008 funding.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
High Energy Density Laboratory Plasmas			
Science	15,459	15,942	24,636

Advisory and Consultative Activities

DOE 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 Fusion Energy Sciences Advisory Committee (FESAC) is a standing committee that provides independent advice to the DOE on complex scientific and technological FES program issues.

In FY 2005, FESAC produced a report on "Scientific Challenges, Opportunities, and Priorities for the U.S. Fusion Energy Sciences Program." They identified six themes for scientific campaigns around which the FES program could be organized, which are identified in the Description section. The FES program is being focused on using these campaign topics to define the critical science drivers to motivate program research activities. In addition, the FES program has added the additional campaign topic of burning plasma behavior. A very recent FESAC report (late FY 2007) on research gaps and opportunities arising in the ITER era is being integrated into a long-term strategic planning activity which is being launched in FY 2008.

The National Research Council's Plasma Science Committee, which serves as a continuing connection to the general plasma physics community, recently released a review of plasma science[a]. In 2004 it published an assessment of the DOE Fusion Energy Sciences strategy for addressing the physics of burning plasmas[b]. 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 high-level program reviews and peer reviews of research proposals provide a sound basis for developing program plans and priorities and allocating 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. Comprised primarily of researchers from outside the host facility, these PACs also include non-U.S. members. They review proposals for research to be carried out on the facility, 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, thereby avoiding unnecessary duplication.

Another review mechanism, described previously in the PART Assessment section, involves charging FESAC to establish a COV to review program management practices of selected elements of the FES program each year, such that the entire program is reviewed every three to five years. In general, these COVs have concluded that the FES-supported research programs are of high quality and that the biggest concern has been flat budgets for these programs. Further, the COVs have found that FES program managers are serious, conscientious, and dedicated, and are doing a good job managing their individual program elements.

In May 2006, the third COV completed its review of the research portfolio and peer review process for the FES Tokamak Research and Enabling R&D programs. This committee agreed with the recommendations of earlier COVs, and concluded that there was much evidence that the FES program managers have already implemented many of the recommendations of earlier COVs and were working to make further improvements in programs and processes. However, the committee noted that further

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[a] *Plasma Science – Advancing Knowledge in the National Interest.* Plasma 2010 Committee of the Plasma Science Committee. National Research Council, National Academies Press, 2007, Washington, D.C.

[b] *Burning Plasma – Bringing a Star to Earth.* Burning Plasma Assessment Committee of the Plasma Science Committee. National Research Council, National Academies Press, 2004, Washington, D.C.

work was needed to make the content of the review folders complete and consistent across the programs. The committee also developed the following new recommendations:

- statistics on the award process would be helpful,
- the review sheet used for program renewals should explicitly include a review of progress,
- some form of the proposal score should be communicated to the Principal Investigator (PI) in addition to reviewer comments,
- the reviewer pool size should be increased, and
- the Junior Faculty Award program should be eligible to those outside of basic plasma science.

These recommendations were implemented for proposals requesting funds beginning in FY 2007 and beyond.

Planning and Priority Setting

Planning and setting of priorities is especially relevant since almost all elements of the FES research program will be in flux over the next few years. Research related to magnetic fusion energy will look forward to the ITER burning plasma era, and domestic research activities must evolve to reflect the next step in fusion science. Energy-related HEDP is becoming recognized as a new area of physics in its own right, and growth in activities in this area is expected, especially as NIF comes into operation and moves toward demonstrating significant gain in inertial fusion experiments.

Following the recommendations of the 2004 NAS Burning Plasma Report, participation in ITER is the top priority of the magnetic fusion research program. This includes preparatory research in the domestic program. An initial list of priority issues to be addressed was formed in 2007 in response to the Energy Policy Act of 2005, which required a plan for participation in ITER[a]. More generally, the magnetic fusion science research is organized around six scientific campaigns as defined by the FESAC Priorities study. These are macroscopic stability, multiscale turbulence and transport, plasma-boundary interactions, waves and energetic particles, burning plasma integration, and fusion engineering sciences. The scientific opportunities identified in the 2007 NAS Plasma Science Report and the 2003 Frontiers in High Energy Density Physics studies will be used with peer review to guide funding choices in the general plasma science and HEDP research programs.

Significant Program Shifts

The funding for the Quasi-Poloidal Stellarator development at Oak Ridge National Laboratory (ORNL) is eliminated in FY 2009 to provide funding for higher research and operational priorities.

ITER

Status of ITER Activities

U.S. participation in ITER is a Presidential initiative to internationally build and operate the first fusion science facility capable of producing a sustained burning plasma. The mission for ITER is to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes. The European Union is hosting the site for the international ITER Project at Cadarache, France.

In accordance with Section 972(c)(5)(C) of the Energy Policy Act, the Department has submitted to Congress the following reports: a ‘Plan for U.S. Scientific Participation in ITER’; a report describing the

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[a] Planning for U.S. Fusion Community Participation in the ITER Program. Prepared by the U.S. Burning Plasma Organization, Energy Policy Act Task Group, June, 2007. (Available at: http://www.ofes.fusion.doe.gov/News/EPAct_final_June06.pdf)

management structure of the ITER and estimate of the cost of U.S. participation; and a report describing how U.S. participation in ITER will be funded without a funding reduction in other SC programs. The Department's FY 2009 budget request supports the $214,500,000 for ITER almost entirely from new funds added to the FES budget request.

- **Entry into Force of the ITER Joint Implementing Agreement in 2007:**

  The ITER Joint Implementing Agreement was signed by representatives of the seven ITER Members on November 21, 2006 in Paris, France. The Members also agreed at that time to provisionally apply the Agreement while ratification activities were undertaken. Thus, on December 1, 2006, the international ITER Organization commenced operating on a provisional basis, and since that time the Members have each domestically undertaken the necessary steps for ratification. All seven Members have completed their ratification processes thereby enabling the ITER Joint Implementing Agreement to enter into force on October 24, 2007. For its part, the U.S. deposited its instrument of ratification with the International Atomic Energy Agency (IAEA) on June 8, 2007.

- **Status of the International ITER Organization:**

  Since its inception on December 1, 2006 as a provisional legal entity, significant progress has been made in terms of establishing an operational international ITER Organization. The Director General, the Principal Deputy Director General, and the six Deputy Director Generals (DDGs) are all in place as employees of the international ITER Organization, and staff recruitment is ongoing. The DDGs are responsible for the following areas: Environment, Safety & Health (ES&H) including Quality Assurance and Licensing; Administration; Fusion Science and Technology; Tokamak; Central Engineering and Plan Support; and ITER Control, Data Access and Communications Systems (CODAC), Heating Systems, and Diagnostics. As of November 30, 2007, there were a total of about 200 people working in the international ITER Organization in Cadarache.

  The other key element of the ITER management structure is the ITER Council, which comprises four representatives from each Member. Nominally meeting semi-annually, the Council oversees the Director General and the international ITER Organization. The Council has two subsidiary bodies to provide it with assistance in carrying out its oversight function: the Management Advisory Committee (MAC), and the Scientific and Technology Advisory Committee (STAC). The Council and advisory committees are operational, each having held their first two meetings during the period of provisional application in 2007.

- **Cost Sharing in ITER:**

  For the Construction Phase, the ITER Joint Implementing Agreement stipulates that each of the six non-hosts, including the United States, provide an overall contribution (in-kind and in-cash) equal to a $^{1}/_{11}$ share (about 9.1%) of the total ITER scope of hardware, personnel, and cash (including a central reserve). The corresponding host share for the European Union (EU) is $^{5}/_{11}$ (45.4%). As set forth in the Agreement's Common Understandings on Procurement Allocation, the allocation of in-kind hardware deliverables from each Member has been established based on the same sharing proportions. Should the ITER Council approve new parties to join the current seven ITER Members, the cost sharing arrangements will be adjusted.

- **ITER Design Review:**

  The international ITER Organization concluded a Design Review in November 2007 aimed at updating the 2001 ITER Final Design Report and resolving a number of outstanding design issues in order to establish a new ITER baseline design in 2008. This design will serve as the basis for

Procurement Arrangements being developed between the international ITER Organization and the ITER Members for their "in-kind" hardware contributions. The U.S. was fully engaged in the Design Review process through the participation of scientific and technical experts from throughout the U.S. fusion program in the various Design Review Working Groups. These efforts were funded by the U.S. Contributions to ITER Project.

- **U.S. Contributions to ITER Project:**

  The U.S. Contributions to ITER Project is being managed by the U.S. ITER Project Office (USIPO) located at ORNL with partners PPPL, and the Savannah River National Laboratory (SRNL). The USIPO staff includes the Project Manager, Deputy Project Manager, Project Controls Manager, Project Engineering Manager, Procurement Manager, Business Manager, Environmental, Safety and Health (ES&H) and Quality Assurance (QA) Manager, Chief Scientist, Chief Technologist, and managers for the work breakdown structure elements of magnet systems, first wall and shield systems, port limiters, tokamak cooling water system, vacuum pumping and fueling systems, ion cyclotron heating system, electron cyclotron heating system, tokamak plant exhaust processing system, steady-state electric power system, and diagnostics. All U.S. Contributions to ITER Project activities are being overseen by a DOE Federal Project Director at the DOE Oak Ridge Office.

  In FY 2006 and FY 2007, and in accordance with DOE Order 413.3A, the FES program and the USIPO have been preparing for Critical Decision 1 (CD-1), Approve Alternative Selection and Cost Range, which was approved in December 2007, and Critical Decision 2 (CD-2), Approve Performance Baseline, in FY 2009–10. It is important that the U.S. schedule for the Critical Decision milestones be consistent with the international ITER Project schedule. The schedule for establishing the performance baseline for the U.S. Contributions to ITER Project at CD-2 is dependent on the ability of the international ITER Organization to finalize the design and schedule for the ITER Project.

  The Total Project Cost (TPC) range established at CD-1 for the U.S. Contributions to ITER Project is described in more detail in the Facility Operations subprogram of the FES budget. Funding in FY 2009 provides for $208,500,000 for Total Estimated Cost (TEC) activities and $6,000,000 for Other Project Costs (OPC). The planned FY 2008 funding of $160,000,000 was reduced in December 2007 to $10,626,000 by the FY 2008 Energy and Water Development and Related Agencies Appropriations Act. The resulting curtailment of activities in FY 2008 will impact cost and schedule, the full impact of which is still being assessed. Additional details are provided in the Facility Operations subprogram.

  Research activities in the domestic fusion program continue to enhance the physics basis and technology support for ITER. While these activities are of general interest to developing the underlying knowledge base for fusion energy, they synergistically support the move to science research on ITER in the future by:

  - Providing research and development (R&D) on ITER physics and technology issues and exploring new modes of operation to extend tokamak and ITER performance;
  - Developing safe and environmentally attractive technologies relevant to ITER;
  - Advancing fusion simulation as a tool to examine the complex behavior of burning plasmas in tokamaks, which will impact the planning and conduct of experimental operations in ITER;
  - Conducting experiments on our national science facilities to develop diagnostics and plasma control techniques that can be extrapolated to ITER; and

- Integrating all that is learned into a forward-looking approach to future fusion applications.

During the negotiations and start-up of the international ITER Organization, the U.S. domestic program has continued to support the domestic technical preparations for the ITER project and has begun to plan for the operation of ITER. These activities are being promoted and coordinated through the U.S. Burning Plasma Organization (USBPO) established in May 2005 for this purpose. The Director of USBPO is also the USIPO Chief Scientist.

The Energy Policy Act of 2005 required development of a plan by DOE for the participation of U.S. scientists in ITER that includes a U.S. research agenda, methods to evaluate whether ITER is promoting progress toward making fusion a reliable and affordable source of power, and a description of how work at ITER will relate to other elements of the U.S. fusion program. The Act requires that this plan be developed in consultation with FESAC, and reviewed by the NAS.

The USBPO produced a ‘Plan for U.S. Scientific Participation in ITER’ with technical details in May 2006. As called for, the Plan was presented to FESAC for consultation. FESAC reviewed and agreed with the Plan in early June 2006. The Plan was forwarded to Congress on August 11, 2006, for a 60-day review, as required by the Energy Policy Act of 2005 Section 972(c)(4)(A)(i-iii), and it was concurrently submitted to NAS for review. The NAS review started during the summer of 2007. Their final report is expected in late spring, 2008.

- **U.S. ITER Project Accomplishments:**

The USIPO is responsible for the management of the U.S. contributions of hardware, personnel, and cash. Since the establishment of the USIPO in July 2004, the following accomplishments have been made:

- appointments of key management positions within the USIPO were completed;
- preliminary cost and schedule estimates have been prepared, periodically reviewed by SC, and updated to reflect the remaining uncertainties associated with the ITER Project;
- project management documentation required by DOE Order 413.3A has been prepared and approved; and
- the Deputy Secretary of Energy approved CD-0, Approve Mission Need, and CD-1, Approve Alternative Selection and Cost Range as called for in DOE Order 413.3A.

- **Project Management**

FES will continue to apply the Department’s project management procedures as required by DOE Order 413.3A and use the oversight functions of the Department to ensure that the U.S. investment in ITER is optimized and protected. This oversight will be accomplished through regular SC Office of Project Assessment “Lehman” Reviews, International ITER Reviews, and the overall coordination and management activities among FES, the USIPO and the international ITER Organization

In preparation for CD-2, the USIPO will develop a performance baseline for the U.S. Contributions to ITER Project that is consistent with the baseline for the international ITER project, which is due to be completed in 2008. After CD-2, FES will track these performance baselines on a regular basis. The target for ITER is the same as for other projects: cost-weighted mean percent variance from established cost and schedule baselines kept to less than 10%.

In addition, now that the ITER Agreement has entered into force and the international ITER Organization is operational, the ITER Council is providing management controls and safeguards.

- **ITER Test Blanket Module Program**

  Since the earlier phases of ITER, a TBM program has been envisioned as a means to demonstrate a key element of fusion technology, namely the breeding of tritium for a closed fuel cycle in a fusion power plant. While not part of the construction scope of ITER as defined in the Joint Implementing Agreement, the seven ITER Members have been engaged in discussions on how to move forward with a TBM program that would be one of several possible upgrades to the ITER facility. A TBM program will have near-term financial implications since certain improvements to the currently designed ITER civil infrastructure must be made to accommodate TBMs. Basic TBM design parameters are already being factored into the ongoing French nuclear regulatory licensing process. The international ITER Organization expects to develop a more definitive TBM plan in 2008. DOE will not enter into any agreements that expand the scope of U.S. financial commitments — contributions to a TBM program would be one example — until the successful construction of the ITER project as originally agreed to in 2003 is assured.

Science

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Science			
Tokamak Experimental Research	45,916	52,870	51,119
Alternative Concept Experimental Research	54,078	57,345	61,694
Theory	23,732	24,486	24,283
SciDAC	6,540	7,138	7,212
Fusion Simulation Project	—	—	1,976
General Plasma Science	14,306	14,648	14,869
SBIR/STTR	—	7,417	7,282
Total, Science	144,572	163,904	168,435

Description

The Science subprogram is developing a predictive understanding of fusion plasmas in a range of plasma confinement configurations. The emphasis is presently weighted towards understanding the plasma state and its properties for stable fusion systems, but increasing emphasis is expected in the areas of multiphase plasma-material states and effects of the nuclear fusion environment as the burning plasma regime is encountered.

A magnetically confined burning plasma will be demonstrated in ITER for the first time. This event would be major steps in establishing the viability of earth-based fusion as a potentially major energy source for the second half of this century.

Plasmas, the fourth state of matter, comprise over 99% of the visible universe and are rich in complex, collective phenomena. During the past decade there has been considerable progress in our fundamental understanding of key individual phenomena in fusion plasmas, such as transport driven by micro-turbulence, and macroscopic equilibrium and stability of magnetically confined plasmas. Over the next ten years the Science subprogram will continue to advance our understanding of plasmas and the fusion environment through an integrated program of experiments, theory, and simulation as outlined in the FESAC report, “Scientific Challenges, Opportunities and Priorities for the Fusion Energy Sciences Program.” This integrated research program focuses on well-defined 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 ITER operation. Research on ITER is expected to provide sufficient information on the complex science of burning plasmas to make a definitive assessment of the scientific feasibility of fusion power. This integrated research program also will benefit from ignition experiments performed at the NNSA-sponsored NIF.

A science-based portfolio approach is the most effective means to ensuring the success of the FES effort to establish the scientific base for practical fusion power. While sufficient understanding is now in hand to build ITER to investigate a burning plasma, significant challenges remain to develop the remaining fusion science and technology knowledge base needed for a potential future demonstration power plant based on what we will learn from ITER. A strong core research program consisting of experiments on domestic and international facilities, comprehensive theory and simulation, and fusion engineering science development is needed to make the exciting discoveries that will identify successful operating regimes and techniques for ITER and beyond, and to develop the skilled workforce needed to carry out this long-term research program.

Plasma science contributes not only to fusion research, but also too many other fields of science and technology, such as industrial processing, national security, space propulsion, and astrophysics. A portfolio approach also advances our knowledge of basic plasma physics and associated technologies, thereby yielding near-term benefits in a broad range of scientific disciplines. An additional objective of the Science subprogram is to broaden the intellectual and institutional base in fundamental plasma science and HEDP. Two activities, a NSF/DOE partnership in plasma physics and engineering, and the Junior Faculty development grants for members of university plasma physics faculties, will continue to contribute to this objective. The ongoing Fusion Science Centers, funded under General Plasma Science, will also foster fundamental understanding and connections to these related sciences.

FY 2007 Science Accomplishments

- ***Basic Plasma Physics Experiment: Implications for Hurricane Modeling:*** Using magnetized electrons as a fluid, the University of Delaware recently observed a classical fluid instability that was first predicted over 100 years ago by A.E.H. Love, but never seen in traditional fluid tank experiments due to the high measurement accuracy required to resolve it in traditional fluid experiments. The Delaware studies suggest that Love's predicted instability may be common in fluid flows. One example of a physical system where the instability may occur is in incipient hurricanes. The Delaware results could lead to improved modeling of how incipient hurricanes either break up or become organized as they cross the ocean.
- ***Localized Magnetic Chaos Controls Dangerous Edge Instability:*** The edge plasma in high performance tokamak plasmas is a remarkable thermal insulator (temperatures drop millions of degrees in only a few centimeters), but is subject to impulsive instabilities that produce periodic bursts of heat and particles that can damage the walls of the tokamak. Scientists at DIII-D have succeeded in eliminating these bursts (called Edge Localized Modes [ELMs]) by applying small 3-D magnetic perturbations to the normal 2-D magnetic field of the tokamak. This technique has been applied successfully on the Joint European Torus (JET) facility, and variations of the underlying theory are being tested on DIII-D to contribute to optimizing the design requirements of control coils for ITER.
- ***Understanding how Microwaves Can Sustain a Tokamak Plasma:*** In order to operate in steady state, a tokamak-based power plant would require that a toroidal plasma current be sustained through a combination of pressure-driven currents and externally applied non-inductive techniques. One of the most efficient external techniques utilizes microwaves which can penetrate into the plasma, and deliver toroidal momentum to a localized population of high energy electrons. Recently such a toroidal plasma current was sustained in Alcator C-Mod using phased microwaves at or near world-record efficiencies. Detailed measurements of the location of the driven current and distributions of the current-carrying electrons have been used to validate state-of-the-art computational models (used in SciDAC projects), providing increased confidence in the predictive capability of these models for fusion applications.
- ***China-U.S. Partnership Enables Control of the Experimental Advanced Superconducting Tokamak (EAST):*** Because all major coil systems on ITER will be superconducting, it will be important to gain operational experience on controlling plasmas in superconducting advanced

tokamaks prior to ITER operation. Using the EAST/DIII-D Plasma Control System (PCS), developed at GA and based on the multi-cpu DIII-D PCS, the newly completed EAST facility at the Academy of Sciences Institute of Plasma Physics (ASIPP) in Hefei, China achieved first plasma within three days of beginning startup operations in September 2006. The extraordinary rapidity of this startup process of a completely new type of tokamak is due to the partnership between the ASIPP team and a team of experienced U.S. physicists and control experts from GA and PPPL who supported EAST startup, both onsite and remotely.

- ***First High-Fidelity Simulations of Sawtooth Oscillations in Tokamaks:*** Sawtooth oscillations are periodic events occurring near the center of tokamak plasmas which can have a significant impact upon the performance of burning plasmas. Understanding and controlling sawteeth is therefore important for the operation of ITER. Researchers at the SciDAC Center for Extended Magnetohydrodynamic Modeling (CEMM) have performed self-consistent simulations of repetitive sawtooth cycles for a small tokamak, the Current Drive Experiment, using the two extended nonlinear MHD codes of the Center, and obtained excellent agreement between the two codes and good agreement with the experiment. These CEMM simulations represent a significant first step toward a first-principles predictive understanding of this important phenomenon.

Detailed Justification

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Tokamak Experimental Research	**45,916**	**52,870**	**51,119**

The tokamak magnetic confinement concept has 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 GA and Alcator C-Mod at MIT. Both DIII-D and Alcator C-Mod are operated as national collaborative science facilities with research programs established through public research forums, program advisory committee recommendations, and peer review. There is also a very active program of collaboration with comparable facilities abroad aimed at establishing an international database of tokamak experimental results. In association with the International Tokamak Physics Activity (ITPA), both DIII-D and Alcator C-Mod continue to give high priority to their efforts on joint experiments with other major facilities in Europe and Japan in support of ITER-relevant physics issues.

In FY 2009, U.S. tokamak research will continue to focus on supporting the ITER project. DIII-D will utilize its upgraded microwave heating system to further explore active plasma control and optimization techniques needed for ITER using electron cyclotron current drive. C-Mod will pursue a program with high magnetic field and high power densities incident on ITER-candidate materials for plasma facing components, while utilizing recent hardware upgrades to improve control of various plasma parameters and pursue "hybrid" advanced operating scenarios for ITER. In international collaborations, the scope of joint ITPA experiments will be enhanced to accommodate new experiments in support of ITER. These activities will improve the understanding of key ITER physics issues, including plasma stability control, disruption mitigation, wave-particle interaction, energy and particle transport, and development of improved plasma discharges for burning plasma studies on ITER.

As the new superconducting tokamaks in China (EAST) and Korea (Korean Superconducting Tokamak Advanced Research (KSTAR) project) begin research operations, collaborations with those programs will be expanded to investigate steady state physics and technology issues.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009

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

	FY 2007	FY 2008	FY 2009
▪ **DIII-D Research**	**24,531**	**27,060**	**26,249**

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

The primary goal of the DIII-D program is to establish the scientific basis for the optimization of the tokamak approach to fusion energy. This will be accomplished by advancing basic scientific understanding across a broad front of fusion plasma topical areas including transport, stability, plasma-wave physics, and interactions with physical boundaries. Integrating this knowledge in cross cutting research campaigns will help enable the success of ITER and enhance burning plasma research. Over the past few years, the investigation of ITER-relevant discharge scenarios, including the development of advanced enhanced performance scenarios, has gained emphasis in the DIII-D experimental program.

In FY 2009, the DIII-D program will continue to focus on experiments to provide solutions to key ITER issues and build a firm physics basis for ITER program planning. With the completion of an upgrade to the infrastructure power system and the ability to use all auxiliary heating systems at full power (including all eight neutral beam sources), the DIII-D program will have a very significant set of control tools to demonstrate integrated performance of advanced tokamak operating modes. Priority experiments will be conducted to assess the optimum plasma configuration through the active control of internal plasma parameters and the mitigation of instabilities. This will include the continued examination of techniques to detect, lessen, and avoid the effects of plasma disruptions. The DIII-D program will also be able to accommodate a number of ITPA joint experiments with the international community.

	FY 2007	FY 2008	FY 2009
▪ **Alcator C-Mod Research**	**8,267**	**9,600**	**9,030**

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

	FY 2007	FY 2008	FY 2009
	(dollars in thousands)		

relevant to ITER. The facility has made significant contributions to the world's fusion program in the areas of plasma heating, stability, and confinement in high field tokamaks, all of which are important integrating issues for burning plasmas.

In FY 2009, C-Mod will conduct a strong research program primarily in support of ITER. Experiments will focus on elucidating the physics of self-generated plasma rotation and on advanced operating "hybrid" scenarios for ITER involving shallow reversal of the shear in the confining magnetic fields. These scenarios are known to have special stability and good confinement properties and are capable of enabling longer discharge duration. High power lower hybrid microwave and ion cyclotron radio frequency wave heating and current drive capabilities of the facility will be employed to this goal.

Other ITER-relevant topics that the C-Mod team will continue to focus on in FY 2009 include plasma surface interaction with all-metal walls (especially in the divertor area), measuring the effects of and mitigating disruptions in the plasma, understanding the physics of the plasma edge in the presence of large heat flows, controlling the current density profile for better stability, and helping to build international cross-machine databases using dimensionless parameter techniques. C-Mod will continue participation in many joint experiments organized by the ITPA involving all seven ITER members.

	FY 2007	FY 2008	FY 2009
▪ **International**	**4,710**	**4,982**	**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 in Europe, Japan, China, South Korea, the Russian Federation, and India—the ITER members, and conduct comparative studies to enhance the understanding of underlying physics. The U.S. programs in return host visiting scientists from the international community for participation in U.S. experiments. The FES 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 fusion facilities that exist abroad. These include the world's highest performance tokamaks JET in England and Japan Torus 60 Upgrade [JT-60U] in Japan), a stellarator (the Large Helical Device in Japan), a superconducting tokamak (Tore Supra in France), AxiSymmetric Divertor Experiment Upgrade (ASDEX-UG) and Tokamak Experiment for Technology Oriented Research (TEXTOR) in Germany, and several smaller devices. In addition, the United States is collaborating with South Korea on KSTAR, as that device begins operation, and with China on research using EAST. The U.S. collaboration on EAST was instrumental in that device achieving its first plasma on September 26, 2006 and its first elongated, diverted plasmas in early 2007. These collaborations provide a valuable link with the 80% of the world's fusion research that is conducted outside the United States and provide a firm foundation to support ITER activities.

The United States is a major participant in the ITPA, which identifies high-priority physics needs for ITER and assists in their implementation through collaborative experiments among the major international tokamaks, and analysis and interpretation of experiments for extrapolation to ITER.

In FY 2009 the United States will participate in high priority research activities in support of ITER. These include joint ITPA experiments with teams from the large tokamak programs JET and JT-60U, some joint experiments on medium sized tokamaks such as Tore Supra in France and TEXTOR and ASDEX-UG in Germany, and other joint ITER-relevant experiments in the areas of plasma wall

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009

interactions, plasma instabilities, and first wall design considerations for ITER. Some of the above activities will be impacted as the level of U.S. participation in steady-state physics and technology issues on KSTAR and EAST is expanded and total funding for International activities decreases slightly in FY 2009. These activities will prepare U.S. scientists for participation in burning plasma experiments on ITER. In addition to these tokamak collaborations there are also some collaborations, in the stellarator area with Japan and the European Union.

	FY 2007	FY 2008	FY 2009
▪ **Diagnostics**	**3,768**	**4,141**	**3,912**

Support for the development of unique measurement capabilities (diagnostic instruments) will continue. Diagnostic instruments serve two important functions: to provide a link between theory/computation and experiments for an understanding of the complex behavior of the plasma in fusion research devices; and to provide sensory tools for feedback control of plasma properties in order to enhance device operation. In FY 2009, research will include the development of diagnostics for fundamental plasma parameter measurements, state-of-the-art measurement techniques, and R&D for ITER-relevant diagnostic systems. Diagnostic systems will be installed and operated on current experiments in the United States and on non-U.S. fusion devices through collaborative programs.

The key areas of diagnostic development research are those identified in the FESAC report "Scientific Challenges, Opportunities and Priorities for the U.S. Fusion Energy Sciences Program," April 2005.

A competitive peer review of the diagnostics development program was conducted in FY 2007 for funding that began in FY 2008.

	FY 2007	FY 2008	FY 2009
▪ **Other**	**4,640**	**7,087**	**7,028**

Funding in this category supports educational activities such as research at historically black colleges and universities, graduate and postgraduate fellowships in fusion science and technology, and summer internships for undergraduates. In addition, there is funding for outreach efforts related to fusion science and enabling R&D and operational costs for the U.S. Burning Plasma Organization and FESAC.

	FY 2007	FY 2008	FY 2009
Alternative Concept Experimental Research	**54,078**	**57,345**	**61,694**

This program element broadens the fusion program by exploring the science of confinement optimization in the extended fusion parameter space, with plasma densities spanning twelve orders of magnitude, by seeking physics pathways to improve confinement, stability, and reactor configurations. Through this scientific diversity, the program element adds strength and robustness to the overall fusion program by lowering overall programmatic risks in the quest for practical fusion power in the long term, for which economic and environmental factors are important. At present, three alternate concepts are being pursued at the larger-scale, proof-of-principle level. A number of concepts are also being pursued at a concept-exploration level with smaller-scale experiments, as well as research in establishing a knowledge base for high energy density plasmas. The smaller scale experiments and the cutting-edge research have proven to be effective in attracting students, and strongly contribute to fusion workforce development and the intellectual base of the fusion program. The research has also resulted in new ideas for the larger toroidal devices, including ITER.

	FY 2007	FY 2008	FY 2009
	(dollars in thousands)		
▪ **NSTX Research**	**14,608**	**16,730**	**16,163**

NSTX is one of two large spherical torus confinement experiments in the world; the other is the MegaAmp Spherical Tokamak (MAST) in the United Kingdom. The spherical torus is an innovative confinement device that produces a plasma that is shaped like a sphere with a hole through its center. The properties of a spherical torus plasma are predicted to be different from a conventional tokamak plasma, which is "donut" shaped. For example, theory predicts that a spherical torus plasma will be stable even when very high ratios of plasma-to-magnetic field pressure and large self-driven current fractions exist simultaneously, provided there is a nearby conducting wall bounding the plasma. If these predictions are verified in detail, it would indicate that a spherical torus uses applied magnetic fields more efficiently than most other magnetic confinement systems and could, therefore, be expected to lead to a cost-effective facility for carrying out the nuclear engineering science research needed to provide the integrated knowledge base for a fusion energy system.

In FY 2009, the NSTX team will continue to carry out research on topics that are important to ITER, as well as on the development of the spherical torus concept, such as confinement and stability of highly elongated, low-aspect ratio plasmas at high temperatures and densities. Research on macroscopic stability will focus on understanding the physics of resistive wall mode stabilization and control as a function of rotation. Research on energetic particle modes will investigate how the plasma current density is modified by super-Alfvénic ion driven modes. In the area of integrated, high performance plasma operation, the NSTX team will study conditions in which the toroidal plasma current is maintained for durations longer than the plasma current redistribution time using various current drive methods. To achieve high performance, the NSTX team will use increased plasma elongation to maximize the contribution of the self-driven "bootstrap" current and active stabilization to control pressure-driven instabilities.

▪ **Experimental Plasma Research**	**16,476**	**17,050**	**13,288**

Experimental Plasma Research was started to explore Innovative Confinement Concepts (ICC). In the ICC program, a number of small concept-exploration level facilities have been constructed, an ICC-centric theory center has been formed, and several small topic-specific investigations have been supported. The facilities built include spheromaks, field-reversed configurations, a levitated dipole, a flow-stabilized z-pinch, centrifugally confined magnetic mirrors, and electrostatic confinement. In general, these cover emerging concepts for plasma confinement and stability. These studies have intrinsic value to the plasma science and fusion energy missions of the FES program since they provide unique tests and extensions of our understanding of confined plasmas. In that sense, these programs complement the larger tokamak programs to help establish the predictive understanding of fusion plasma behavior. The program will undergo a peer review in FY 2009, the goal of which is to select a portfolio of concepts to generate sufficient experimental data to elucidate the underlying physics principles upon which these concepts are based and, as needed, to develop computational models of promising concepts to a sufficient degree of scientific fidelity to allow an assessment of the relevance of those concepts to future fusion energy systems. The funding reduction in FY 2009 is largely the result of two changes: the Sustained Spheromak Physics Experiment (SSPX) project at LLNL will be completed in FY 2008; and the Quasi-Poloidal Stellarator is not supported in FY 2009 to provide funding for higher research and operational priorities.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
▪ **HEDLP**	**15,459**	**15,942**	**24,636**

High energy density laboratory plasma physics is the study of ionized matter at extremely high density and temperature. According to the recent National Academy of Sciences report on plasma science[a], high energy density (HED) physics begins when matter is heated or compressed (or both) to a point that the stored energy in the matter exceeds about 10^{10} Joule per cubic meter. This is approximately the energy density of solid material at about 10,000 Kelvins, and corresponds to a pressure of about 100,000 atmospheres. HED conditions exist in the interior of the Sun where hydrogen has been fused to produce energy for billions of years. Supernovae, gamma ray bursts, accretion disks around black holes, pulsars, and astrophysical jets are examples of HED astrophysical phenomena. On Earth, HED conditions can only be created transiently in the laboratory by using intense pulses of lasers, particle beams (electrons or ions), plasma jets, magnetic pinches, or their combinations. Because of its potentially immense impact on energy security, the NAS report recommended that SC provide stewardship of HED plasma science related to inertial fusion including the use of magnetized targets.

In response to a number of recent NRC and other federally sponsored studies, the interagency Task Force on HEDP recommended that the stewardship for HEDLP be improved. However, the Task Force also recommended that the Federal stewardship be organized in such a way as to maintain the multi-disciplinary nature of the field. Thus the HED science related to stockpile stewardship should remain under the purview of NNSA while the HED science related to energy applications should be the focus for the FES stewardship for the field. The FES program in HEDLP follows closely the recommendations of the interagency Task Force as well as the NAS, within the limits of available budgets.

In FY 2009, the proposed budget will fund research in on-going areas and increased funding is requested for new initiatives as the HEDLP Joint Program evolves. The on-going areas include studies of warm dense matter driven by heavy ion beams, fast ignition, and magnetized high energy density plasmas including plasma jets. A rolling series of competitive solicitations will be started to identify initiatives to be supported under the Joint Program in HEDLP. These solicitations will cover the above three areas and other relevant HEDLP areas, such as laser-plasma interactions, compressible hydrodynamics, and laboratory astrophysics. The merit of these areas for funding as well as the amount of funding available as part of the solicitation will be determined by competitive peer-review and recommendations of pending workshops and conferences. In addition, a program in HEDLP will be initiated in FY 2009 at LLNL.

▪ **Madison Symmetrical Torus**	**6,760**	**6,910**	**6,915**

The goal of the Madison Symmetrical Torus (MST), at the University of Wisconsin-Madison, is to obtain a fundamental understanding of the physics of reversed field pinches (RFPs), particularly magnetic fluctuations and their macroscopic consequences, and to use this understanding to develop the RFP fusion configuration. The RFP is geometrically similar to a tokamak, but with a much weaker magnetic field that reverses direction near the edge of the plasma. Research in the RFP's self-organization properties has astrophysical applications and may lead to a more cost-effective

[a] *Plasma Science – Advancing Knowledge in the National Interest.* Plasma 2010 Committee of the Plasma Science Committee. National Research Council, National Academies Press, 2007, Washington, D.C.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009

fusion system. 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 a RFP are being investigated in this experiment. MST is one of the four leading RFP experiments in the world, and is unique in that it pioneered the reduction of magnetic fluctuations by current density profile control. In recent years, this approach has led to a ten-fold increase in energy confinement time.

In FY 2009, the major plans of the MST program are to complete the construction of a multi-point charge exchange recombination spectroscopic system and measure a range of ion temperatures, and to begin measurement of electron temperature fluctuations using a fast Thomson scattering system. The plan also includes improving experimental facilities such as incorporation of a long pulse, high power neutral beam, a diagnostic neutral beam for motional stark effect diagnostics, and a programmable power supply for controlling the toroidal loop voltage.

	FY 2007	FY 2008	FY 2009
▪ **NCSX**	**775**	**713**	**692**

This funding supports the research portion of the program to be executed with the NCSX at PPPL, which involves participation and a leadership role within the National Compact Stellarator Program (NCSP). PPPL, ORNL, and LLNL are the participants in NCSX research that keep abreast of physics developments in domestic and international stellarator research, factoring those developments into planning of the NCSX experimental program, as well as preparation of long-lead-time physics analysis tools for NCSX application. These tools have a dual use: setting physics requirements for hardware upgrades and interpreting data from future NCSX operation. The NCSX team will analyze plasma equilibria to establish requirements and physics designs for in-vessel magnetic diagnostic upgrades and trim coils; develop design requirements for the initial plasma-facing components and edge diagnostics; and conduct a research forum to continue the community-wide planning of NCSX research campaigns, obtain feedback on NCSX plans and priorities, and identify collaborator interests and opportunities.

	FY 2007	FY 2008	FY 2009
Theory	**23,732**	**24,486**	**24,283**

The Theory program provides the conceptual scientific underpinning for FES by supporting three of its thrust areas: burning plasmas, fundamental understanding, and configuration optimization. Theory efforts meet the challenge of describing the complex multiphysics, multiscale, non-linear plasma systems at the most fundamental level and, in doing so, generate world-class science. These descriptions—ranging from analytic theory to highly sophisticated computer simulation codes—are used to interpret results from current experiments, plan new experiments on existing facilities, design future experimental facilities, and assess projections of their performance. The program focuses on both tokamaks and alternate concepts. Work on tokamaks is aimed at developing a predictive understanding of advanced tokamak operating modes and burning plasmas—both of which are important to ITER—while the emphasis on alternate concepts is on understanding the fundamental processes determining equilibrium, stability, and confinement for each concept. The theory program also provides the input needed in the FES large-scale simulation efforts that are part of the SciDAC portfolio and, together with SciDAC, is expected to lead to a predictive understanding of how fusion plasmas can be sustained and controlled.

The Theory program is a broad-based program with researchers located at six national and federal laboratories, over thirty universities, and several private companies. Theorists in larger groups, located mainly at national laboratories and private industry, generally support major experiments, work on large

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009

problems requiring a team effort, or tackle complex issues requiring multidisciplinary teams. Those at universities tend to support smaller, innovative experiments or work on more fundamental problems in plasma physics while training the next generation of fusion plasma scientists.

Some of the issues to be addressed by theory researchers in FY 2009 include the turbulent transport of toroidal and poloidal momentum in tokamak plasmas and the understanding of spontaneous toroidal rotation, progress toward a predictive understanding of particle and electron transport, the physics of the edge pedestal and the transition from the Low to the High (L-to-H) confinement modes in tokamaks, the formation of edge and internal transport barriers, the first-principles formulation of moment closures in extended magnetohydrodynamics (MHD) models, the calculation of atomic and molecular collision processes of importance in fusion reactors, the study of the effect of magnetic islands on the stability properties of 3-D equilibria in stellarators and other innovative confinement concepts, the understanding of fast magnetic reconnection in high temperature fusion plasmas, and the development of predictive integrated computational models for tokamak plasmas.

SciDAC	**6,540**	**7,138**	**7,212**

The SciDAC program is a set of coordinated research efforts across all SC programs with the goal of achieving breakthrough scientific advances through computer simulation that are otherwise impossible using theoretical or laboratory studies alone. By taking advantage of the exponential advances in computing and information technologies as tools for discovery, SciDAC encourages and enables a new model of multi-disciplinary collaboration among physical scientists, mathematicians, computer scientists, and computational scientists. The product of this collaborative approach is a new generation of scientific simulation codes that can fully exploit the emerging capabilities of terascale and petascale computing.

The current FES SciDAC portfolio includes eight projects, which are set up as strong collaborations among 29 institutions with 44% of the funding going to national laboratories, 38% going to universities, and 18% going to private industry. Of these, five are focused on topical science areas, such as macroscopic stability, the simulation of electromagnetic wave-plasma interaction, the study of turbulent transport in burning plasmas, and the physics of energetic particles. During the last funding period (FY 2005–FY 2007), these projects developed high-performance computational tools which have provided us with new and significant insights into questions of fundamental importance in fusion plasma science. These included the simulation of mode conversion of radio frequency (RF) waves in tokamak plasmas, the modeling of the sawtooth instability and Edge Localized Modes (ELMs) in tokamaks, and the understanding of the inward spreading of ion temperature gradient driven turbulence from the edge to the core of tokamak plasmas. These projects were competitively reviewed in 2007. The new and renewed projects resulting from this competition will be focusing their efforts in FY 2008–FY 2010 on the needs of burning plasmas and ITER and will address issues such as the interaction of RF waves with the edge plasma, the development of a predictive understanding of turbulent transport with emphasis on the electron, particle, and momentum transport channels using computational models with increased physics fidelity, and the macroscopic stability of fusion plasmas using extended nonlinear MHD codes with more complete physics models and realistic parameters including validation with experiments. In addition, a new project focused on the physics of energetic particles has been added to our SciDAC portfolio, recognizing the critical importance of this area for ITER and burning plasmas.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009

The remaining three projects, which were jointly funded by the FES and ASCR programs in FY 2006 and FY 2007 for a five-year period, are known as Fusion Simulation Prototype Centers or proto-FSPs and focus on code integration and computational framework development in the areas of edge plasma transport, interaction of RF waves with MHD, and the coupling of the edge and core regions of tokamak plasmas. In FY 2009, these centers will continue to focus their efforts on issues important to burning plasmas and ITER, such as the development of physics-based models of RF control of sawtooth oscillations and neoclassical tearing modes, the development of a first-principles edge pedestal model for ITER, and the development of advanced computational frameworks for integrated simulations.

Fusion Simulation Project	**—**	**—**	**1,976**

The Fusion Simulation Project (FSP) is a computational initiative led by FES with collaborative support from ASCR. The FSP is aimed at the development of a predictive simulation capability relevant to ITER and other toroidal fusion devices, taking advantage of the high performance computing resources at our leadership class facilities. In May 2007, a national workshop was held to refine the long-term vision for the FSP and develop a detailed description of what must be accomplished during the next five years to make progress toward an integrated simulation capability. The workshop report was recently evaluated by FESAC, which recommended that the project move forward to a Project Definition phase, and is now in the process of being evaluated by the ASCR Advisory Committee.

General Plasma Science	**14,306**	**14,648**	**14,869**

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 Fusion Science Centers, the Plasma Physics Junior Faculty Award Program, the General Plasma Science program carried out at the DOE laboratories, and basic plasma physics user facilities at laboratories and universities (sharing costs with NSF where appropriate). The Fusion Science Centers perform plasma science research in areas of such wide scope and complexity that it would not be feasible for individual investigators or small groups to make progress and strengthen the connection between the fusion research community and the broader scientific community. Atomic and molecular data for fusion will continue to be generated and distributed through openly available databases. FES will continue to share the cost with NSF of the multi-institutional plasma physics frontier science center started in FY 2003.

SBIR/STTR	**—**	**7,417**	**7,282**

In FY 2007, $6,505,000 and $781,000 were transferred to the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, respectively. The FY 2008 and FY 2009 amounts are the estimated requirements for the continuation of these programs.

Total, Science	**144,572**	**163,904**	**168,435**

Explanation of Funding Changes

	FY 2009 vs. FY 2008 ($000)
Tokamak Experimental Research	
▪ **DIII-D Research**	
Redirecting resources to higher priorities will require some staff reductions but will support the DIII-D national research team at the level necessary to conduct experiments and analysis relevant to burning plasma physics and ITER at the planned 10 weeks of operation.	-811
▪ **Alcator C-Mod Research**	
Redirecting resources to higher priorities will result in a reduced level of effort in analyzing experimental results.	-570
▪ **International**	
Funding for the Tore Supra exchange with the European Union is reduced slightly to provide funding to support other higher priority program needs.	-82
▪ **Diagnostics**	
Redirecting resources to higher priorities will result in a reduction in the level of effort for developing new base-program and ITER-relevant diagnostics.	-229
▪ **Other**	
The decrease will slightly reduce education outreach activities.	-59
Total, Tokamak Experimental Research	**-1,751**
Alternative Concept Experimental Research	
▪ **NSTX**	
Redirecting resources to higher priorities will require some reduction in scientific staff and a reduced level of effort on experiments and data analysis.	-567
▪ **Experimental Plasma Research**	
The decrease reflects completion of SSPX at LLNL ($2,282,000), and elimination of funding for the Quasi-Poloidal Stellarator ($-1,111,000) to provide support for higher research and operational priorities in FY 2009 and in the future, as well as an overall reduction of effort in this area of $369,000.	-3,762
▪ **HEDLP**	
The increase is for the expansion of DOE's efforts in on-going and new projects in fast ignition and dense plasmas in ultrahigh magnetic fields including plasma jets, and for initiation of a program in HEDLP at LLNL. The technical scope of the program will expand according to the recommendations of the recent Workshop in HEDLP held at Argonne National Laboratory (May 2007). Funding will be awarded through competitive peer-reviewed solicitations that will be launched in FY 2008.	+8,694

	FY 2009 vs. FY 2008 ($000)
▪ **Madison Symmetrical Torus**	
Funding is increased slightly from FY 2008 resulting in continued full operation of the device.	+5
▪ **NCSX**	
With the delay in the project schedule, the experimental research program for NCSX is reduced slightly.	-21
Total, Alternative Concept Experimental Research	**+4,349**
Theory	
Redirecting resources to higher priorities will result in a slight reduction in the overall theory efforts in both tokamaks and alternates.	-203
SciDAC	
The increase will strengthen efforts in targeted areas critical to burning plasmas and ITER, in particular energetic particle effects and turbulent transport.	+74
Fusion Simulation Project	
The funding in FY 2009 will support the planning and design of this new project.	+1,976
General Plasma Science	
The increase will support additional high-quality grants funded under the NSF/DOE Partnership in Basic Plasma Science and Engineering.	+221
SBIR/STTR	
Support for SBIR/STTR is funded at the mandated level.	-135
Total Funding Change, Science	**+4,531**

Facility Operations

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Facility Operations			
DIII-D	32,138	34,600	31,811
Alcator C-Mod	13,993	15,510	14,177
NSTX	18,917	22,100	19,274
NCSX (MIE)	15,822	15,900	19,560
GPP/GPE/Other	5,468	2,117	2,578
U.S. Contributions to ITER (MIE TPC)	60,000[a]	10,626[a]	214,500
Total, Facility Operations	146,338	100,853	301,900

Description

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

Our facilities enable U.S. scientists from universities, laboratories, and industry, as well as visiting foreign scientists, to conduct world-class research funded in the Science and Enabling R&D subprograms. The facilities consist of magnetic plasma confinement devices, plasma heating and current drive systems, diagnostics and instrumentation, experimental areas, computing and computer networking facilities, and other auxiliary systems. The Facility Operations subprogram provides funds for operating and maintenance personnel, electric power, expendable supplies, replacement parts, system modifications and facility enhancements.

As a result of the FY 2008 Appropriations, DIII-D, Alcator C-Mod, and NSTX have been provided additional funding to increase operating weeks during FY 2008. The funding requested in FY 2009 will provide research time for about 500 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 NCSX project at PPPL was expected to be completed in FY 2009. As described previously, the project cost and schedule baseline must be changed for the project to continue. This budget assumes that

[a] Starting in FY 2009, the U.S. Contributions to ITER project TEC and OPC funds are consolidated and requested in this subprogram. FY 2007 and FY 2008 funding displayed here reflects this change. Previous budgets reflected the OPC costs under the Enabling R&D subprogram ($18,000,000 in FY 2007 and $10,626,000 in FY 2008).

the project will be rebaselined. The Department will formally make the decision on whether to proceed with this rebaselining in the first half of FY 2008.

The FY 2009 Request provides for the fourth year of funding for the U.S. Contributions to ITER project. The FY 2009 funding of $214,500,000 in the Facilities Operations subprogram provides for: operation of the USIPO; U.S. design, R&D, and hardware contributions; U.S. personnel seconded to the international ITER Organization; cash for common needs such as infrastructure, hardware assembly, and installation of ITER components; and cash for the international ITER Organization central reserve.

The schedule of the work to be completed in FY 2009 will be re-planned based on the impact to the project of the funding reduction contained in the FY 2008 Energy and Water Development and Related Agencies Appropriations Act.

Funding is also included in this subprogram for general plant projects (GPP) and general purpose equipment (GPE) at PPPL. GPP and GPE supports essential facility renovations, and other necessary capital alterations and additions to buildings and utility systems.

FY 2007 Facility Operations Accomplishments

- **DIII-D at GA, San Diego**

  DIII-D completed the additions and modifications to the microwave system infrastructure to support three additional long-pulse microwave tubes (gyrotrons), supported experiments with two of the new tubes, and began operational testing of the third gyrotron. Two of the ion cyclotron frequency (ICRF) systems were also refurbished and resumed operation, providing up to 3 megawatts (MW) of auxiliary power for experiments. Spare neutral beam ion sources were successfully manufactured in order to support operation of an eighth neutral beam in FY 2009.

- **Alcator C-Mod at MIT**

  Alcator C-Mod was outfitted with a divertor cryopump which has allowed much better density control of the discharge which enables operation in high confinement regimes not possible before. Many other minor upgrades to diagnostic systems were also performed.

- **NSTX at PPPL**

  The NSTX operations group has nearly completed the design of a system to provide electron cyclotron heating and electron Bernstein wave heating (ECH/EBW system) based on a source generating either 200 kilowatts (kW) power at 28 gigahertz (GHz) or 100 kW at 15.3 GHz. When completed, this system will enable an initial experimental test of the EBW heating in NSTX.

- **NCSX at PPPL**

  PPPL completed winding 15 of the 18 NCSX modular coil winding forms (MCWFs) and initiated fabrication of the toroidal field coils. The MCWFs are steel structures that support the modular coil windings and position them with high accuracy. Installation of heating/cooling risers and diagnostics continued on the vacuum vessel sector. The vacuum vessel is a highly shaped structure with stringent requirements on vacuum quality and magnetic permeability.

Detailed Justification

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
DIII-D	**32,138**	**34,600**	**31,811**

Support is provided for operation, maintenance, and improvement of the DIII-D facility and its auxiliary systems. A facility power infrastructure upgrade will be completed in FY 2008 to support maximum utilization of the existing auxiliary heating systems, and modifications to the coil connections to allow long pulse operations will be finished. Along with the recently regained capability to operate all eight neutral beam heating sources, this gives the DIII-D tokamak exceptional tools to explore integrated advanced tokamak operating modes. In FY 2009, 10 weeks of single shift plasma operation will be conducted, during which time essential scientific research will be performed as described in the Science subprogram. Funding will be provided for improvements to the microwave heating system to upgrade its capability to actively track and suppress plasma instabilities.

DIII-D	FY 2007	FY 2008	FY 2009
Optimal hours (estimated)	1,000	1,000	1,000
Achieved Operating Hours	512	720	400
Total Number of Users	220	240	240

Alcator C-Mod	**13,993**	**15,510**	**14,177**

Support is provided for operation, maintenance, minor upgrades, and improvement of the Alcator C-Mod facility and its auxiliary systems, including initiation of the tokamak outer divertor redesign and improvements of the Charge Exchange Recombination and soft X-ray diagnostics to allow better measurements in plasma rotation studies. In FY 2009, C-Mod will be operated for 13 weeks, focusing on ITER-relevant experiments.

Alcator C-Mod	FY 2007	FY 2008	FY 2009
Optimal hours (estimated)	800	800	800
Achieved Operating Hours	480	480	416
Total Number of Users	105	105	105

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
NSTX	**18,917**	**22,100**	**19,274**

Support is provided for operation, maintenance, and a few diagnostics upgrades, including the full poloidal charge exchange recombination spectroscopy system, a fast-ion D-alpha camera, divertor diagnostics, and installation of next-step fluctuation diagnostics. In FY 2009, there is funding for 11 weeks of operation mostly to explore long pulse, high beta experiments.

NSTX	FY 2007	FY 2008	FY 2009
Optimal hours (estimated)	1,000	1,000	1,000
Achieved Operating Hours	508	720	440
Total Number of Users	140	150	150

NCSX	**15,822**	**15,900**	**19,560**

Funding is requested in FY 2009 for the continuation of the NCSX MIE. This project was initiated in FY 2003 and consists of the design and fabrication of a compact stellarator proof-of-principle class experiment. PPPL will continue the fabrication of the major components and assembly of the entire 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 NCSX MIE project has experienced higher than expected costs to date with fabrication activities and with the complicated assembly process still ahead, it is now evident that this MIE project cannot be completed within the approved cost and schedule baseline. PPPL performed a bottoms-up cost and schedule estimate to complete the project, and is preparing a revised baseline. The total project cost has increased at least 39 percent over its second cost baseline (now 69 percent over the original baseline). SC charged FESAC to conduct a scientific and programmatic review of NCSX and the stellarator program to determine the value to both the national and international stellarator communities. FESAC reported its findings in October 2007 and concluded that the NCSX should be completed to maintain U.S. interests in this field. Princeton University then performed an external independent technical review in October/November 2007 to determine whether PPPL could build and maintain NCSX successfully. The Review Team concluded that PPPL can succeed in building and maintaining this stellarator. These reviews have provided the necessary input to allow DOE to make the decision to either rebaseline the project or cancel it. That decision will be made in the first half of FY 2008. If the decision is to proceed with the fabrication of NCSX, DOE's Office of Construction and Engineering Management will conduct an External Independent Review to assess the proposed cost and schedule baseline. The FY 2009 request for the NCSX MIE assumes validation and approval of the proposed rebaseline.

	(dollars in thousands)	
FY 2007	FY 2008	FY 2009

Milestones for NCSX are shown in the following table:

FY 2007	FY 2008	FY 2009
Complete winding of one half of the modular coils.	Complete winding of all of the modular coils.	This budget assumes a re-baseline of the NCSX MIE Project which is estimated to be ~$50 million over budget and 34 months behind schedule. For additional discussion of this situation, see the Facility Operations subprogram section.

	FY 2007	FY 2008	FY 2009
GPP/GPE/Other	**5,468**	**2,117**	**2,578**

These funds are provided primarily for general infrastructure repairs and upgrades for the PPPL site based upon quantitative analysis of safety requirements, equipment reliability, and research needs. This category also funded the ORNL move of all fusion personnel and equipment from the Y-12 to the X-10 site. This move will be completed early in FY 2008.

	FY 2007	FY 2008	FY 2009
U.S. Contributions to ITER TPC	**60,000**[a]	**10,626**[a]	**214,500**
U.S. Contributions to ITER OPC (R&D)	**18,000**	**10,626**	**6,000**
U.S. Contributions to ITER TEC	**42,000**	**—**	**208,500**

The U.S. Contributions to ITER project provides hardware (including the supporting design and R&D), personnel, cash for common expenses, and cash to the international ITER Organization’s central reserve.

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

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

[a] Starting in FY 2009, the U.S. Contribution to ITER project TEC and OPC funds are consolidated and requested in this subprogram. FY 2007 and FY 2008 funding displayed here reflects this change. Previous budgets reflected the OPC costs under the Enabling R&D Subprogram ($18,000,000 in FY 2007 and $10,626,000 in FY 2008).

	(dollars in thousands)	
FY 2007	FY 2008	FY 2009

The ITER device is a long-pulse tokamak with elongated plasma shape and a single-null poloidal divertor. In nominal inductive operation, the goal is to produce 500 MW of deuterium-tritium fusion power for a burn duration of at least 400 seconds, with a power gain factor of at least 10, which is close to what should be required in a power plant.

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

DOE will comply with all U.S. environmental and safety requirements such as the National Environmental Policy Act applicable to the ITER work that will be conducted in the U.S.

DOE's commitment to the international ITER Organization is a $^{1}/_{11}$th share (~9.1%) of the international ITER construction project costs per the value estimate in the ITER Joint Implementing Agreement, which is identical to the other non-host participants. In addition to scientists and engineers assigned to the international ITER Organization, the U.S. has provided one senior management staff member to the international ITER Organization: the Deputy Director General for Tokamak Systems. All U.S. personnel assigned to the international ITER Organization will comply with the environmental and safety requirements of the host country and with the applicable U.S. legal requirements.

The requested FY 2008 funding of $160,000,000 was reduced in December 2007 to $10,626,000 by the FY 2008 Energy and Water Development and Related Agencies Appropriations Act. While the conference report accompanying the Act eliminated funding for the ITER project TEC, it did not direct termination of the project. Therefore, DOE plans to use the funds provided for the ITER project OPC ($10,626,000) plus previous year carryover funds to preserve the core U.S. ITER Project Team and, to the extent possible, meet minimum U.S. commitments to the ITER Organization in France until FY 2009 funds become available. Further design work, long-lead hardware procurements, and additional cash contributions to the ITER Organization will be delayed until that time.

In FY 2009, the $214,500,000 requested will be used to resume the full range of U.S. participation in ITER. These activities will focus on material bonding R&D for first wall components; design and analysis of the central solenoid magnet structure, first wall and shield, port limiters, tokamak cooling water system, fueling pellet injector, tokamak exhaust processing system, ion and electron cyclotron heating transmission lines, and diagnostics; and initiating long-lead procurements of toroidal field magnet conductor materials, tokamak cooling water system components, and first articles of the first wall and shield modules. In addition, the funds will be used to support the USIPO, provide U.S. secondees to the international ITER Organization, and provide cash contributions to the international ITER Organization per the terms of the ITER Joint Implementing Agreement. Some work originally planned for FY 2009 will be delayed into FY 2010 and beyond.

	FY 2007	FY 2008	FY 2009
(dollars in thousands)			

The schedule and funding projections for the U.S. Contributions to ITER project are reflected in the tables at the end of the Facility Operations subprogram budget. The FY 2008 funding reduction will cause U.S. hardware fabrication and delivery to be delayed, which will lead to cost growth. The schedule and cost estimate for the U.S. Contributions to ITER project remains preliminary until the baseline scope, cost, and schedule are established at CD-2, planned for FY 2009-2010.

Total, Facility Operations	**146,338**	**100,853**	**301,900**

Explanation of Funding Changes

	FY 2009 vs. FY 2008 ($000)
DIII-D	
The decrease in funding for FY 2009 will reduce the weeks of operation from 18 in FY 2008 to 10 in FY 2009. Minor upgrades to the microwave steering systems (launchers) will be completed to improve the capability to actively track and suppress instabilities.	-2,789
Alcator C-Mod	
The decrease in funding for FY 2009 will reduce the weeks of operation from 15 in FY 2008 to 13 in FY 2009.	-1,333
NSTX	
The decrease in funding for FY 2009 will reduce the weeks of operation from 18 in FY 2008 to 11 in FY 2009.	-2,826
NCSX	
This increase supports the estimated rebaseline for the NCSX project.	+3,660
GPP/GPE/Other	
This reflects a modest increase in general infrastructure repairs and upgrades at the PPPL site.	+461
U.S. Contributions to ITER project	
This increase provides for the fourth year of funding for the MIE project. Activities in FY 2009 will focus on resuming the full range of U.S. participation in ITER to include advancement and/or completion of various design, analysis, and R&D activities and long-lead procurements for major U.S. components.	+203,874
Total Funding Change, Facility Operations	**+201,047**

U.S. Contributions to ITER project

	Fiscal Quarter				Total Estimated Cost ($000)	Total Project Cost ($000)
	Procurements Initiated	Procurements Complete	Personnel Assignments to Foreign Site Start	Personnel Assignments to Foreign Site Complete		
FY 2006 Budget Request	3Q FY 2006	4Q FY 2012	2Q FY 2006	4Q FY 2013	1,038,000	1,122,000[a]
FY 2007 Budget Request	4Q FY 2006	4Q FY 2012	2Q FY 2006	FY 2014	1,077,051	1,122,000[a]
FY 2008 Budget Request	1Q FY 2008	4Q FY 2014	2Q FY 2006	FY 2014	1,078,230	1,122,000[a]
FY 2009 Budget Request	2Q FY 2009	4Q FY 2014–4Q FY 2017[b]	2Q FY 2006	FY 2014–FY 2017	TBD	1,450,000–2,200,000[b]

ITER Financial Schedule
Total Project Costs (TPC)[c]

(budget authority in thousands)

Fiscal Year	Total Estimated Cost	Other Project Costs	Total Project Costs
2006	15,866	3,449	19,315
2007	42,000	18,000	60,000
2008	—	10,626	10,626
2009	208,500	6,000	214,500
Outyears	TBD	TBD	TBD

Estimated ITER TPC Range

Although the ITER Joint Implementing Agreement has entered into force, there is still much to be done in preparation for construction. As the project enters 2008, a number of significant cost risks remain that could affect the U.S. ITER TPC. The sources of potential cost growth can be categorized as follows: The FY 2008 Energy and Water Development and Related Agencies Appropriations Act signed on December 26, 2007 that reduced the U.S. ITER project funding from $160,000,000 to $10,626,000; actions taken by the ITER Council and the international ITER Organization; external factors outside of DOE's control; and design maturity.

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[a] Mission Need (CD-0) was approved in July 2005 with a preliminary TPC of $1,122,000,000 (the U.S. cap). The funding profile was also preliminary.

[b] Alternative Selection and Cost Range (CD-1) was approved in December 2007 with a TPC range of $1.45 to $2.20 billion and a completion schedule range of FY 2014 to FY 2017. During FY 2008 and FY 2009, U.S. reviews will be conducted to validate the cost and schedule estimates for the U.S. Contributions to ITER project. These reviews will reflect the impact of the FY 2008 Energy and Water Development and Related Agencies Appropriation Act. In addition, international ITER Project activities in FY 2008 will establish the international cost and schedule baselines which can have an effect on the U.S. Contributions to ITER project. The baseline TPC, including the funding profile, will be established at CD-2 planned for FY 2009-2010. The FY 2009 Budget Request is for continued engineering design and long-lead procurements only. Engineering design may include limited fabrication and testing of design concepts.

[c] A complete baseline funding profile, including the outyears, will be established at CD-2, which is anticipated to be in FY 2009–2010.

Among the aspects under the international ITER Organization's purview, the principal cost drivers are the overall project schedule, design changes and other actions impacting hardware scope and manufacturing costs, and licensing/regulatory requirements. The international ITER Organization is developing a schedule for the construction phase that includes detailed inputs from the seven Domestic Agencies, which is to be made available by mid-2008. Likewise, there are several technical issues in the reference design to be resolved in 2008 that may require design changes, some of which may increase the U.S. ITER TPC. There may also be cost impacts from French and European regulatory requirements imposed on the ITER design.

External factors include changes in currency exchanges rates, escalation rates, commodity prices, and market conditions for hardware procurement. The ITER Joint Implementing Agreement requires cash contributions from the Members to be made in Euros, which has already cost the U.S. ITER Project considerably more than was previously foreseen due to the exchange rate. Prices for raw materials used in manufacturing U.S. supplied hardware have also been steadily increasing. The responses to date from industry in response to USIPO requests for price quotes have indicated that the future bidding climate will be unfavorable for many types of hardware.

Finally, the reference design for ITER is not mature in certain areas such as the Central Solenoid Magnet System, for which the U.S. has manufacturing responsibility. This means that there could be adverse cost impacts as the design is finalized prior to fabrication.

Prior to the FY 2008 funding reduction, all of these risks were evaluated to develop a TPC range for CD-1. It was determined that the bottom of the range should be set at $1.45 billion. The increase from the previous $1.122 billion preliminary TPC to this level accounts for those risks that were deemed to be highly likely to occur. The $1.45 billion estimate still includes a reasonable contingency amount (equal to 27 percent of the hardware cost). The other contributors to the increase from $1.122 billion were overall project schedule slippage, deterioration of the dollar versus the Euro, and commodity price growth. The difference between $1.45 billion and the top end of the TPC range, $2.2 billion, essentially represents additional contingency for known risks in the above categories as well as an amount for unidentified risks. Most of the TPC cost increase is related to potential actions of the international ITER Organization and external factors that could impact U.S. hardware costs. The impact of the funding reduction in the FY 2008 Energy and Water Development and Related Agencies Appropriations Act will be evaluated as part of developing the schedule and cost baselines for CD-2.

ITER Related Annual Funding Requirements

The current estimate in the table below incorporates the terms of the ITER Joint Implementing Agreement on cost sharing during operations, deactivation and decommissioning. Specifically, it considers the procedure for converting currencies into Euros and the 20-year period of annual contributions to the decommissioning fund in conjunction with ITER operations.

	(dollars in thousands)	
	Current Estimate	Previous Estimate
FY 2015–FY 2034[a]		
U.S. share of annual facility operating costs including commissioning, maintenance, repair, utilities, power, fuel, improvements, and annual contribution to decommissioning fund for the period 2015 to 2034. Estimate is in year 2015 dollars.	80,000	56,900
FY 2035–FY 2039		
U.S. share of the annual cost of deactivation of ITER facility for the period 2035–2039. Estimate is in year 2037 dollars.	25,000	18,200

[a] FY 2016 is the estimated date for start of operations based on the current international ITER schedule.

Enabling R&D

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Enabling R&D			
Engineering Research	16,075	15,991	17,924
Materials Research	4,679	5,800	4,791
Total, Enabling R&D	20,754[a]	21,791[a]	22,715

Description

The Enabling R&D subprogram develops, and continually improves, the hardware and systems that are incorporated into existing fusion research facilities, thereby enabling these facilities to achieve higher levels of performance within their inherent capability. In addition, the Enabling R&D subprogram supports the development of new hardware that is incorporated into the design of next generation facilities, thereby increasing confidence that the predicted performance of these new facilities will be achieved.

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

[a] Starting in FY 2009, ITER OPC is consolidated and requested in Facility Operations. Funding of $18,000,000 in FY 2007 and $10,626,000 in FY 2008 previously reflected in this subprogram is now reflected in the Facility Operations subprogram.

The Materials Research element focuses on the key science issues of materials for practical and environmentally attractive uses in fusion research and future facilities. This element uses both experimental and modeling activities, which makes it more effective at using and leveraging the substantial work on nanosystems and computational materials science being funded by the Basic Energy Sciences program and other government-sponsored programs, as well as making it more capable of contributing to broader 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 is accomplished through a Virtual Laboratory for Technology (VLT), with community-based coordination and communication of plans, progress, and results.

In FY 2009, research efforts will continue supporting the development of enabling technologies that enhance plasma performance on both our current and planned domestic machines as well as for our international collaborations with existing facilities such as JET and possibly with new facilities such as Korea's KSTAR and China's EAST. In addition, resources will be used to continue to develop a database for materials that can be used in future facilities, to address potential issues that may occur during ITER operation, and to develop the next generation of technology that could be tested in current facilities or in ITER.

FY 2007 Enabling R&D Accomplishments

- ***Modeling improves understanding of experimental data:*** Development of science-based fracture toughness assessment methods is vital to determining how materials will react given certain conditions and ensuring safe and reliable operation of structures in the harsh fusion environment. As part of the U.S.-Japan (DOE-Japan Atomic Energy Agency [JAEA]) fusion materials collaboration, multiscale modeling was performed to elucidate the micromechanical mechanisms underpinning the shape of the fracture toughness master curve, the relationships among yield stress increase, ductile to brittle transition temperature (DBTT) shift, and specimen size effects in fracture toughness assessments. For a large number of steels, test temperatures, and strain rates, the results show that yield dynamics and fracture dynamics are the same. Analysis of the different relationships between DBTT shift and yield stress increase for conventional reactor pressure vessel steels and reduced activation ferritic/martensitic steels for fusion illustrates the important role of irradiation on strain hardening.

- ***Complex Fluid Dynamics modeled:*** Simulation capabilities are critical to elucidate the complex, coupled, nuclear science phenomena expected in liquid metal systems and in experiments in the magneto-nuclear environment of fusion facilities. The first three dimensional, fully viscous and inertial, magnetohydrodynamic (MHD) simulations of liquid metal flows through a complex geometry flow distribution manifold have been performed this year at the University of California at Los Angeles. These simulations show the strong impact of MHD interactions between highly conductive liquid metal and plasma magnetic confinement. These first-of-a-kind simulations may lead to effective flow control and help ensure uniform flow distribution (and thus heat removal) in liquid metal cooled structures. They are being used to develop an understanding of the impact of the magnetic field strength, orientation, and spatial distribution with various geometric configurations and electrical coupling techniques.

- ***Improvements in Edge Localized Mode (ELM) Mitigation:*** ELM mitigation is essential to reduce large transient heat loads, which can damage the plasma facing surface of the containment vessel. If left unmitigated, plasma ELMs in ITER and follow-on devices could potentially deliver large transient heat loads to the material surfaces that contain the burning plasma. ELM mitigation techniques, for both current and future experiments, were investigated using high frequency small pellets to generate small, benign ELMs. An experiment to test this scheme was installed on the DIII-D tokamak and is being used to extrapolate the necessary pellet sizes and speeds required to mitigate potential ELMs. Modeling shows that the same technology developed for fueling can be employed to produce steady state ELM mitigation. The frequent injection of cold fuel pellets is a promising technique for reducing the severity of these transient heat loads and mitigating their effects.

Detailed Justification

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Engineering Research	**16,075**	**15,991**	**17,924**
▪ **Plasma Technology**	**13,531**	**13,391**	**13,351**

Plasma Technology efforts will focus resources on developing enabling technologies for current and future machines, both domestically and internationally, and on addressing potential ITER operational issues in the area of safety and plasma materials interactions. In addition, a new U.S.-Japan Collaborative Program (Tritium Irradiation Thermofluid American-Japanese Network [TITAN]) will be initiated on plasma facing and blanket materials for use in future experiments. During FY 2009, the following specific activities will be supported:

- Continue studies of tungsten-carbon-beryllium mixed materials layer formation and redeposition with attached hydrogen isotopes in the Plasma Interaction with Surface and Components Experimental Simulator facility at the University of California at San Diego, and the Tritium Plasma Experiment at the Idaho National Laboratory (INL). Results will be applied to evaluate tritium accumulation in plasma facing components that will occur during ITER operation.
- Initiate a new series of material science experiments under the TITAN cost-sharing collaboration with Japan in the Safety and Tritium Applied Research Facility at INL to resolve key issues of tritium behavior in materials proposed for use in fusion systems.

Besides the above activities, research will be conducted on plasma facing components, heating technologies, and blanket concepts that could be tested in ITER. In addition, this category funds research in safety and plasma-surface interaction and modeling that support addressing potential issues that could be encountered during operation of ITER or future devices.

▪ **Advanced Design**	**2,544**	**2,600**	**4,573**

This effort will continue to focus on system studies of devices that could lead the program toward a demonstration power plant. The studies will be done using a team of individuals drawn from all over the research community to assure highly innovative solutions to the many issues facing the program.

	FY 2007	FY 2008	FY 2009

(dollars in thousands)

In FY 2009, the Pathways study initiated in FY 2007 will be completed. The final effort of the project will be to gain a consensus on what the remaining major R&D areas are, which must be addressed before moving ahead to a demonstration reactor. A major assumption is that ITER will be successful in reaching its major goals and objectives. The Pathways study will identify the R&D areas that can be explored using existing devices and simulation facilities, and will provide cost/performance attributes of possible new major facilities that may be required. The design team will interact with leaders of the research community and DOE in defining possible projects for FY 2010 and beyond.

In addition, a series of studies will be initiated in FY 2009 within the research community to identify critical scientific issues and missions for the next stage in the U.S. fusion research program in the ITER era. Building off recent community and FESAC studies, this effort will concentrate on defining specific scientific issues to address and possible approaches to be taken to address them. The long-term objective is to identify potential initiatives and facilities that may be pursued at the pre-conceptual level.

Materials Research	**4,679**	**5,800**	**4,791**

Materials Research remains the key element in establishing the scientific foundations for safe and environmentally attractive uses of fusion as well as providing solutions for materials issues faced by other parts of the FES program. The FY 2009 request will maintain a highly beneficial Materials Research program that addresses material needs for nearer and longer term fusion devices. The funding will be used for both modeling and experimental activities aimed at the science of materials behavior in fusion environments, including research on candidate materials for the structural elements of fusion chambers. Two cost-shared international collaborations (DOE/JAEA and TITAN) focusing on irradiation testing of candidate fusion materials in U.S. facilities will continue.

Total, Enabling R&D	**20,754**	**21,791**	**22,715**

Explanation of Funding Changes

	FY 2009 vs. FY 2008 ($000)
Engineering Research	
▪ **Plasma Technology**	
The decrease will slightly reduce the level of effort in the blanket and plasmas materials interaction programs.	-40
▪ **Advanced Design**	
The increase will support a series of new studies to identify critical scientific issues and missions for the next stage in the U.S. fusion research program in the ITER era.	+1,973
Total, Engineering Research	+1,973

	FY 2009 vs. FY 2008 ($000)
Materials Research	
The decrease will reduce the level of effort in the experimental activities reflecting a redirection of resources to higher priorities.	-1,009
Total Funding Change, Enabling R&D	**+924**

Capital Operating Expenses and Construction Summary

Capital Operating Expenses

(dollars in thousands)

	FY 2007	FY 2008	FY 2009
General Plant Projects	3,860	1,587	1,968
Capital Equipment	64,857	20,099	231,013
Total, Capital Operating Expenses	68,717	21,686	232,981

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

(dollars in thousands)

	Total Estimated Cost (TEC)	Other Project Costs (OPC)	Total Project Cost (TPC)	Prior Year Appro-priations	FY 2007	FY 2008	FY 2009	Completion Date
NCSX, PPPL	142,430[a]	9,570	152,000[a]	58,337	15,822	15,900	19,560	FY 2012[a]
U.S. Contributions to ITER, Cadarache, France	TBD	TBD	1,450,000–2,200,000[b]	15,866	42,000	—	208,500[b]	FY 2014–FY 2017[b]
Total, Major Items of Equipment					57,822	15,900	228,060	

[a] The NCSX TEC, TPC, and FY 2009 funding level and completion date reflect the estimated rebaseline.

[b] Funding is for the fourth year of the project, U.S. Contributions to ITER. The TPC and completion schedule ranges were approved at CD-1 in December 2007. The TPC and completion schedule performance baselines will be established at CD-2, planned for FY 2009-2010.