United States Government Accountability Office

GAO

Report to Congressional Committees

October 2007

FUSION ENERGY

Definitive Cost Estimates for U.S. Contributions to an International Experimental Reactor and Better Coordinated DOE Research Are Needed

GAO

Accountability * Integrity * Reliability

GAO-08-30

October 2007

GAO
Accountability • Integrity • Reliability

Highlights

Highlights of GAO-08-30, a report to congressional committees

FUSION ENERGY

Definitive Cost Estimates for U.S. Contributions to an International Experimental Reactor and Better Coordinated DOE Research Are Needed

Why GAO Did This Study

The United States is pursuing two paths to fusion energy—magnetic and inertial. On November 21, 2006, the United States signed an agreement with five countries and the European Union to build and operate the International Thermonuclear Experimental Reactor (ITER) in Cadarache, France, to demonstrate the feasibility of magnetic fusion energy. The United States also built and operates facilities to pursue inertial fusion energy research. This report discusses (1) U.S. contributions to ITER and the challenges, if any, in managing this international fusion program and (2) the Department of Energy's (DOE) management of alternative fusion research activities, including National Nuclear Security Administration (NNSA) initiatives. In performing this work, GAO analyzed budget documents, briefings, and reports that focused on research and funding priorities for the fusion program. GAO also met with officials from DOE, NNSA, and the ITER Organization in France.

What GAO Recommends

GAO recommends, among other things, that (1) DOE and NNSA develop a research plan to coordinate fusion research activities to advance inertial fusion and (2) DOE develop a strategy to hire, train, and retain staff with the specialized skills needed to accomplish its mission. DOE neither agreed nor disagreed with our recommendations, but questioned several of our findings.

To view the full product, including the scope and methodology, click on GAO-08-30. For more information, contact Gene Aloise at (202) 512-3841 or aloisee@gao.gov.

What GAO Found

Over 9 years, DOE estimates it will spend $1.12 billion to help build ITER, but this is only a preliminary estimate and may not fully reflect the costs of U.S. participation. This preliminary estimate has not been independently validated, as DOE guidance directs, because the reactor design is not complete. Moreover, the $1.12 billion for ITER construction does not include an additional $1.2 billion the United States is expected to contribute to operate and decommission the facility. In addition, the ITER Organization, which manages the construction and operation of ITER, faces a number of management challenges to build ITER on time and on budget that also may affect U.S. costs. For example, the ITER Organization must develop quality assurance standards, test the reliability and integrity of components built in different countries, and assemble them with a high level of precision. Many of these challenges stem from the difficulty of coordinating international efforts and the need for consensus before making critical management decisions.

GAO has identified several challenges DOE faces in managing alternative fusion research activities. First, NNSA and the Office of Fusion Energy Sciences (OFES), which manage the inertial fusion program within DOE, have not effectively coordinated their research activities to develop inertial fusion as an energy source. For example, they do not have a coordinated research plan that identifies key scientific and technological issues that must be addressed to advance inertial fusion energy and how their research activities would meet those goals. Second, DOE may find it difficult to manage competing funding priorities to advance both ITER-related research and alternative magnetic fusion approaches. DOE officials told GAO they are focusing limited resources on ITER-related research activities. As a result, as funding for ITER-related research has increased, the share of funding for the most innovative alternative magnetic fusion research activities decreased from 19 percent of the fusion research budget in fiscal year 2002 to 13 percent in fiscal year 2007. According to DOE officials, this level of funding is sufficient to meet research objectives. However, university scientists involved in fusion research told us that this decrease in funding has led to a decline in research opportunities for innovative concepts, which could lead to a simpler, less costly, or faster path to fusion energy, and reduced opportunities to attract students to the fusion sciences and train them to fulfill future workforce needs. Finally, while the demand for scientists and engineers to run experiments at ITER and inertial fusion facilities is growing, OFES does not have a human capital strategy to address expected future workforce shortages. These shortages are likely to grow as a large part of the fusion workforce retires over the next 10 years.

Contents

Abbreviations

DOE	Department of Energy
HAPL	High Average Power Laser
IFMIF	International Fusion Materials Irradiation Facility
ITER	International Thermonuclear Experimental Reactor
NIF	National Ignition Facility
NNSA	National Nuclear Security Administration
OFES	Office of Fusion Energy Sciences

United States Government Accountability Office
Washington, DC 20548

October 26, 2007

The Honorable Byron Dorgan
Chairman
The Honorable Pete Domenici
Ranking Member
Subcommittee on Energy and Water Development
Committee on Appropriations
United States Senate

The Honorable Peter Visclosky
Chairman
The Honorable David Hobson
Ranking Member
Subcommittee on Energy and Water Development
Committee on Appropriations
House of Representatives

On November 21, 2006, the United States signed an agreement with five countries[1] and the European Union to help build and operate the International Thermonuclear Experimental Reactor (ITER) in Cadarache, France, to demonstrate the feasibility of fusion energy. The construction, operation, and decommissioning of ITER is expected to cost about $14 billion. Fusion occurs when the nuclei of two light atoms—typically hydrogen isotopes—collide and fuse together when heated at high temperatures and placed under tremendous pressure. This reaction releases a large amount of energy that some day, it is hoped, may be captured to produce electricity. Over the last 50 years, scientists around the world have made progress in understanding how to create the conditions for fusion, but there are many outstanding scientific and technical issues that must still be resolved before fusion can be used as an energy source. As a result, the United States, along with the six parties to the agreement, identified ITER as the critical experiment that could finally produce more power from fusion reactions than is needed to operate the device—the first step toward producing electricity from fusion energy. ITER's objectives are to resolve fundamental physics issues in using fusion

[1]These countries include the People's Republic of China, Japan, India, the Republic of South Korea, and the Russian Federation.

as an energy source and to develop and test the technology needed for a future fusion power plant. Construction of ITER is scheduled to begin in 2008 and be completed in 2016, followed by 20 years of experiments and eventual decommissioning. The ITER Organization was established to manage the construction, operation, and decommissioning of this facility. If ITER meets its objectives, as the last critical step toward fusion energy, the United States and other countries will need to design and test different fusion power plants to capture the energy and produce electricity.

The Department of Energy (DOE) identified ITER as the number one priority for new research facilities because fusion power holds the promise of reducing concerns over imported oil, rising gasoline prices, and global warming. With decreasing fossil fuel resources and increasing awareness that the use of fossil fuels is harming the environment, fusion is a potentially new source of energy for meeting future energy needs. Fusion offers many potential benefits, including no emissions of greenhouse gases, an abundant source of fuel, no risk of the type of severe accidents that could occur with existing nuclear power plants, no severe consequences of a terrorist attack, and no long-lived radioactive waste. In addition, U.S. participation in ITER allows the United States to share the cost of building this complex and expensive fusion device while leveraging the scientific and technological expertise of the other ITER parties.

The United States is pursuing two paths to fusion energy—magnetic and inertial. Magnetic fusion relies on magnetic forces to confine electrically charged atoms, known as plasma, and sustain a fusion reaction. ITER will be a magnetic fusion device known as a "tokamak."[2] While a tokamak has been the most successful magnetic fusion device, there is still uncertainty that it will produce fusion energy or lead to a commercially viable fusion energy device. To reduce the risk of investing in only one device, DOE's Office of Fusion Energy Sciences (OFES), which is responsible for managing the U.S. fusion energy program, also funds scientific research on alternative types of magnetic devices, primarily at U.S. universities. Universities, such as Princeton University and the University of Washington, are currently testing 10 other magnetic devices with different shapes and magnetic currents that may lead to a simpler, less costly, or faster path to fusion energy.

[2]The term "tokamak" comes from a Russian acronym for a fusion device that was developed in the former Soviet Union during the 1950s and 1960s.

In contrast, inertial fusion relies on powerful lasers to repeatedly strike small pellets of fuel, yielding bursts of energy. The National Nuclear Security Administration (NNSA), a separately organized agency within DOE, is leading efforts in inertial fusion because it can be used for defense needs, such as validating the integrity and reliability of the U.S. nuclear weapons stockpile. NNSA is building a facility—the National Ignition Facility (NIF)—at the Lawrence Livermore National Laboratory that is hoped could be used to demonstrate the feasibility of inertial fusion. Since the science applications of inertial fusion for defense and energy needs are similar, the results of NIF experiments could validate inertial fusion as an alternative path to fusion energy. Other facilities, such as the Naval Research Laboratory, are testing technologies needed to produce energy from inertial fusion.

In the conference report accompanying the fiscal year 2006 energy and water development appropriation,[3] the conferees directed GAO to review OFES's fusion energy program, the activities of major U.S. fusion energy research facilities that are contributing to ITER, and NNSA fusion energy initiatives. As agreed with the committees of jurisdiction, we (1) identified U.S. contributions to ITER and the challenges, if any, in managing this international fusion program and (2) assessed DOE's management of alternative fusion research activities, including NNSA initiatives.

To address these objectives, we collected and analyzed documentation from DOE, NNSA, the ITER Organization, the National Academy of Sciences, DOE's national laboratories, and universities involved in fusion science. To identify U.S. contributions to ITER and the challenges of managing this international project, we analyzed budget documents, including OFES's 5-year budget plan, and interviewed officials from OFES, the Department of State, and the U.S. ITER Project Office at the Oak Ridge National Laboratory in Oak Ridge, Tennessee. We also analyzed documents and met with officials from the three major U.S. magnetic fusion research facilities—located at General Atomics in San Diego, California; the Massachusetts Institute of Technology in Cambridge, Massachusetts; and the Princeton Plasma Physics Lab in Princeton, New Jersey—and received a tour of these facilities to understand how fusion devices are built and operated. Furthermore, we met with officials from the ITER Organization in Cadarache, France, and toured the ITER construction site. To assess DOE's management of alternative fusion

[3]H.R. Rep. No. 109-275, p. 155 (Nov. 7, 2005).

research activities, we interviewed scientists from universities conducting research in alternative paths to fusion funded by OFES and officials from the National Academy of Sciences, and we analyzed reports from DOE's fusion energy advisory committee that focused on funding and research priorities for the fusion program. Lastly, to determine the status of inertial fusion and NNSA fusion initiatives, we analyzed budget documents, briefings, and reports on inertial fusion and met with officials from NNSA's Office of Defense Programs; NIF at the Lawrence Livermore National Laboratory in Livermore, California; the Laboratory for Laser Energetics at the University of Rochester in Rochester, New York; Sandia National Laboratory in Albuquerque, New Mexico; and the Naval Research Laboratory in Washington, D.C. We conducted our work from December 2006 to September 2007 in accordance with generally accepted government auditing standards.

Results in Brief

DOE plans to spend $1.12 billion over 9 years to help build ITER, but this is only a preliminary estimate and may not reflect the full costs of U.S. participation. The management challenges that the ITER Organization faces to build ITER on time and on budget may also affect U.S. costs. With respect to the U.S. contribution to build ITER, the largest portion, or about 44 percent, will be used to purchase U.S.-manufactured components and parts for ITER; the remaining portion will be used to provide cash to the ITER Organization for equipment installation and associated contingencies, to pay for U.S. scientists and engineers sent to the ITER Organization, and to support ITER-related research and development at national laboratories. However, DOE has not been able to assess the full costs to the United States of building ITER because the ITER Organization has not completed the project design for the reactor. According to DOE's project management guidance, DOE cannot develop and validate a definitive cost and schedule estimate for a project until the design is complete. Moreover, the $1.12 billion for ITER construction does not include an additional $1.2 billion the United States is expected to contribute to operate and decommission the facility. With respect to management challenges, the ITER Organization faces five key management challenges that may affect U.S. costs. Many of these challenges stem from the difficulty of coordinating international efforts: six countries and the European Union are designing and building components for ITER and, as members of the ITER Organization, must reach consensus before making critical management decisions. The key challenges include (1) developing quality assurance standards to test the reliability and integrity of the components made in different countries; (2) assembling, with a high level of precision, components and parts built in different countries; (3) finding a new vendor if a country fails to build a component on time or does not meet quality assurance standards; (4) developing a contingency fund that adequately addresses cost overruns and schedule delays; and (5) developing procedures that describe which countries will be responsible for paying for cost overruns.

GAO has identified several challenges DOE faces in managing alternative fusion research activities, including coordinating inertial fusion research activities within DOE, setting funding priorities to advance both ITER- and tokamak-related research and different magnetic fusion energy approaches, and planning for hiring and retaining fusion scientists:

- *Coordination*. Within DOE, NNSA and OFES do not effectively coordinate research activities to leverage scientific and technological advances for developing inertial fusion energy. NNSA provides OFES with limited access to one of its inertial fusion facilities to conduct inertial fusion experiments, and NNSA- and OFES-funded scientists share scientific information. However, NNSA and OFES do not have a coordinated research plan that identifies key scientific and technological questions or the cost, time frames, and detailed research and development tasks needed by each agency to solve those scientific and technological issues to further advance inertial fusion energy. In addition, DOE has not given NNSA and OFES clear roles in the development of inertial fusion energy. NNSA's program is focused on defense needs while OFES is exploring broad scientific issues indirectly related to inertial fusion energy. Without a coordinated research plan, progress in advancing inertial fusion may be delayed.

- *Funding priorities*. Alternative magnetic fusion research competes for funding with ITER- and tokamak-related research. Since the U.S. commitment to ITER, DOE has focused more of its resources on ITER- and tokamak-related research. As a result, funding for alternative, potentially more innovative, magnetic fusion research activities has declined—from $26 million in fiscal year 2002 to $20 million in fiscal year 2007. Moreover, as funding for tokamak-related research has increased, the share of funding for these innovative research activities decreased from 19 percent of the fusion research budget in fiscal year 2002 to 13 percent in fiscal year 2007. University scientists involved in fusion research told us that this decline in funding has led to a decline in research opportunities for innovative concepts, and these concepts could lead to a simpler, less costly, or faster path to fusion energy. In addition, the decline in funding also has reduced opportunities to attract students to the fusion sciences and train them to fulfill future workforce needs. DOE officials responded that they determine the appropriate level of funding based on research priorities identified by DOE's fusion energy advisory committee[4] and the current level of funding is sufficient to sustain the best-performing innovative magnetic devices. However, the last independent assessment of the balance of funding between tokamak-related research and alternative innovative concepts was in 1999 before the United States joined ITER and it became a priority.

- *Human capital.* DOE has not developed a human capital strategy to address future workforce challenges. About one-third of the U.S. fusion energy workforce is retiring in the next 10 years and only a small percentage of doctoral candidates in physics are entering the fusion research field to meet future workforce needs. Without a strategy in place, DOE may face a shortage of scientists with critical skills and expertise at a time when demand for their skills will grow.

To advance U.S. efforts to develop alternative fusion energy sources and to address OFES's human capital challenges, we recommend, among other things, that the Secretary of Energy direct OFES to (1) charge DOE's fusion energy advisory committee with independently assessing whether current funding levels between ITER- and tokamak-related research and innovative magnetic fusion research strike the right balance to meet research objectives and advance both areas of research, and (2) develop a strategy to hire, train, and retain personnel with specialized skills to meet future workforce needs. We also are recommending that the Secretary of Energy direct DOE and NNSA to develop a research plan to coordinate U.S. inertial fusion research activities and identify roles and responsibilities for each program, detailed research and development tasks, budget needs, and time frames for advancing inertial fusion energy.

We provided DOE with a draft copy of this report for its review and comment. In its written comments, DOE neither agreed nor disagreed with our recommendations, but questioned several of our findings, including whether the number of PhDs will be sufficient to meet future workforce needs, the declining share of funding available for innovative magnetic fusion research activities, and the lack of a coordinated research plan. We believe that our analyses and facts as reported are correct. Specifically,

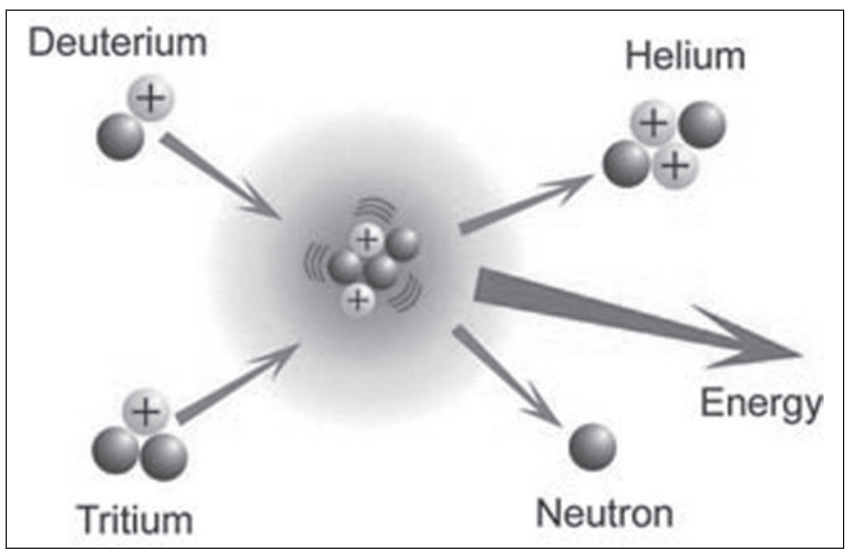
[4]The Fusion Energy Sciences Advisory Committee is chartered pursuant to the Federal Advisory Committee Act, Pub. L. No. 92-463, 86 Stat. 770 (1972). The committee provides independent advice on issues related to planning, implementing, and managing the fusion energy program. DOE relies on this advice to establish scientific and technological as well as funding priorities. Committee members are drawn from universities, national laboratories, and private firms involved in fusion research.

data from DOE's fusion energy advisory committee show that not enough doctoral candidates in plasma physics and fusion science are entering the fusion research field to meet future workforce needs and funding for innovative magnetic fusion research activities has declined in the last 6 fiscal years. In addition, DOE still does not have a coordinated research plan to help advance inertial fusion energy research. DOE also provided technical comments, which we incorporated, as appropriate.

Background

Fusion is the energy source that powers the sun and stars and is a major source of energy for the hydrogen bomb. For more than 50 years, the United States has been trying to control this energy source to produce electricity. Fusion occurs when the nuclei of two light atoms collide and fuse together with sufficient energy to overcome their natural repulsive forces. Scientists are currently using deuterium and tritium—hydrogen isotopes—for this reaction. When the nuclei of the two atoms collide, the collision produces helium and a large quantity of energy (see fig. 1).

Figure 1: The Fusion Reaction



Source: ITER Organization.

For the fusion reaction to take place, the atoms must be heated to very high temperatures—about 100 million degrees centigrade, or 10 times the temperature of the surface of the sun—and placed under tremendous pressure. In a hydrogen bomb, high temperatures are obtained by exploding a uranium or plutonium fission bomb to force the deuterium and tritium together in a violent manner. To achieve controlled fusion, the United States is pursuing two paths—magnetic and inertial. Magnetic fusion involves heating deuterium and tritium to about 100 million degrees centigrade by using an external source of electromagnetic energy. The deuterium and tritium nuclei fuse together to make helium in a very hot and highly charged gas-like condition called a plasma. Strong magnetic fields are then used to confine the plasma. Current magnetic devices have not been able to sustain this fusion reaction for more than a few seconds. For magnetic fusion to produce electricity, a device would need to sustain the reaction for long periods of time. In contrast, inertial fusion relies on intense lasers or particle beams to heat and compress a small, frozen pellet of deuterium and tritium—a few millimeters in size—that would yield a burst of energy. The lasers or particle beams would continuously heat and compress the pellets, which would simulate, on a very small scale, the actions of a hydrogen bomb. The goal for both approaches is to generate more energy than is needed to begin and sustain the reaction.

ITER is an experiment to study fusion reactions in conditions similar to those expected in a future electricity-generating power plant. The goal is to be the first fusion device in the world to produce net power—that is, produce more power than it consumes. The objective is to produce 10 times more power than is needed to operate the device. In contrast, current nuclear power plants produce between 30 and 40 times more power than is needed to operate the plants. ITER also will test a number of key technologies, including the heating, control, and remote maintenance systems that will be needed for a fusion power station. If ITER is successful, it will lead to power plant design and testing.

According to DOE, ITER was first proposed at the U.S.-U.S.S.R. Geneva summit in November 1985, when President Reagan and Soviet Premier Gorbachev recognized that joint activities were needed to diffuse the tension of the arms race during the Cold War and begin the Soviet Union's economic integration into the world economy. The goal was to share scientific and technical information in a program in which both sides had reached a comparable level of knowledge and that offered future commercial gains from developing fusion technology. Following this summit, the United States, the Soviet Union, Japan, and several European countries drafted a proposal to implement ITER.

The United States temporarily withdrew from ITER in 1999 when Congress raised concerns that the technical basis for ITER was not sound, the cost was too high, and the facility was too large. In response to the U.S.

withdrawal, the countries participating in ITER reduced the size of the facility and the cost of building ITER to about $5 billion, or one-half the cost of the original design. A number of scientific advances also increased U.S. confidence that the new ITER design would meet its scientific and technological goals. In January 2003, President Bush announced that the United States would rejoin ITER. This decision was based on a number of studies—from DOE's advisory committee on fusion energy, the National Academy of Sciences, and other groups of experts—that concluded the U.S. fusion program was technically and scientifically ready to participate in ITER and recommended that the United States rejoin it. In 2003, the People's Republic of China and the Republic of Korea also joined; and in December 2005, India became the seventh and most recent party to join. In November 2006, all six countries and the European Union signed the ITER agreement. Figure 2 shows the countries participating in ITER.

Figure 2: Countries Participating in ITER

Source: GAO based on information from the ITER Organization.

NNSA maintains the United States' inertial fusion facilities. NIF, which is scheduled for completion in 2009, will be the world's largest laser facility and will be used to test inertial fusion. It is designed to achieve the first controlled thermonuclear burn, which will release fusion energy.[5] To achieve the temperature and pressure needed for heating and compressing the fuel to release this fusion energy, NIF has 192 laser beams that will

[5]NIF is 705,000 square feet, the size of three football fields side by side, and houses a complex optical system that produces the laser beams. NIF construction began in May 1997 and it has a total project cost of $2.3 billion. An additional $1.3 billion are needed to assemble, install, and test the laser system.

converge and strike frozen deuterium and tritium pellets. No other facility has been able to achieve a controlled thermonuclear burn because it did not have enough energy to heat and compress these targets. For example, NIF is expected to produce 50 times more energy than the OMEGA laser—the world's most powerful laser facility currently operating. The OMEGA laser, at the University of Rochester, is NNSA's main inertial fusion facility until NIF is completed. Lastly, the Z-machine, located at Sandia National Laboratory, is an alternative approach to reaching conditions of extreme temperature and pressure to validate sophisticated computational models of nuclear weapon performance. Rather than using powerful lasers, the Z-machine uses an electrical current to create a powerful magnetic field that compresses and implodes the target. The Z-machine releases the equivalent of 80 times the world's electrical power output for a few billionths of a second, but only a moderate amount of energy is actually used because it relies on generators and amplifiers to store and magnify the energy from the electrical grid. NNSA spent about $60 million to refurbish this machine from July 2006 to May 2007 to increase the power output.

The United States Will Contribute $1.12 Billion Over 9 Years to Help Build ITER, but Management Challenges May Affect Timing and Cost of Construction

DOE plans to spend $1.12 billion over 9 years to help build ITER, but this estimate neither reflects an independently validated cost based on a completed reactor design, nor the costs to operate and decommission the facility. The ITER Organization also faces five key management challenges to build ITER on time and on budget that may affect U.S. costs.

DOE Does Not Yet Have a Definitive and Independently Validated Cost Estimate for the U.S. Contribution to ITER, as DOE Guidance Directs

Based on DOE's fiscal year 2008 congressional budget request, DOE plans to spend $1.12 billion over 9 years—from fiscal years 2006 to 2014—to help build ITER, as figure 3 shows. Of the seven parties contributing to ITER, the United States and five other countries—the People's Republic of China, Japan, India, the Republic of South Korea, and the Russian Federation—are each providing 9.1 percent of the total construction cost. The European Union is the largest contributor—45.4 percent—because it is building the reactor on a member country's soil and it agreed to pay for the infrastructure costs. DOE's preliminary estimate of the U.S. contribution includes the following:

- $487.14 million to purchase U.S.-manufactured components and parts for ITER, such as superconducting cable for the magnets that sustain the fusion reaction and tiles for the inner wall of the reactor that can withstand the heat and pressure of the fusion reaction;

- $203.24 million in cash to the ITER Organization to pay for scientists, engineers, and support personnel working for the ITER Organization; the assembly and installation of the components in France to build the reactor; quality assurance testing of U.S. supplied components; and contingencies;

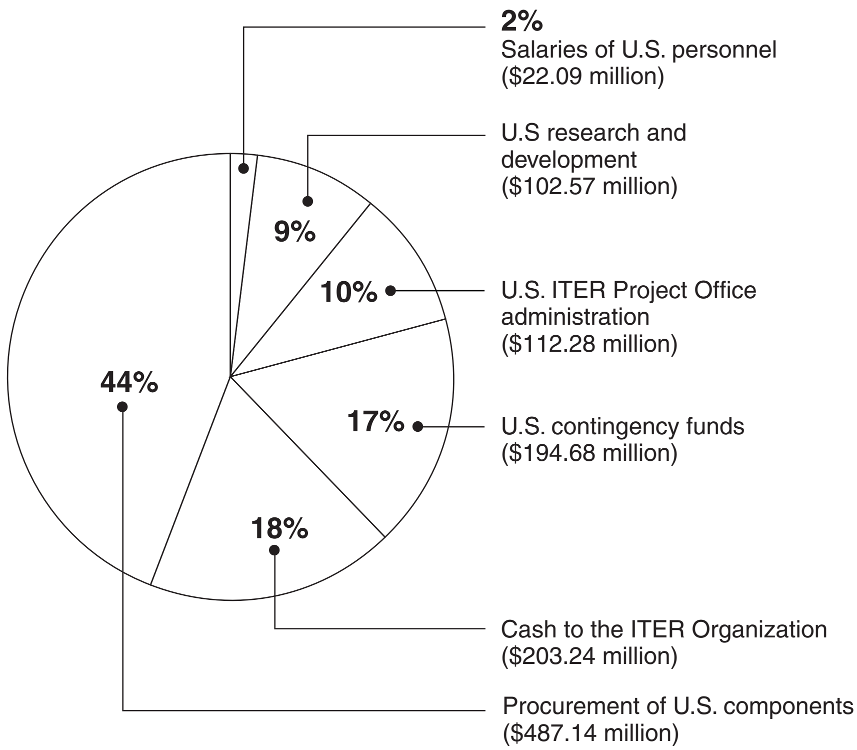
- $194.68 million in contingency funds to address potential schedule delays or increases in costs for manufacturing components;

- $112.28 million for the U.S. ITER Project Office at Oak Ridge National Laboratory to manage the procurement, testing, assembly, and quality assurance of U.S.-manufactured components;

- $102.57 million to fund research and development activities and complete the design work of U.S. components and parts at national laboratories, universities, and private industry; and

- $22.09 million to pay the salaries of U.S. scientists and engineers working at the ITER Organization.

Figure 3: U.S. Contributions to ITER for Construction



Source: GAO analysis of DOE budget data.

The $1.12 billion is still a preliminary cost estimate and may not reflect the full costs of U.S. contributions to ITER. DOE has not yet developed a definitive cost and schedule estimate, as DOE project management guidance directs. This guidance establishes protocols for planning and executing large construction projects and directs DOE to reach a number of critical decisions before construction begins.[6] Two of these critical decisions are (1) formally approving the project's definitive cost and schedule estimates as accurate and complete and (2) reaching agreement that the project's final design is sufficiently complete so that resources can be committed toward procurement and construction. The cost and schedule estimates also are subject to independent reviews, usually by DOE's Office of Engineering and Construction Management, to ensure

[6]DOE Order 413.3A, Program and Project Management for the Acquisition of Capital Assets, July 28, 2006.

they are accurate and complete. Even though DOE does not have a definitive cost estimate, in fiscal years 2006 and 2007, DOE spent $79.3 million to establish the ITER Project Office and fund research and development activities to design U.S. components. Without a definitive cost estimate, the U.S. Congress has expressed concern that DOE may use funding from the domestic fusion research program to cover any shortfalls in funding for the ITER project.

DOE has not yet reached these critical decisions because of delays by the countries participating in ITER in selecting a construction site for the reactor and in completing the reactor design. In December 2004, DOE reported to Congress that DOE would have a definitive cost and schedule estimate by March 2006. DOE's new goal is to have this estimate by the end of fiscal year 2008 or early fiscal year 2009. DOE officials told us that DOE cannot complete this estimate until the ITER Organization updates the design for the reactor, scheduled for November 2007. DOE must then wait for the ITER Organization to develop the design specifications, quality assurance procedures and tests, and schedule of delivery for the components and parts of the reactor before it can begin manufacturing. The ITER Organization will issue the design specifications from the end of 2007 through 2012, starting with basic infrastructure and components that require a longer time to build. In fiscal year 2008, DOE plans to begin procuring materials needed for the superconducting magnets, the tiles for the inside of the reactor, and pipes for the water cooling system. Even though DOE will not yet have an independently validated cost and schedule estimate before it begins to purchase these materials, DOE project management guidance provides an exception when materials take a long time to manufacture and may delay the construction schedule.

The United States Will Incur Additional Costs Because ITER Is Only the First Step Toward Developing a Fusion Energy Power Plant

The $1.12 billion preliminary estimate does not cover the full costs of the ITER project. DOE estimates that it will cost the U.S. another $1.2 billion to help operate and run experiments on ITER for 20 years after construction is completed and then decommission the facility by removing radioactive materials and debris. Furthermore, ITER is only the first step in developing a fusion power plant, and DOE expects to build or help build additional facilities on the path to fusion energy.

Following ITER's construction, DOE may participate in designing and contributing funds to build another fusion facility, known as the International Fusion Materials Irradiation Facility (IFMIF). This facility would be designed to develop and test radiation-resistant materials that could survive the extreme conditions inside a fusion reactor. Fusion reactions continuously produce neutrons, which cause materials to become radioactive and damage them over time. The IFMIF would produce neutrons, and one goal of this facility would be to place materials inside the test chamber to determine which would best be suited for a future fusion reactor. If DOE participates in IFMIF, DOE's fusion energy advisory committee estimated that the U.S. contribution to IFMIF would be about $150 million over 7 years.

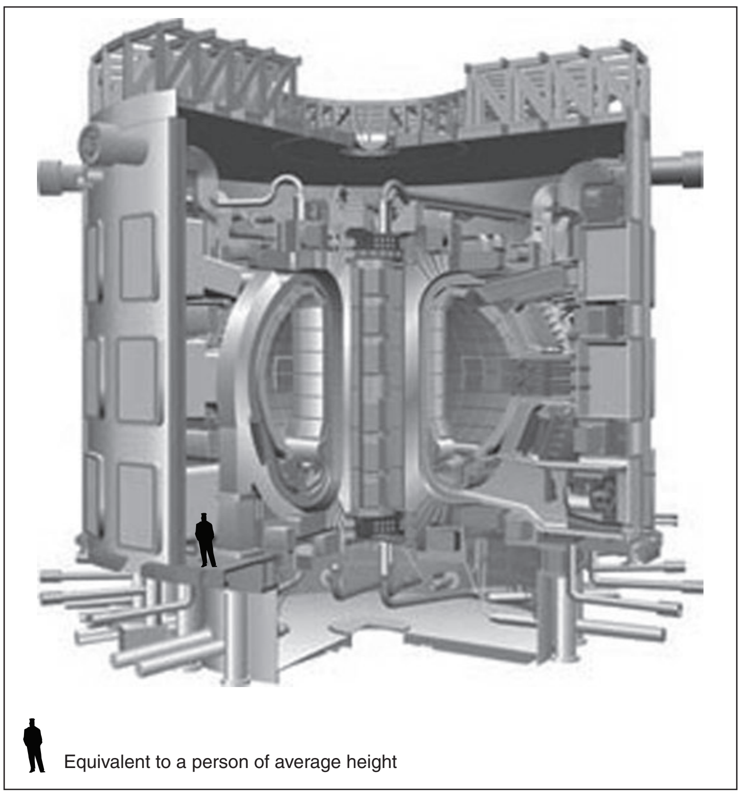
Another facility also may be needed to test technologies that would convert fusion power into practical energy, such as electricity. Neutrons from a fusion reaction will release energy if they collide with atoms of another material, causing the substance to heat. A prime candidate for this material for future fusion power plants is the liquid metal lithium. Lithium that is heated by colliding neutrons could transfer the heat to water, producing steam. The steam, in turn, would drive a steam turbine and generator, producing electricity. The purpose of a new facility would be to test different materials and systems for collecting neutrons, converting fusion energy into heat, and producing tritium—one of the fuels for fusion reactions. DOE's fusion energy advisory committee estimates that the construction of this facility would cost around $1.5 billion. After testing materials and technologies and assessing the scientific results of ITER and other magnetic fusion devices, DOE would then be ready to design a demonstration power plant that would produce electricity.

The ITER Organization Faces Management Challenges that May Limit Its Ability to Build ITER on Time and on Budget

The ITER Organization faces several management challenges that may limit its ability to build ITER on time and on budget and may affect U.S. costs. Many of these challenges stem from the difficulty of coordinating the efforts of six countries and the European Union that are designing and building components for ITER and, as members of the ITER Organization, must reach consensus before making critical management decisions. The key management challenges include (1) developing quality assurance standards to test the reliability and integrity of the components made in different countries; (2) assembling, with a high level of precision, components and parts built in different countries; (3) finding a new vendor if a country fails to build a component on time or does not meet quality assurance standards; (4) developing a contingency fund that adequately addresses cost overruns and schedule delays; and (5) developing procedures that describe which countries will be responsible for paying for cost overruns.

First, the ITER Organization has not yet developed quality assurance standards for manufactured parts and components. Quality assurance standards establish the tests each manufacturing company must pass before the ITER Organization can certify that a part or an entire component meets performance requirements, such as being able to withstand tremendous pressure and heat inside the reactor. According to DOE officials, quality assurance testing is critical because a failure of a poorly manufactured component or part during scientific experiments could shut down the reactor for a significant time, increase costs because of required repairs, or skew scientific results. The countries participating in ITER cannot begin manufacturing components until these quality assurance standards are in place. Figure 4 demonstrates the scale and complexity of the ITER reactor.

Figure 4: Section View of the Proposed Design for the ITER Reactor



Sources: ITER Organization and Art Explosion (clip art).

Second, the ITER Organization faces the challenge of assembling more than 10,000 parts and components manufactured by different countries. For example, the ITER Organization is responsible for installing the tiles that line the inside of the reactor, but the tiles are being manufactured by all seven parties. These tiles must be manufactured and installed with great precision. According to ITER Organization officials, a millimeter difference between the tiles could significantly affect scientific results. However, countries participating in ITER construction follow two different building codes.[7] ITER Organization officials told us they have not yet selected which building code countries must follow. There is a risk that countries unfamiliar with the required building code could take longer to manufacture a part under those standards or manufacture a part that will not fit properly with other manufactured parts for the same component.

Third, the ITER Organization assumes the responsibility of finding a suitable vendor in another country if a country fails to build a component on time or does not meet quality assurance standards. According to ITER Organization officials, the ITER Organization would have to negotiate the terms of manufacturing an item under an expedited schedule, and the country that failed to build the part on time would have to provide the ITER Organization with the funds needed to manufacture the item. Another vendor may not be able to produce the part in an expedited manner and the construction schedule may slip. In addition, there is no clear guidance on how to properly compensate a vendor in another country for all manufacturing costs, such as start-up costs, materials, and labor. Any disagreement between the new vendor, the country paying for the manufactured part, and the ITER Organization on proper compensation also could delay construction and increase the total project cost.

Fourth, the ITER Organization's contingency fund does not adequately address potential cost overruns and schedule delays. The ITER Organization's contingency fund is about 10 percent of the total cost, or about $712 million based on current estimates. If there are cost overruns, the ITER Organization has a contingency fund to pay for additional costs associated with procuring manufactured components that it is responsible for purchasing, installation of parts, research and development activities

[7]The two building codes are Règles de Conception et Construction – Mécanique Rapide and the codes from the American Society of Mechanical Engineers.

related to designing components, and hiring more staff. According to DOE officials, the ITER Organization did not determine this amount through a risk-based assessment. Rather, the contingency fund was created after India joined in 2005 as the most recent party to ITER. Since the project cost was already fixed, the countries participating in ITER decided to use the additional funds from India's assessment to create a contingency fund. According to DOE officials, some of the countries participating in ITER did not want to create a contingency fund because it was not standard practice in their project management. Moreover, according to DOE officials, a 10 percent contingency may not be adequate for a project of this cost and complexity. In contrast, these officials cited the Spallation Neutron Source at Oak Ridge National Laboratory, which produces short but intense pulses of neutrons that can be used to develop new materials, such as plastics. DOE completed the construction of this facility in 2006. The facility had a total project cost of $1.4 billion and required the coordination of six DOE national laboratories. Based on total cost and complexity, DOE had a contingency fund of about 20 percent of total costs. According to DOE officials, ITER is more technologically complex and involves greater risk because of the large number of manufacturers from different countries.

Finally, the ITER Organization does not have procedures that identify who is responsible for paying for potential cost overruns that exceed available contingency funds and how costs should be shared. Construction could be further delayed if there is no consensus before construction begins on how to share the costs for cost overruns.

Lack of Coordination, Competing Funding Priorities, and Human Capital Challenges May Hamper Progress in Alternative Fusion Research

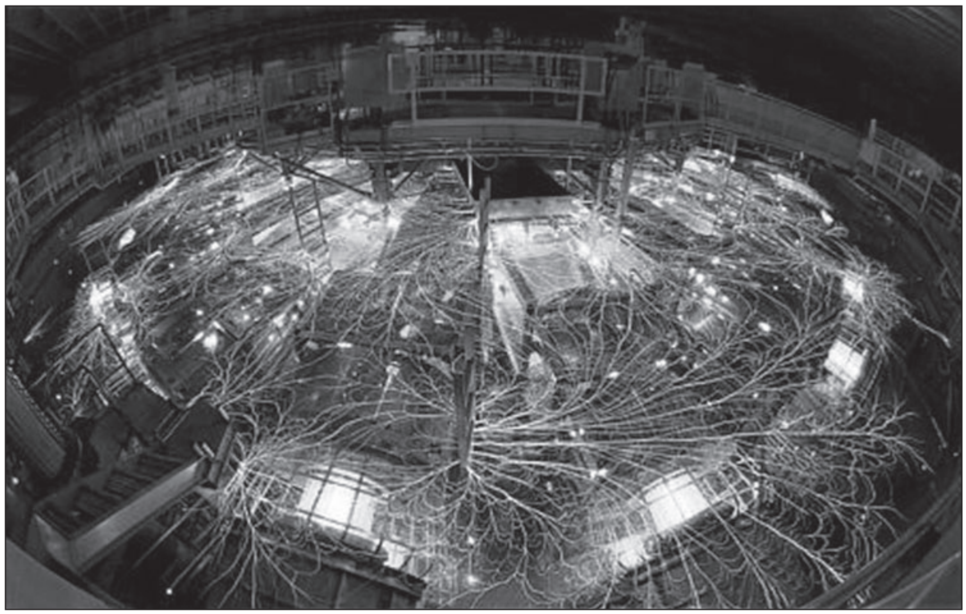
Within DOE, NNSA and OFES do not have a coordinated research program for inertial fusion energy. They do not have a research plan that identifies key scientific and technological issues that must be addressed to advance inertial fusion energy and how their research activities would meet those goals. Without a coordination research plan and clear responsibility for developing inertial fusion energy, DOE may not see progress in developing inertial fusion energy as a promising alternative to magnetic fusion. In addition, alternative magnetic fusion research competes for funding with ITER- and tokamak-related research. Since the U.S. commitment to ITER, funding for alternative innovative magnetic devices has declined over the last 6 fiscal years while funding for tokamak-related research has increased. According to university scientists involved in fusion research, this decrease in funding has led to a decline in research opportunities for innovative devices. Finally, while the demand for scientists and engineers to run experiments at ITER and NIF is growing, OFES does not have a human capital strategy to address expected future workforce shortages; these shortages are likely to grow as a large part of the fusion workforce retires over the next 10 years.

DOE and NNSA Do Not Have a Coordinated Research Program for Inertial Fusion Energy

DOE has three separately funded inertial fusion research programs: NNSA's inertial fusion research activities related to the nuclear weapons program, a High Average Power Laser Program (HAPL) to develop technology needed for energy for which funding is directed by a congressional conference committee, and OFES's inertial fusion research activities aimed at exploring the basic science for energy applications. Experiments in each of these programs help advance inertial fusion energy, but these experiments are not coordinated and each program has a separate mission and different scientific and technological objectives. NNSA provides OFES with limited access to one of its inertial fusion facilities to conduct inertial fusion experiments, and NNSA- and OFES-funded scientists share information from the results of inertial fusion experiments. However, there is no research plan that identifies key scientific and technological questions that need to be addressed to achieve inertial fusion energy or the cost, time frames, and detailed research and development tasks needed by each agency to solve those scientific and technological issues to further advance inertial fusion energy. In addition, DOE has not assigned to either NNSA or OFES clear roles in developing inertial fusion energy. NNSA is focused on stockpile stewardship, but it maintains the major inertial fusion facilities. OFES is responsible for developing paths to fusion energy, but it is focused on ITER and magnetic fusion. A lack of a coordinated research plan and clear responsibility among these programs for developing inertial fusion energy may delay the progress of inertial fusion energy as a promising alternative to magnetic fusion.

NNSA operates the three major inertial fusion facilities in the United States—the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory, the OMEGA Laser at the University of Rochester, and the Z-machine at Sandia National Laboratory. Figure 5 shows the Z-machine in operation. In fiscal year 2006, NNSA spent about $544 million for NIF construction, upgrades, and operations for the other two facilities, and to conduct inertial fusion research. NNSA uses these facilities primarily to investigate technical issues related to stockpile stewardship by testing the reliability and integrity of nuclear weapons and simulating the conditions of a thermonuclear explosion without detonating them.[8]

Figure 5: The Z-machine Creating an X-ray Pulse to Test Materials in Conditions of Extreme Temperature and Pressure



Source: Sandia National Laboratory.

OFES's inertial fusion research activities are focused on energy applications. In fiscal year 2006, OFES spent $15.5 million, or 5.5 percent of its $280.7 million budget, on these research activities. While OFES officials told us that inertial fusion is an attractive path to fusion energy and the only alternative to magnetic fusion, the office has limited funding for inertial fusion research because its priority is to support ITER and magnetic fusion research activities. Consequently, OFES relies heavily on NNSA's inertial fusion research activities and facilities. NNSA experiments at NIF, which will begin in 2010, will demonstrate the feasibility of inertial fusion energy because a controlled thermonuclear burn is the first step in using inertial fusion as a potential energy source. In addition, OFES funds

[8]NNSA also uses the facilities to investigate a number of other technical issues such as determining fundamental properties of nuclear materials at temperatures and pressures needed for nuclear weapons, estimating the impact of a new engineering feature, or verifying the performance of weapon design changes.

inertial fusion energy experiments using the OMEGA laser, located at the University of Rochester. NNSA grants access to the OMEGA laser to scientists conducting nondefense work and expects to complete a $98.5 million upgrade to the OMEGA laser early in 2008. This upgrade will add short-pulse, high-power lasers, which can, among other things, test ways to lower the total laser energy required to still compress and heat the target for fusion energy. This approach could reduce the cost of producing fusion energy. However, the university limits access to this facility to about 4 weeks a year, or about 10 percent of the total operating time, because the priority for this facility remains stockpile stewardship. In addition, those 4 weeks are not reserved for inertial fusion energy experiments. Scientists from different areas of science, including astrophysics, materials science, biology, and chemistry, can request the use of the facility and compete for time on the laser. University of Rochester officials told us that they may be able to increase access to this facility for inertial fusion experiments, but OFES would have to provide funding. NNSA pays for the facility's operation, but OFES would have to fund the experiment, including the targets, which cost $10,000 to $15,000 each; personnel costs; and specialized equipment to measure the results of the experiment. NNSA also is planning to provide access to NIF for nondefense experiments, but it has not yet determined how much operating time to free up. According to officials at NIF, NNSA plans to free up 15 percent of its operating time to external users, including OFES, but its primary mission is for stockpile stewardship and access to the facility for nondefense research, such as inertial fusion energy experiments, will depend on NNSA first meeting its scientific goals.

While NIF and other NNSA facilities can demonstrate the fundamental science of inertial fusion, they are not designed to produce fusion energy efficiently and to test whether inertial fusion energy can be commercially viable. In addition to understanding the conditions necessary to heat and compress a frozen pellet of fuel to release fusion energy, DOE would have to overcome a number of technical issues before inertial fusion energy can be commercially viable. These issues include (1) designing the pellet of fuel, which consists of frozen layers of deuterium and tritium, to release the most amount of energy when it is struck by a laser; (2) developing a system that can keep the pellets of fuel cryogenically frozen and inject five of them every second with great accuracy into the target chamber; (3) designing a laser that can compress and heat five frozen pellets of fuel every second to release fusion energy; (4) testing materials inside the chamber wall that could withstand these repetitive explosions while also harvesting the neutrons needed to produce electricity; and (5) clearing the inside of the reactor of debris after each shot. According to officials from the Naval Research Laboratory, the lasers need to strike five frozen pellets of fuel a second to release a sufficient amount of fusion energy for electricity production.

Since neither NNSA nor OFES were funding research to investigate these technical issues, beginning in 1999, congressional conference committees directed NNSA to allocate funding for HAPL to develop the technologies needed for inertial fusion energy. According to NNSA officials, NNSA does not request funding for this program in its congressional budget requests because the program exceeds NNSA's mission goals of developing a laser system to test new weapons designs and the reliability of nuclear weapons. NNSA officials told us that their current facilities, such as NIF, OMEGA, and the Z-machine, are sufficient to meet their needs. NIF will be able to strike a target once every 4 hours and OMEGA once every 2 hours—far short of the 5 targets a second needed for fusion energy, but adequate for the stockpile stewardship mission.

Congressional conference committees have directed funds for inertial fusion research:

- Conference committees have directed about $25 million a year to two competing lasers systems that could be used for fusion power plants at the Naval Research Laboratory and Lawrence Livermore National Laboratory and for experiments to design the targets for inertial fusion energy at General Atomics.
- Conference committees have directed $4 million in fiscal years 2004 and 2005 to explore the Z-machine's ability to produce fusion energy for a potential power plant, as an alternative to the laser systems. In fiscal year 2006, Sandia National Laboratory used $2.6 million of its internal research funding to continue this research. However, this research did not continue in fiscal year 2007, and there are no plans to resume the research in fiscal year 2008 because NNSA has not provided funding for this project.

As another alternative to both the laser systems and the Z-machine, OFES is funding experiments using heavy ion beams to produce fusion energy at the Lawrence Berkeley National Laboratory. Heavy ion beams are made by a particle accelerator—a device that uses electrical fields to propel electrically charged particles at high speeds. The heavy ions, which are heavier than carbon atoms, collide with the targets and cause the compression and heat needed to release fusion energy.

If NIF's controlled fusion experiments succeed, there is still uncertainty about the future of inertial fusion energy. NNSA officials told us that they are not responsible for funding the construction of additional inertial fusion facilities needed to demonstrate inertial fusion energy. OFES officials told us that they do not have the funding to build a $2 billion to $3 billion inertial fusion facility. In fiscal year 2008, OFES and NNSA plan to establish a joint program to explore high-energy density physics, which is aimed at understanding the behavior of matter under extreme pressure. OFES and NNSA plan to combine their funding in this area to fund basic research and share experimental results. While high-energy density physics explores a number of fundamental scientific issues related to inertial fusion energy, it does not address all of the scientific issues that would advance inertial fusion energy.

Decreases in Funding for Innovative Magnetic Fusion Devices May Delay Progress Toward a Fusion Energy Device

Although a tokamak has been the most successful magnetic fusion device, it is still uncertain whether the device will lead to a commercially viable fusion energy device. To reduce the risk of investing in only one device, OFES funds scientific research on alternative types of magnetic devices, in addition to inertial fusion research activities. However, a decrease in research funding for these alternatives may limit DOE's ability to find a simpler, less costly, or faster path to fusion energy.

Research on alternative types of magnetic devices is critical to the fusion energy program, according to officials from the National Academy of Sciences. In 2004, the National Academy of Sciences reported that many outstanding scientific and technical issues had to be resolved before an economically attractive fusion power plant could be designed. These innovative research experiments could address many issues that ITER will not be able to address in a cost-effective manner and lead to a simpler, less costly, or faster path to fusion energy. Moreover, because these innovative and cutting-edge research activities are primarily located at U.S. universities, this program attracts students to fusion sciences and serves as an important recruitment and training tool for scientists and engineers.

Sustained funding is critical to these research activities, according to DOE's fusion energy advisory committee. Specifically, the ability to investigate critical scientific and engineering issues requires sufficient overall funding to build and operate advanced-stage experiments without eliminating the opportunity for new ideas and innovations resulting from smaller, more focused experiments. However, alternative magnetic fusion research competes for funding with ITER- and tokamak-related research. Since the U.S. commitment to ITER, DOE has focused more of its resources on ITER- and tokamak-related research. DOE officials told us that given limited resources, their priority is to fund ITER- and tokamak-related research. According to DOE officials, OFES determines the appropriate level of funding between tokamak-related research and innovative concepts based on scientific and technological priorities identified by DOE's fusion energy advisory committee. The level of funding is, among other things, tied to the complexity of the experiment and the operating costs of the device. Based on these assessments, DOE officials told us they believe the current level of funding for innovative magnetic devices is sufficient to sustain the best-performing devices.

However, in fiscal year 2006, OFES spent about $21 million to fund 25 small-scale experiments at 11 universities, 4 national laboratories, and 2 private companies to test 7 types of magnetic fusion devices with different shapes and magnetic currents. This level of funding represents a decline over the past 6 fiscal years—from $26 million in fiscal year 2002 to $20 million in fiscal year 2007. University scientists involved in innovative fusion research told us that this decrease in funding was not consistent with a 1999 DOE fusion energy science advisory committee study that recommended OFES increase funding for innovative magnetic research activities. OFES relies on this advisory committee to establish priorities for the fusion program and to provide a basis for the allocation of funding.

However, since that report, the share of funding for innovative research activities has decreased even as funding for fusion research has increased. The share of funding has dropped from 19 percent of the fusion research budget in fiscal year 2002 to 13 percent in fiscal year 2007. In addition, while OFES's 5-year budget plan shows an increase in funding for fusion research activities in fiscal years 2008 through 2011, most of this funding will be used for ITER- and tokamak-related research activities at the major facilities. DOE officials also told us there are planned increases in funding for innovative devices, but only to maintain the same level of research. According to university scientists, a number of innovative approaches are ready to advance to the next stage of development that would test the feasibility of producing fusion energy or conduct more sophisticated experiments, but DOE has no plans to advance any of these approaches because it may require an increase in funding to conduct more sophisticated experiments. DOE's fusion energy advisory committee has not assessed the appropriate level of funding between ITER- and tokamak-related activities and innovative concepts since 1999, before the U.S. joined ITER and it became a priority.

Scientists from a number of universities told us that this decline in funding has led to a decline in research opportunities for innovative concepts. For example, university scientists told us that in the last 3 years, they reduced the number of experiments they performed on their devices and they could not upgrade the devices to validate theories and computer simulations. In addition, the decrease in funding reduced opportunities to attract students to the fusion sciences and train them to fulfill future workforce needs.

DOE Does Not Have a Plan to Address Future Workforce Shortages

According to studies by DOE's fusion energy advisory committee and the National Academy of Sciences, the single greatest challenge the fusion program faces may be a rapidly aging workforce. About one-third of the U.S. fusion energy workforce is retiring in the next 10 years. In 2004, DOE's fusion energy advisory committee found that between 2008 and 2014, DOE would have to fill about 250 permanent positions as scientists and technicians retire—an average hiring rate of 42 PhDs per year. However, this figure exceeds the current total PhD production rate in fusion-related fields. In fiscal year 2006, 33 PhDs were awarded to students in plasma physics and fusion science. OFES estimates that 33 and 36 PhDs will be awarded in fiscal years 2007 and 2008 respectively. Furthermore, it may be difficult to retain these new PhDs in fusion-related fields. DOE's fusion energy advisory committee found that about 50 percent of PhDs in plasma science and engineering took positions outside their fields. Moreover, DOE would need to hire more PhDs to increase the number of scientists and engineers needed for ITER and to maintain a strong domestic program. The average hiring rate of 42 PhDs per year would replace retiring personnel, but would not increase the fusion workforce.

OFES has taken some steps to address these challenges by recruiting and training fusion scientists and engineers. OFES established a program that identifies talented faculty members at universities early in their careers in plasma physics and funds their research activities. In 2004, OFES also established Fusion Science Centers at universities to conduct magnetic and inertial fusion research activities and stimulate the involvement and participation of students. Moreover, OFES has a partnership with the National Science Foundation, an independent federal agency that supports basic scientific research in many fields, including physics and engineering, to share their resources and fund research into fundamental issues in plasma science and engineering. OFES officials told us that they are also hiring PhDs in related scientific fields, such as materials science, to leverage their expertise in solving different types of scientific and technological problems encountered during fusion energy research and to reduce any shortfalls in hiring plasma science and engineering PhDs.

Despite these initiatives, OFES still has not developed a plan to address the future shortage of fusion scientists and engineers and increase the number of PhDs working in fusion science. It has not implemented the recommendation from DOE's advisory committee report to develop a 5- to 10-year hiring plan with strategies to increase hiring and training of the most qualified staff. OFES also has not assessed whether its recruitment and outreach efforts are sufficient to meet future workforce needs. In 2004, OFES reported that its outreach and recruitment programs were attracting more graduate and postdoctoral students to fusion energy, but the report did not assess whether it was a sufficient number to sustain fusion research as a large number of scientists begin to retire and whether or how long those students remain in fusion-related research.

Conclusions

Given the size of the U.S. contribution to ITER, it is important to assess the full costs of participation in this scientific endeavor. DOE made a commitment to provide manufactured components and parts to ITER without a definitive cost and schedule estimate and a complete project design. As a result, DOE's preliminary $1.12 billion estimate may be subject to significant change as ITER's design is completed. Moreover, there is a risk that several management challenges facing the ITER Organization, such as developing quality assurance standards for manufactured components and assessing contingencies for cost or schedule overruns, could result in delays in ITER's construction, which would further increase costs for the United States.

DOE could better manage alternative fusion research activities. DOE is not effectively coordinating OFES's and NNSA's inertial fusion activities to advance inertial fusion energy. Since OFES relies on NNSA and the HAPL Program to advance inertial fusion as a potential energy source, it is important that OFES coordinate the research activities of these three programs to explore inertial fusion energy applications. The lack of a research plan and clear mission responsibility between OFES and NNSA on which office has the lead in advancing inertial fusion energy research may delay progress in developing inertial fusion as an energy source in the shortest time possible. NNSA also has not determined how much time will be available at NIF for scientists conducting inertial fusion energy experiments. NNSA may significantly limit access to NIF if there are delays in meeting its stockpile stewardship objectives. Since NIF will be critical in resolving fundamental scientific issues, access issues could further delay progress for inertial fusion energy research.

In addition, the future of alternative magnetic fusion research activities, which may lead to a simpler, less costly, or faster path to fusion energy, is uncertain. Funding for these research activities has steadily declined even though the fusion research budget has increased. A decreasing share of funding for innovative concepts may delay progress in resolving fundamental scientific issues or designing a reactor more quickly. For this reason, DOE needs to ensure there is a proper balance of funding between tokamak-related research and alternative innovative concepts to support U.S. obligations to ITER while continuing to explore different paths to fusion energy. Finally, OFES has not developed a strategy to hire, train, and retain the most talented staff. This effort is critical to meeting the growing demand for scientists and engineers with knowledge about fusion, especially as the United States participates in ITER, the NIF is completed, and interest increases in fusion energy as a long-term energy source.

Recommendations for Executive Action

To advance U.S. efforts to develop alternative fusion energy sources, we recommend that the Secretary of Energy direct

- OFES and NNSA to develop a coordinated research plan to coordinate U.S. inertial fusion research activities and identify roles and responsibilities for each program as well as detailed research and development tasks, budget needs, and time frames for advancing inertial fusion research;
- NNSA to guarantee access to NIF, once it becomes operational, to scientists conducting inertial fusion energy experiments, and work with DOE to determine how to share the costs, operational time, and results of NIF to explore inertial fusion as a viable energy source; and
- OFES to charge DOE's fusion energy advisory committee with independently assessing whether current funding levels between ITER- and tokamak-related research and innovative magnetic fusion research strike the right balance to meet research objectives and advance both areas of research, and, if the current share of funding is not adequate, to recommend appropriate changes.

To address OFES's human capital challenges, we recommend that the Secretary of Energy direct OFES to develop a strategy to hire, train, and retain personnel with specialized skills to meet future workforce needs.

Agency Comments and Our Evaluation

We provided DOE with a draft copy of this report for its review and comment. DOE provided written comments, which are reprinted in appendix I. In its written comments, DOE neither agreed nor disagreed with our recommendations, but questioned several of our findings. First, DOE believes that enough PhDs are being produced to meet future workforce needs and it points to anecdotal data from universities that U.S. participation in ITER is attracting students to fusion sciences. However, data from DOE's fusion energy advisory committee show that not enough doctoral candidates in plasma physics and fusion science are entering the fusion research field to meet future workforce needs. DOE would have to hire an average of 42 PhDs a year to fill about 250 permanent positions as scientists and technicians retire, but awarded 33 PhDs in fiscal year 2006 and plans to award 33 and 36 PhDs respectively in fiscal years 2007 and 2008. Moreover, as we noted in our report, OFES has not assessed whether its recruitment and outreach efforts are sufficient to meet future workforce needs. Anecdotal evidence about student interest in fusion sciences is not a substitute for objective data on recruitment and retention rates.

Second, DOE questioned our finding that that the share of funding for alternative, potentially more innovative, magnetic fusion research activities has declined in the last 6 fiscal years. DOE argued that the share of funding for non-tokamak research has not declined, but rather remained flat, and alternative fusion research activities include more than innovative magnetic research. We agree that alternative fusion research activities include more than innovative magnetic research. However, with respect to funding levels, our analysis of DOE's budget using DOE's definition of innovative magnetic fusion research shows a clear result. Funding for innovative magnetic fusion research activities has declined and this decline may delay progress in finding a simpler, less costly, or faster path to fusion energy. In its budget documents, DOE describes these research activities as cutting edge and the main objective of these activities is to explore innovative and better ways to achieve fusion energy. In addition, DOE has stated in its budget documents that these activities have been effective in attracting students to the fusion workforce.

Third, DOE questions our finding that it does not have a coordinated research plan to advance inertial fusion energy. DOE noted that, in 2003, its advisory committee developed a plan that identified critical milestones, research and development tasks, and budget needs to build an inertial fusion demonstration power plant within 35 years. However, DOE decided not to implement this plan because fundamental scientific issues had not yet been resolved and there was no agreement between OFES and NNSA on which agency had the responsibility of developing inertial fusion as an energy source. When DOE rejected its advisory committee's plan, it did not develop an alternative. A plan that identifies key scientific and technological questions as well as the cost, time frames, and detailed research and development tasks would help OFES and NNSA better coordinate three separately funded inertial fusion research programs that have different scientific and technological objectives. Our recommendation does not involve increasing funding for inertial fusion research activities, but rather better managing the existing research activities. In addition, a plan would help OFES and NNSA determine which agency has the lead in advancing inertial fusion energy research. DOE also noted that OFES and NNSA plan to establish a joint program in fiscal year 2008 that will address fundamental scientific issues related to inertial fusion energy. As we recognized in our report, OFES's and NNSA's joint program in high-energy density physics may explore a number of fundamental scientific issues related to inertial fusion energy, but it will not address all of the scientific issues that would advance inertial fusion energy. A coordinated research plan would help identify gaps in scientific knowledge.

Finally, DOE questioned our statement that the joint program would not address "most" of the scientific issues that would advance inertial fusion energy. We agree with DOE that, as currently designed, the joint program may address many of the scientific issues related to inertial fusion energy and we made the appropriate change to the report. However, the joint program has not yet been established and as a result, it is too early to tell if all or most of the scientific issues will be addressed.

DOE requested that we reprint their enclosure with technical comments. The technical comments repeated the major points discussed in the general comments. As a result, we addressed the technical comments in our response or made changes to the report, as appropriate.

We are sending copies of this report to the Secretary of Energy and interested congressional committees. We will also make copies available to others upon request. In addition, the report will be available at no charge on the GAO Web site at http://www.gao.gov.

If you or your staff have any questions about this report, please contact me at (202) 512-3841 or aloisee@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made major contributions to this report are listed in appendix II.

Gene Aloise

Gene Aloise
Director, Natural Resources
and Environment

Appendix I: Comments from the Department of Energy

Department of Energy
Washington, DC 20585

October 10, 2007

Mr. Gene Aloise
Director, Natural Resources and Environment
U.S. Government Accountability Office
441 G Street NW
Washington, DC 20548

Dear Mr. Aloise:

We have reviewed the draft Government Accountability Office (GAO) report entitled "Fusion Energy, Definitive Cost Estimates for U.S. Contributions to an International Experimental Reactor and Better Coordinated DOE Research Are Needed" (GAO-08-30). We have coordinated these comments with NNSA, and the general comments below, as well as the page-specific comments on the report that are enclosed, represent a coordinated DOE response.

- We recognize the concern raised about the preliminary nature of the $1.2 billion cost estimate for the U.S. contribution to ITER project. Based on the ITER International Organization's projected progress, we believe we will have a baseline cost and schedule for the U.S. ITER project by late FY 08 to early FY 09. That said, however, we believe that the risks of this big international cooperative project are balanced by the financial and scientific benefits of sharing the project among the seven international partners.

- In the DOE report released in November, 2003, *Facilities for the Future of Science: A Twenty-Year Outlook*, the Office of Science identified ITER as the highest priority facility. The other elements of the Fusion Energy Sciences program support the ITER project to the maximum extent possible to insure its success. This is consistent with recommendations that the Fusion Energy Sciences Advisory Committee made in 2005 on the priorities for the program.

- The report makes statements about human capital challenges in the area of fusion sciences. As stated more fully in the attached comments, we believe that the annual Ph.D. production in this area is sufficient, and is supplemented by students in other science and engineering disciplines who have expressed an interest in working specifically on ITER-related research.

- The report gives the erroneous impression that alternative magnetic fusion approaches have been disproportionately decreased in support over the past five years, as ITER-related research has increased. This error comes from considering only a subset of the research activities, self-defined by their advocates as the most innovative alternate research activities. Using the objective designations of the alternate magnetic approaches as discussed in the 2004 National Academies study of the program, the share of funding

Printed with soy ink on recycled paper

in non-tokamak experimental research has remained essentially flat at approximately 37% of the OFES funding.

- The report makes a fundamental assumption that an explicit program to develop inertial fusion as an energy source exists but is not coordinated. This is not agreed to by the Department, and no such program presently exists. The joint program on HEDLP will address underlying scientific issues that will be relevant to future considerations of inertial fusion energy. The first step in motivating a program to develop inertial fusion as an energy source is the demonstration of ignition on NIF under the NNSA defense programs.

- We disagree with the conclusion that this joint program "will not address most of the scientific issues that would advance inertial fusion energy". The joint program in HEDLP and the large NNSA program in inertial confinement fusion will encompass most of the science issues related to IFE target physics, which are the most compelling scientific issues underpinning the potential application of inertial fusion to energy at this stage of the research.

- OFES and NNSA acknowledge the report's recommendation, "to develop a research plan to coordinate fusion research activities to advance inertial fusion energy", but reject the claim that no such plan exists. A detailed plan was in fact developed by FESAC in 2003, and presented to DOE. It was determined that it was not appropriate to allocate the much larger level of funding called for in this plan while underlying scientific issues have yet to be resolved.

Additional page-specific comments and corrections on the draft report are enclosed for your consideration. The Department requests that its full comments including the enclosure be included in the GAO's final report.

Sincerely,

Raymond J. Fonck

Raymond J. Fonck
Associate Director of the Office of Science
for Fusion Energy Sciences

Enclosure

Appendix II: GAO Contact and Staff Acknowledgments

GAO Contact

Gene Aloise at (202) 512-3841 or aloisee@gao.gov

Staff Acknowledgments

In addition to the contact named above, Christopher Banks, Leland Cogliani, Omari Norman, Keith Rhodes, Carol Herrnstadt Shulman, and Ned Woodward made significant contributions to this report.

GAO's Mission

The Government Accountability Office, the audit, evaluation, and investigative arm of Congress, exists to support Congress in meeting its constitutional responsibilities and to help improve the performance and accountability of the federal government for the American people. GAO examines the use of public funds; evaluates federal programs and policies; and provides analyses, recommendations, and other assistance to help Congress make informed oversight, policy, and funding decisions. GAO's commitment to good government is reflected in its core values of accountability, integrity, and reliability.

Obtaining Copies of GAO Reports and Testimony

The fastest and easiest way to obtain copies of GAO documents at no cost is through GAO's Web site (www.gao.gov). Each weekday, GAO posts newly released reports, testimony, and correspondence on its Web site. To have GAO e-mail you a list of newly posted products every afternoon, go to www.gao.gov and select "E-mail Updates."

Order by Mail or Phone

The first copy of each printed report is free. Additional copies are $2 each. A check or money order should be made out to the Superintendent of Documents. GAO also accepts VISA and Mastercard. Orders for 100 or more copies mailed to a single address are discounted 25 percent. Orders should be sent to:

U.S. Government Accountability Office
441 G Street NW, Room LM
Washington, DC 20548

To order by Phone:	Voice:	(202) 512-6000
	TDD:	(202) 512-2537
	Fax:	(202) 512-6061

To Report Fraud, Waste, and Abuse in Federal Programs

Contact:

Web site: www.gao.gov/fraudnet/fraudnet.htm
E-mail: fraudnet@gao.gov
Automated answering system: (800) 424-5454 or (202) 512-7470

Congressional Relations

Gloria Jarmon, Managing Director, JarmonG@gao.gov, (202) 512-4400
U.S. Government Accountability Office, 441 G Street NW, Room 7125
Washington, DC 20548

Public Affairs

Susan Becker, Acting Manager, BeckerS@gao.gov, (202) 512-4800
U.S. Government Accountability Office, 441 G Street NW, Room 7149
Washington, DC 20548