Hearing Charter

COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON ENERGY AND ENVIRONMENT
U.S. HOUSE OF REPRESENTATIVES

The Next Generation of Fusion Energy Research

Thursday, October 29, 2009
10 a.m. – 12 p.m.
2318 Rayburn House Office Building

Purpose

On Thursday, October 29, 2009 the House Committee on Science & Technology, Subcommittee on Energy and Environment will hold a hearing entitled *"The Next Generation of Fusion Energy Research."*

The Subcommittee will receive testimony on research activities conducted by the Department of Energy (DOE) Office of Science's Fusion Energy Sciences (FES) program, as well as its collaborations with DOE's National Nuclear Security Administration (NNSA). In addition, the Subcommittee will examine the status of international partnerships in fusion energy research.

Witnesses

- **Dr. Edmund Synakowski** is Director of FES. Dr. Synakowski will testify on DOE's current fusion research activities and his vision for how the program should evolve over the next ten years.

- **Dr. Stewart Prager** is Director of the Princeton Plasma Physics Laboratory (PPPL) in Princeton, NJ and former Chair of DOE's Fusion Energy Sciences Advisory Committee (FESAC). Dr. Prager will testify on PPPL's current and future roles as a leading center of fusion energy research.

- **Dr. Thom Mason** is Director of Oak Ridge National Laboratory (ORNL) in Oak Ridge, TN. Dr. Mason will describe the current status of the ITER international fusion project and the role of ORNL as the headquarters of the U.S. ITER Project Office.

- **Dr. Riccardo Betti** is an Assistant Director of the University of Rochester's Laboratory for Laser Energetics in Rochester, NY and former Chair of the National Academies Plasma Science Committee. He was also Chair of a 2009 DOE report on *"Advancing the Science of High Energy Density Laboratory Plasmas."* Dr. Betti will testify on the status of inertial fusion energy (IFE) research and his vision for how DOE should steward IFE over the next ten years.

- **Dr. Raymond Fonck** is a Professor of Engineering Physics at the University of Wisconsin – Madison and former Director of FES. He was also Chair of the 2004 National Academies report *"Burning Plasma: Bringing a Star to Earth."* Dr. Fonck will testify on his experience as FES Director and his vision for a viable U.S. fusion program over the next several decades.

Background

Fusion is the process that powers the sun and the stars, and U.S. scientists have investigated ways to replicate this process here on earth for over 50 years. Research into fusion for military purposes began in the early 1940s as part of the Manhattan Project, but was not successful until 1952. Research on creating controlled fusion devices to meet growing demands for new energy sources began in the 1950s, and continues to this day. In one type of this reaction, two atoms of hydrogen combine together, or fuse, to form an atom of helium. In the process some of the mass of the hydrogen is converted into energy, following Einstein's formula: E (Energy) = m (mass) times c (the speed of light) squared. The easiest fusion reaction to artificially recreate combines deuterium (a "heavy" form of hydrogen as it includes both a proton and a neutron[1]) with tritium (made up of a proton and two neutrons - the heaviest form of hydrogen found in nature) to make helium and a neutron. Deuterium is plentifully available in ordinary water, and tritium can be produced by combining a fusion neutron with the relatively abundant lithium atom. Thus, if its significant remaining scientific questions and engineering challenges can be overcome, fusion may have the potential to be a practically inexhaustible source of energy.

All nuclei in atoms are positively charged, so they have a natural electromagnetic repulsion pushing them apart. This is because, while opposite charges attract, like charges repel. Thus to induce the fusion process, hydrogen gas is typically heated to very high temperatures (100 million degrees or more) to give the atoms sufficient energy to overcome this repulsion and fuse. In the process the gas becomes *ionized*, meaning that atomic nuclei and their electrons have too much energy to stay bound to each other as neutrally charged atoms. Thus what is known as a *plasma* is formed. Plasmas are considered the fourth state of matter, after solids, liquids, and gases. Plasmas are unique from normal gases because large portions of them are either unbound electrons or charged nuclei (*ions*), so they can be manipulated by electric and magnetic fields. If a very hot plasma is held together (i.e. confined) long enough, then the sheer number of fusion reactions may produce more energy than what's required to heat the gas, generating excess energy that can be used for other applications. The sun and stars do this with gravity. Artificial approaches on earth include magnetic confinement, in which a strong magnetic field holds the plasma together while its ions and electrons are heated by microwaves or other energy sources, and inertial confinement, where a tiny pellet of frozen hydrogen is compressed and heated by intense pressure so quickly that fusion occurs before the deuterium and tritium atoms can fly apart from each other. This level of pressure may be attained by utilizing a powerful laser or a heavy ion beam.

[1] See charter for hearing entitled *Investigating the Nature of Matter, Energy, Space, and Time* held on October 1st, 2009 for further explanation of "protons" and "neutrons", which are the primary constituents of an atom's nucleus.

If successful, fusion devices for energy production are expected to be relatively environmentally friendly, producing no combustion products or greenhouse gases. While fusion is a nuclear process, the products of a fusion reaction are not intrinsically radioactive and cannot themselves be weaponized. Relatively short-lived radioactive material (~100 years, compared to thousands of years for some nuclear fission products) would result from interactions of the fusion products with the reactor wall. A long-term, large-scale geologic repository for waste from fusion would be unnecessary. Fusion also is not dependent on chain reactions that must be constantly monitored and regulated, so there should be no danger of a runaway process leading to a reactor meltdown.

The above are the major reasons why most industrialized nations pursue fusion research today. However, several significant questions in this field remain, including:

Can we adequately control a fusion plasma – meaning a plasma that receives a significant portion of its heat from its own fusion reactions?

Given the intense heat and neutron flux expected inside a reactor, what material(s) should be used in the first wall facing a fusion plasma?

Even if all fundamental technical challenges are overcome, how economical can a fusion reactor be in comparison to other energy options?

And specifically with regard to inertial fusion:

Can we actually build a system that perfectly implodes and recovers energy from ~10 pellets of hydrogen per second – the currently estimated rate necessary to produce significant net energy?

DOE Office of Science - Fusion Energy Sciences (FES)

(dollars in thousands)

	FY 2008 Current Appropriation	FY 2009 Original Appropriation	FY 2009 Additional Appropriation[a]	FY 2010 Request
Fusion Energy Sciences				
Science	155,032	172,387	+56,511	176,067
Facility Operations	116,968	207,253	+34,512	221,742
Enabling R&D	22,933	22,910	—	23,191
Total, Fusion Energy Sciences	294,933[bc]	402,550	+91,023	421,000

represents the Department's plans for additional funding to be allocated from the American Recovery and Reinvestment Act of 2009, which includes $28.6M for upgrades to and enhanced operation of the three major U.S. magnetic fusion facilities, $31M for facilities that examine high energy density plasmas relevant to inertial fusion research, and $26.4M for basic plasma science research, student fellowships, and early career awards. $426M was appropriated for FES in FY 2010. FES has yet to announce how the additional $5M above its request will be allocated.

FES is the lead program in the federal government that supports research in the science and engineering required to magnetically confine plasmas for the purposes of generating net fusion

energy. It is also the lead program that stewards basic research in plasma science, which has applications in a broad range of areas from microchip processing to astrophysics. In addition, FES examines the science underlying what are called "high energy density laboratory plasmas," or HEDLP, which are relevant to current and proposed inertial fusion energy facilities. However, the federal government currently has no official steward of research in inertial fusion for the purposes of energy generation. This will be described in greater detail in the section on the National Ignition Facility below.

ITER

ITER (pronounced "eater") is a major international research project with the goal of demonstrating the scientific and technological feasibility of nuclear fusion energy. ITER was originally an acronym for International Thermonuclear Experimental Reactor, but that title was later dropped due to the potentially negative popular connotation of the word "thermonuclear." The project's leaders now note that *iter* also means "the way" in Latin. The project is being designed and built by the members of the ITER Organization: the European Union, India, Japan, China, Korea, Russia, and the United States, with additional partner nations currently under consideration. The ITER Organization was formally established on October 24th, 2007 following ratification of the ITER International Agreement by all current members. The device will be built at Cadarache in southeastern France with the European Union serving as the host party, and it is scheduled to begin preliminary operations in 2018.

By roughly 2025, ITER is expected to generate fusion power that is at least 10 times greater than the external power delivered to heat its plasma. The project is designed to be the top scientific tool for exploring and testing expectations of plasma behavior in what is called the *burning plasma regime*, wherein the fusion process itself provides the primary heat source to sustain its high temperatures. A clear and comprehensive understanding of this type of plasma is needed to confidently extrapolate its behavior and related control technologies beyond ITER to a reliable fusion power plant.

The United States will primarily contribute hardware components and personnel during ITER's construction phase, with nearly all of these components being manufactured in the U.S. and then shipped to Cadarache. Throughout this phase, the United States is an equal, non-host partner responsible for about 9% of its total construction cost, though this cost may decrease if additional partners are added to the ITER Organization. DOE currently estimates the total U.S. cost in as-spent dollars to be between $1.45 and $2.2 billion, with an official baseline expected to be determined and announced over the next year. However, the total international cost for the project has not been determined because different partners use very different accounting practices for their contributions. For example, many do not include contingency, labor, and in some cases not even inflation in their announced estimates.

The U.S. ITER Project Office is hosted by Oak Ridge National Laboratory in partnership with Princeton Plasma Physics Laboratory and Savannah River National Laboratory. Oak Ridge was chosen by the Department of Energy in large part because its recently commissioned Spallation Neutron Source facility is considered to be a major success in billion-dollar level project

planning and execution, and the lab is employing nearly the same management and acquisitions team for the U.S. ITER contribution.

In FY 2010, the U.S. plans to provide contributions valued at $135 million for the ITER project, which is included in the Facility Operations budget line in Table 1.

Science

FES's Science subprogram includes several activities, much of which involve research in the leading configuration for magnetic fusion devices - including ITER - called the *tokamak*. Tokamaks, first conceived of by Russian scientists in the 1950s, are devices that are essentially toroidally (i.e. doughnut) shaped at their core. External coils induce magnetic fields which wind around the inside of the toroid and confine the hot plasma within. The U.S. hosts three major magnetic fusion facilities, two of which are tokamaks and one is known as a "spherical torus", which is essentially a uniquely shaped tokamak that, at its core, appears to be a ball which a narrow hole down its middle. These facilities include:

- **DIII-D** (pronounced "D. 3. D.") – This tokamak operated by General Atomics in San Diego, CA is the largest magnetic fusion facility in the United States. It is also geometrically the closest to the ITER configuration. DIII-D has unique capabilities to shape its plasma and provide feedback control of errant magnetic fields that affect the stability of the plasma.

- **Alcator C-Mod** (pronounced "ALKator See Mahd") – This facility at the Massachusetts Institute of Technology is the only tokamak in the world operating at and above the ITER design magnetic field and plasma densities. It also produces the highest pressure tokamak plasma in the world, approaching pressures expected in ITER, allowing for materials testing relevant to both ITER and an eventual fusion power plant.

- **The National Spherical Torus Experiment** – NSTX is a unique magnetic fusion device that was constructed by the Princeton Plasma Physics Laboratory (PPPL) in collaboration with the Oak Ridge National Laboratory, Columbia University, and the University of Washington at Seattle. Its spherical torus configuration may have several advantages over conventional tokamaks, a major one being the potential ability to confine a higher plasma pressure for a given magnetic field strength, which could enable the development of smaller, more economical fusion reactors.

In addition to direct research on these facilities, the Science subprogram also supports research in:

- Non-tokamak magnetic fusion concepts and experiments of various sizes and shapes at several universities and national laboratories

- High Energy Density Laboratory Plasmas (HEDLP), which are relevant to current and proposed inertial fusion facilities as well as the understanding of various astrophysical phenomena such as supernovae

- Theory and advanced simulation of fusion plasma behavior

- Basic plasma science

Facility Operations

The mission of the Facility Operations subprogram is to provide for the operation, maintenance, and enhancements of the three major fusion research facilities - DIII-D, Alcator C-Mod, and NSTX - to meet the needs of the scientific collaborators using the facilities. In addition, this subprogram is responsible for the execution of new projects and upgrades of major fusion facilities, such as installation of new diagnostics, in accordance with the Office of Science's project management standards and with minimum deviation from approved cost and schedule baselines. As noted above, Facility Operations also includes the U.S. contributions to the ITER project.

Enabling R&D

The Enabling R&D subprogram focuses on developing and continually improving the hardware, materials, and technology that are incorporated into existing fusion research facilities, thereby enabling these facilities to achieve higher levels of performance within their inherent capability. Enabling R&D efforts also develop near-term technology advancements enabling U.S. researchers, through international collaborations, to access plasma conditions not available in domestic facilities. In addition, this subprogram supports the development of new hardware, materials and technology that are incorporated into the design of next generation facilities to increase confidence that the predicted performance of these new facilities will be achieved.

National Ignition Facility and Inertial Fusion Energy Research

The National Ignition Facility (NIF), located at Lawrence Livermore National Laboratory in Livermore, CA, is the largest inertial fusion facility in the world. Its construction was certified complete on March 31, 2009, and the facility was officially dedicated on May 29, 2009 with experiments beginning in June. NIF's construction was supported entirely by DOE's National Nuclear Security Administration (NNSA), not FES. The total cost to build the facility was approximately $3.5 billion. Its primary mission is to produce data relevant to ensuring the reliability of the U.S.'s nuclear weapons stockpile through the study of controlled fusion events similar to the detonation of a thermonuclear warhead.

To do this, NIF's designers created the world's largest and highest-energy laser, which can be used to form 192 powerful laser beams. In 2010, NIF will begin experiments that will focus all

of these beams on a BB-sized target filled with deuterium and tritium fuel. NIF's researchers believe that by 2012, they will be able to consistently implode these pellets, igniting the fusion process and creating the first man-made fusion system to produce more energy than it uses.

While this facility was not primarily designed for energy research applications, the achievement of net fusion energy production in NIF may become strong justification for a significant inertial fusion energy program. At this time, however, neither NNSA nor FES, nor DOE as a whole, has determined which (if either) subagency would take a leading role in developing such a program, nor determined how such a program would be stewarded in the future. Until FY09, a small inertial fusion energy research program had been funded solely through Congressional direction at NNSA. Recently, in the FES section of the Conference Report for the Energy and Water Development Appropriations Act, 2010, DOE was directed to review an inertial fusion energy research project at the Naval Research Laboratory and report on its findings within 60 days. The Conference Report also states: "The conferees encourage the Secretary to explore all possible opportunities to ensure that this program, which offers unique potential for long-term energy independence, is not abandoned for lack of a bureaucratic home."