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73–328PS
2002

DEPARTMENT OF ENERGY
OFFICE OF SCIENCE—
ISSUES AND OPPORTUNITIES

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY
COMMITTEE ON SCIENCE
HOUSE OF REPRESENTATIVES

ONE HUNDRED SEVENTH CONGRESS

FIRST SESSION

MAY 17, 2001

Serial No. 107–37

Printed for the use of the Committee on Science

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DOE Science for the Future, A Discussion Paper, December 14, 2000

DEPARTMENT OF ENERGY OFFICE OF SCIENCE—ISSUES AND OPPORTUNITIES

THURSDAY, MAY 17, 2001

House of Representatives,

Subcommittee on Energy,

Committee on Science,

Washington, DC.

The Subcommittee met, pursuant to call, at 10:23 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Roscoe G. Bartlett [Chairman of the Subcommittee] presiding.

HEARING CHARTER

SUBCOMMITTEE ON ENERGY

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COMMITTEE ON SCIENCE

U.S. HOUSE OF REPRESENTATIVES

Department of Energy Office of

Science—Issues and Opportunities

THURSDAY, MAY 17, 2001

10:00 A.M.–1:00 P.M.

2318 RAYBURN HOUSE OFFICE BUILDING

I. Purpose

On Thursday, May 17, 2001 at 10:00 a.m., the Subcommittee on Energy will hold a hearing on the *Department of Energy Office of Science—Issues and Opportunities.* The purpose of the hearing is to examine the current status of the Department of Energy (DOE) Office of Science programs, future opportunities, and major issues that confront the Office.

There will be two panels of witnesses. The first panel will consist of the chairs of the six Office of Science Advisory Committees: (1) Professor Frederick J. Gilman (Department of Physics Carnegie Mellon University), Chair, High Energy Physics Advisory Panel, and Department of Physics Carnegie Mellon University; (2) Dr. T. James Symons (Nuclear Sciences Division, Lawrence Berkeley National Laboratory), Chair, DOE/NSF Nuclear Science Advisory Committee; (3) Dr. Geraldine L. Richmond (Department of Chemistry, University of Oregon), Chair, Basic Energy Sciences Advisory Committee; (4) Dr. Keith O. Hodgson (Director, Stanford Synchrotron Radiation Laboratory Department of Chemistry, Stanford

University), Chair, Biological and Environmental Research Advisory Committee; (5) Professor Richard D. Hazeltine (University of Texas at Austin, Institute for Fusion Studies), Chair, Fusion Energy Sciences Advisory Committee; and (6) Dr. Margaret H. Wright (Bell Laboratories/Lucent Technologies), Chair, Advanced Scientific Computing Advisory Committee. The second panel will include: (1) Dr. Robert C. Richardson, Vice Provost for Research, Cornell University, and recipient of the 1996 Nobel Prize in Physics; (2) Dr. Charles V. Shank, Director, Lawrence Berkeley National Laboratory; and (3) Professor James F. Blake, Institute for Plasma Research, University of Maryland.

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2. Overview

With a current year budget of $3.155 billion, DOE's Office of Science is the largest Federal funder of scientific facilities and the physical sciences (physics, chemistry, etc.) and plays a major role supporting other scientific fields, including life sciences, mathematics, computation, engineering, and environmental sciences.(see footnote 1) It also provides the largest share of funding for 10 DOE Laboratories: (1) Ames Laboratory at Ames, IA; (2) Argonne National Laboratory (ANL) at Argonne, IL; (3) Brookhaven National Laboratory (BNL) at Upton, NY; (4) Fermi National Accelerator Laboratory (Fermilab) at Batavia, IL; (5) Lawrence Berkeley National Laboratory (LBNL) at Berkeley, CA; (6) Oak Ridge National Laboratory (ORNL) at Oak Ridge, TN; (7) Pacific Northwest National Laboratory (PNNL) at Richland, WA; (8) Princeton Plasma Physics Laboratory (PPPL) at Princeton, NJ; (9) Stanford Linear Accelerator Center (SLAC) at Stanford, CA; and (10) Thomas Jefferson National Accelerator Facility (TJNAF) at Newport News, VA. The Office of Science also funds programs at the Idaho National Engineering and Environmental Laboratory (INEEL) at Idaho Falls, ID; at the National Renewable Energy Laboratory (NREL) at Golden, CO; at the three DOE weapons laboratories—Lawrence Livermore National Laboratory (LLNL) at Livermore, CA; Los Alamos National Laboratory (LANL) at Los Alamos, NM; and Sandia National Laboratories (SNL) at Albuquerque, NM and at Livermore, CA—as well as a number of research facilities located at universities. In addition, two DOE Operations Offices—Chicago and Oak Ridge—report to the Office and the Office also manages DOE's Technical Information Management Program.

The Office of Science funds six major programs: (1) High Energy Physics; (2) Nuclear Energy Physics; (3) Biological and Environmental Research; (4) Basic Energy Sciences; (5) Advanced Scientific Computing Research; and (6) Fusion Energy Sciences. Each of these programs also has an advisory committee to provide independent advice regarding the complex scientific and technical issues that arise in their planning, management, and implementation: (1) the High Energy Physics Advisory Panel (HEPAP); (2) the joint DOE/NSF Nuclear Science Advisory Committee (NSAC); (3) the Basic Energy Sciences Advisory Committee (BESAC); (4) the Biological and Environmental Research Advisory Committee (BERAC); (5) the Fusion Energy Sciences Advisory Committee (FESAC); and (6) the Advanced Scientific Computing Advisory Committee (ASCAC).

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2.1 High Energy Physics

DOE's High Energy Physics (HEP) Program funds over 90 percent of all U.S. high energy physics research and supports laboratory- and university-based high energy physics research at the B–Factory(see footnote 2) at SLAC, at the Main Injector for the Tevatron(see footnote 3) at Fermilab, and at the Alternating Gradient Synchrotron (AGS) at BNL on an incremental cost basis. In addition, HEP, along with NSF, also participates in the European Laboratory for Particle Physics (CERN) Large Hadron Collider (LHC)(see footnote 4) project. In addition, HEP funds non-accelerator experiments, and theory and accelerator R&D programs.

2.2 Nuclear Physics

The DOE Nuclear Physics (NP) program funds about 85 percent of all U.S. nuclear physics research and conducts research activities needed to understand the structure of atomic nuclei and the fundamental forces required to hold nuclei together. NP supports nuclear physics theoretical research and a number of research facilities located at National Laboratories and universities, including the following:

Argonne Tandem-Linac Accelerator System (ATLAS) at ANL—Provides variable energy, precision beams of stable ions from protons through uranium, at energies up to 10 million electron volts (MeV per nucleon) using a superconducting linear accelerator for Heavy Ion Nuclear Physics research;

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MIT Bates Linear Accelerator Center in Massachusetts—Carries out Medium Energy Nuclear Physics research with electron beams up to 1 billion electron volts (GeV) in energy;

Relativistic Heavy Ion Collider (RHIC) at BNL—Provides colliding-beam collisions of 100 GeV per atomic mass unit per beam for heavy ions as massive as gold for the study of nuclear matter as it undergoes a phase transition to a plasma of gluons and quarks;

88-inch Cyclotron at LBNL—Provides high intensity stable beams from protons to bismuth at energies up to 15 MeV per nucleon;

Holifield Radioactive Ion Beam Facility (HRIBF) at ORNL—Only radioactive nuclear beam facility in the U.S. to use the isotope separator on-line (ISOL) method and provides a wide range of both proton-rich and neutron-rich nuclei to a suite of instruments designed for studies in nuclear structure, dynamics and astrophysics using radioactive beams; accelerates secondary radioactive beams to higher energies (up to 10 MeV per nucleon) than any other facility in the world with such a broad selection of ions;

Continuous Electron Beam Accelerator Facility (CEBAF) at the TJNAF—Capable of providing polarized and unpolarized electron beams of up to 5.7 GeV to three experimental halls for Medium Energy Nuclear Physics research; and

Facilities at four universities—Texas A&M Cyclotron Institute (TAMU), Triangle Universities Nuclear Laboratory (TUNL) at Duke University, Yale University A.W. Wright Nuclear Structure Laboratory tandem Van de Graaff accelerator, and the University of Washington Nuclear Physics Laboratory tandem Van de

Graaff and superconducting linac accelerators.

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2.3 Biological and Environmental Research

The Biological and Environmental Research program aims to develop the knowledge needed to identify, understand and mitigate the adverse health and environmental consequences of energy production, development, and use. The program is structured along the following four subprograms:

Life Sciences focuses on understanding and mitigating the potential effects of energy production, use, and waste cleanup. Structural Biology analyzes and predicts gene function and is concerned with recognition and repair of DNA damage. Molecular and Cellular Biology has several elements: the completed sequencing of over 50 microbes for possible use in solving DOE problems in energy, waste, cleanup, and carbon management; microbes will be used for methane and hydrogen production from carbon sources and for carbon sequestration; the microbial cell project, which sought a complete understanding of a single cell, has evolved into the Genomes to Life project which will look at multi-cellular systems to predict their behavior and response to environmental cues; and, research on biological effects of low dose radiation will determine safe radiation exposure levels for clean-up workers and the general public. The Human Genome program had a major milestone in June 2000 when the President announced completion of a working draft of the human DNA sequence, and in February 2001, the draft sequence was published. Much work remains, including understanding biological systems, gene function and variation and how they affect human disease, comparative sequencing, and understanding the role of the "junk" DNA. The Health Effects subprogram seeks an understanding of normal human development and disease processes. Construction continues on the Laboratory for Comparative and Functional Genomics at ORNL;

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Environmental Processes represents DOE's contribution to the U.S. Global Change Research Program (USGCRP). Working with other federal agencies, the program will continue to develop climate models with improved abilities to predict climate on regional scales. Program elements include: climate modeling; the Atmospheric Radiation Measurement program to understand the role of clouds and solar radiation in climate prediction; atmospheric chemistry and the carbon cycle; and, studying the effects of elevated carbon dioxide (CO) levels on terrestrial ecosystems. It also supports partnerships on terrestrial and ocean carbon cycles;

Environmental Remediation performs research related to remediation and restoration of the nation's nuclear weapons production sites. The Natural and Accelerated Bioremediation Research (NABIR) program focuses on determining the use of bioremediation in subsurface environments. Funding is provided for operation of the William R. Wiley Environmental and Molecular Sciences Laboratory at PNNL; and

Medical Applications and Measurement Science develops new medical diagnostic and therapeutic tools. Research activities include: continuation of Boron Neutron Capture Therapy and radionuclide therapies for cancer treatment, radiopharmaceutical design for disease diagnosis and treatment, non-invasive imaging techniques, and biomedical engineering.

2.4 Basic Energy Sciences

The Basic Energy Sciences (BES) program supports fundamental research to provide the foundations for new and improved energy technologies and for understanding and mitigating the environmental impacts of energy use. The BES mission includes planning, construction, and operation of major scientific user facilities serving researchers at universities, national laboratories and industrial laboratories. Research is conducted in four areas—Materials Science, Chemical Sciences, Engineering and Geosciences, and Energy Biosciences.

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Materials Sciences performs research to make materials perform better at acceptable cost through new methods of synthesis and processing. Research in nanoscale science has become a major focus.

Chemical Sciences seeks to understand fundamental interactions of atoms, molecules, and ions with photons and electrons, and is crucial to improving combustion systems and solar photoconversion processes. It also underpins improvements in energy systems, catalytic systems, catalysis for fuels and chemical production, waste management and environmental remediation. The program also supports nanoscale science.

The Materials and Chemical Sciences subprograms also plan, construct, and operate major scientific user facilities that include: four synchrotron light sources (Advanced Photon Source at ANL, Advanced Light Source at LBNL, the National Synchrotron Light Source at BT–L, the Stanford Synchrotron Radiation Laboratory at SLAC). Also included are three neutron sources: the Intense Pulsed Neutron Source at ANL; the High Flux Isotope Reactor at ORNL, Tennessee; and the Los Alamos Neutron Science Center at LANL. In addition, BES manages four electron beam micro-characterization facilities and five other specialized facilities, such as the Combustion Research Center at SNL-Livermore, that are located throughout the U.S. BES is currently supporting construction of a major new scientific user facility, the $1.4117 billion Spallation Neutron Source (SNS) at ORNL, which when completed, will be the world's most powerful spallation neutron source.

Within Engineering and Geosciences, Engineering research supports DOE's mission needs of the Department including: robotics and intelligent machines; nano-engineering; and data and engineering analysis. Geosciences research seeks to improve the fundamental understanding of earth processes that affect energy production and environmental quality.

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Energy Biosciences supports research in the formation, storage, and interconversion of energy by plants and microorganisms. This includes renewable fuel resources, agents to restore disrupted environmental sites, and photosynthesis.

2.5 Advanced Scientific Computing Research

The Advanced Scientific Computing Research program supports world leadership in areas of scientific computing research relevant to the DOE missions, and supports the goal of providing extraordinary tools for extraordinary science. Research in Mathematical, Information, and Computational Sciences concentrates on advanced computing applications and techniques that enable researchers to analyze, model, simulate, and predict complex physical, chemical, and biological phenomena relevant to DOE. Mathematical methods are developed to model these complex systems, and software is developed to support these large applications on high performance, terascale computers. This program also provides the resources for these applications. The National Energy Research Scientific Computing Center (NERSC) at Lawrence Berkeley National Lab supports over 2,000 users, and is in the process of being upgraded to a five teraflop computer. The Energy Sciences Network (ESNET) links the Office of Science researchers and facilities, and by the year 2005 plans to have network speeds 500 times faster than today's highest speeds. The program also provides software tools for collaboratory projects that link geographically distributed research teams with experimental and computational facilities.

The Laboratory Technology Research subprogram supports cost-shared partnerships with the private sector to transfer high-risk, long-term basic research to applied energy efficiency and utilization technologies.

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2.6 Fusion Energy Sciences

The Fusion Energy Sciences (FES) program seeks to understand and control the process of fusion of deuterium and tritium that can produce an enormous release of energy. The program mission is to advance plasma science, fusion science, and fusion technology. In recent years the program has refocused its emphasis from development of a new energy source to a strong science-based program in fusion (magnetic and inertial confinement) and plasma physics.

FES has three subprograms:

(1) Science, which supports tokamak research, investigation of alternative concepts, plasma science, theory and inertial confinement fusion;

(2) Facilities Operations, which funds operation and maintenance of the DIII–D tokamak at General Atomics (GA) in San Diego, the Alcator C–Mod tokamak at MIT, and the National Spherical Tokamak Experiment (NSTA) in Princeton, and also funds decontamination and decommissioning of the Tokamak Fusion Test Reactor (TFTR) at Princeton; and

(3) Enabling R&D, which provides engineering and materials research support.

3. Issues

Budgets. For about a decade, DOE Office of Science budgets have been declining in purchasing power, and have fared significantly less well than those of other agencies. What has caused this situation and how might this best be addressed?

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Infrastucture. Most of the DOE Office of Science laboratories were established in the late 1940's and early 1950's. How is the Office dealing with the infrastructure issue?

Tension between Science and Security. In the past two years, there has been an increased DOE-wide emphasis on security. While most of the emphasis has been on the DOE weapons laboratories, the Office of Science labs have also been impacted. How is the Office of Science coping with this situation?

Coordination with Other Agencies. DOE's Office of Science and NSF fund similar types of research, particularly in the physical sciences (high energy and nuclear physics, materials sciences, chemistry, etc.) How is the research coordinated to avoid duplication?

Coordination with Other DOE Offices. Much research funded by DOE's Office of Science is directly applicable to the work of other DOE Offices, such as the Office of Energy Efficiency and Renewable Energy, Fossil Energy, Nuclear Energy, etc. How does the Office of Science coordinate its work with that of other DOE Offices?

Facility Operations. DOE's Office of Science is the largest Federal funder of scientific facilities (high energy and nuclear physics accelerators, fusion facilities, and synchrotron and neutron sources), which represent billions of dollars of investments. In most cases, past, current and projected budgets result in either a decrease in the operating times or sub-optimal utilization of these facilities.

Interaction with DOE National Nuclear Security Administration laboratories. In FY 2001, the Office of Science is funding almost $155 million in research at the three National Nuclear Security Administration (NNSA) National Laboratories—Lawrence Livermore, Los Alamos, and Sandia—and the FY 2002 request includes nearly $153 million. By statute, these labs report directly the NNSA. In addition, by statute, a NNSA contractor employee "shall not be responsible to, or subject to the authority, direction, or control of, any officer, employee, or agent of the Department of Energy who is not an employee of the Administration, except for the Secretary of Energy." How does the Office of Science maintain programmatic control over this research under this arrangement?

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Attachment—Office of Science FY 2002 Budget Request

DOE's FY 2002 Science appropriation request funds DOE's Office of Science (SC) programs, which include High Energy Physics, Nuclear Energy Physics, Biological and Environmental Research, Basic Energy Sciences, Advanced Scientific Computing Research. Energy Research Analysis, Multiprogram Energy Laboratories-Facilities Support, Fusion Energy Sciences, Safeguards and Security, and Program Direction. In addition, SC manages the Technical Information Management Program, which is contained in the Energy Supply appropriation account. The Science Committee has sole jurisdiction over the Science appropriation account programs, and shares jurisdiction over the Technical Information Management program with the Energy and Commerce Committee.

SC is the largest Federal funder of scientific facilities and the physical sciences (physics, chemistry, etc.) and plays a major role supporting other scientific fields, including life sciences, mathematics, computation, engineering, and environmental sciences. It provides the largest share of funding for 10 DOE Laboratories: (1) Ames Laboratory at Ames, IA; (2) Argonne National Laboratory (ANL) at Argonne, IL; (3) Brookhaven National Laboratory (BNL) at Upton, NY; (4) Fermi National Accelerator Laboratory (Fermilab) at Batavia, IL; (5) Lawrence Berkeley National Laboratory (LBNL) at Berkeley, CA; (6) Oak Ridge National Laboratory (ORNL) at Oak Ridge, TN; (7) Pacific Northwest National Laboratory (PNNL) at Richland, WA; (8) Princeton Plasma Physics Laboratory (PPPL) at Princeton, NJ; (9) Stanford Linear Accelerator Center (SLAC) at Stanford, CA; and (10) Thomas Jefferson National Accelerator Facility (TJNAF) at Newport News, VA. SC also funds programs at the Idaho National Engineering and Environmental Laboratory (INEEL) at Idaho Falls, ID; at the National Renewable Energy Laboratory (NREL) at Golden, CO; at the three DOE weapons laboratories—Lawrence Livermore National Laboratory (LLNL) at Livermore, CA; Los Alamos National Laboratory (LANL) at Los Alamos, NM; and Sandia National Laboratories (SNL) at Albuquerque, NM and at Livermore, CA—as well as a number of research facilities located at universities. In addition, two DOE Operations Offices report to SC—Chicago and Oak Ridge.

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As shown in Table 1 below, the FY 2002 request for the Office of Science under the Science Committee's jurisdiction is $3.160 billion. This is an increase of $335.0 million—or 11.9 percent—above the FY 2000 appropriation of $2.825 billion, and an increase of $4.4 million—or 0.1 percent—above the FY 2001 appropriation of $3.155 billion. Table 2 below also shows the SC funding by DOE Laboratory and by universities and other performers.

The FY 2002 request for most SC accounts show minor increases above the FY 2001 level. There are two exceptions: (1) Biological and Environmental Research (BER), whose FY 2002 request of $443.0 million is a reduction of $39.6 million or 8.2 percent—due to the zeroing out of $43.0 million in FY 2001 Congressional earmarks; and (2) Fusion Energy Sciences, whose FY 2002 request of $238.5 million is a reduction of $10.0 million or 4.0 percent. The DOE plans to submit a budget amendment to increase the Fusion account by $10.0 million offset by decreases to High Energy Physics (–$5.0 million), Advanced Scientific Computing Research (–$2.7 million), Energy Research Analysis (–$0.3 million), and Program Direction (–$2.0 million).

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1. High Energy Physics *(FY 2001 = $712.001 million; FY 2002 = $721.1 million)*

DOE's High Energy Physics (HEP) Program funds about 90 percent of all U.S. high energy physics research and supports laboratory- and university-based high energy physics research at the B–Factory(see footnote 5) at SLAC, at the Main Injector for the Tevatron(see footnote 6) at Fermilab, and at the Alternating

Gradient Synchrotron (AGS) at BNL on an incremental cost basis. HEP, along with NSF, also participates in the European Laboratory for Particle Physics (CERN) Large Hadron Collider (LHC)(see footnote 7) project. In addition, HEP funds non-accelerator experiments, and theory and accelerator R&D programs.

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The FY 2002 HEP budget request is $721.1 million, as shown in Table 3.(see footnote 8) This is an increase of $38.05 million—or 5.6 percent—over the FY 2000 appropriation of $683..05 million, and an increase of $9.099 million—or 1.3 percent—above the FY 2001 appropriation of $712.001 million. Funding by DOE Laboratory and by universities and other performers is shown in Table 4.

73328t4.eps

In FY 2002, the program will focus on "windows of opportunity" related to finding the Higgs Boson (Fermilab) and on CP violation (SLAC) to explore the preponderance of matter over antimatter. HEP will continue its participation in the Large Hadron Collider project, but at a reduced level as agreed to by CERN. Construction funding is reduced with completion of two projects in FY 2001 and another nearing completion in FY 2002.

Funding for Research and Technology *(FY 2001 = $242.836 million; FY 2002 = $247.87 million)* increases by $5.034 million primarily to support research and future facility upgrades at Fermilab (related to the search for the Higgs Boson) *(FY 2001 = $33.4 million; FY 2002 = $35.1 million)*, and at SLAC (for CP violation investigations) *(FY 2001 = $34.4 million; FY 2002 = $36.6 million).* University R&D declines by $5.6 million *(FY 2001 = $110.9 million; FY 2002 = $105.3 million).*

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High Energy Physics Facility Operations *(FY 2001 = $436.836 million; FY 2002 = $456.83 million)* focuses on enhanced operations of Fermilab and SLAC. Fermilab *(FY 2001 = $211.406 million; FY 2002 = $244.739 million)* will operate for 22 weeks in FY 2001 and 39 weeks in FY 2002 as it increases its search for the Higgs Boson. Fermilab funding includes continued fabrication of the MINOS Detector *(FY 2001 = $15.0 million; FY 2002 = $18.0 million)* for the Neutrinos at the Main Injector (NuMI) project, and other facility improvement projects. SLAC *(FY 2001 = $116.449 million; FY 2002 = $125.078 million)* will operate for 34 weeks in FY 2001 and 35 weeks in FY 2002, concentrating on CP violation investigations. SLAC funding includes a $2.5 increase for GLAST, a joint DOE/NASA effort to study cosmic radiation from a satellite. Funding for the Large Hadron Collider declines to a level agreed upon by CERN *(FY 2001 = $58.9 million; FY 2002 = $49.0 million).*

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Construction funding *(FY 2001 = $32.329 million; FY 2002 = $11.4 million)* decreases at Fermilab with completion of the Wilson Hall Safety Improvements project in FY 2001 (–$4.191 million) and completion of funding for the NuMI project in FY 2002 *(FY 2001 = $22.949 million; FY 2002 = $11.4 million).* At

SLAC, the SLAC Research Office Building is completed in FY 2001 (–$5.189 million).

2. Nuclear Physics *(FY 2001 = $360.508 million; FY 2002 = $360.51 million)*

The DOE Nuclear Physics (NP) program funds about 85 percent of all U.S. nuclear physics research and conducts research activities needed to understand the structure of atomic nuclei and the fundamental forces required to hold nuclei together. NP supports nuclear physics theoretical research and a number of research facilities located at National Laboratories and universities, including the following:

Argonne Tandem-Linac Accelerator System (ATLAS) at ANL—Provides variable energy, precision beams of stable ions from protons through uranium, at energies up to 10 million electron volts (MeV per nucleon) using a superconducting linear accelerator for Heavy Ion Nuclear Physics research.

MIT Bates Linear Accelerator Center in Massachusetts—Carries out Medium Energy Nuclear Physics research with electron beams up to 1 billion electron volts (GeV) in energy.

Relativistic Heavy Ion Collider (RHIC) at BNL—Provides colliding-beam collisions of 100 GeV per atomic mass unit per beam for heavy ions as massive as gold for the study of nuclear matter as it undergoes a phase transition to a plasma of gluons and quarks.

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88-inch Cyclotron at LBNL—Provides high intensity stable beams from protons to bismuth at energies up to 15 MeV per nucleon.

Holifield Radioactive Ion Beam Facility (HRIBF) at ORNL—Only radioactive nuclear beam facility in the U.S. to use the isotope separator on-line (ISOL) method and provides a wide range of both proton-rich and neutron-rich nuclei to a suite of instruments designed for studies in nuclear structure, dynamics and astrophysics using radioactive beams; accelerates secondary radioactive beams to higher energies (up to 10 MeV per nucleon) than any other facility in the world with such a broad selection of ions.

Continuous Electron Beam Accelerator Facility (CEBAF) at the TJNAF—Capable of providing polarized and unpolarized electron beams of up to 5.7 GeV to three experimental halls for Medium Energy Nuclear Physics research.

Facilities at four universities—Texas A&M Cyclotron Institute (TAMU), Triangle Universities Nuclear Laboratory (TUNL) at Duke University, Yale University A.W. Wright Nuclear Structure Laboratory tandem Van de Graaff accelerator, and the University of Washington Nuclear Physics Laboratory tandem Van de Graaff and superconducting linac accelerators.

The FY 2002 NP budget request is $360.51 million, as shown in Table 5. This is an increase of $19.641 million—or 5.8 percent—over the FY 2000 appropriation of $340.869 million, and an increase of $2,000—or 0.0 percent—above the FY 2001 appropriation of $360.508 million. Funding by DOE Laboratory and by universities and other performers is shown in Table 5.

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The FY 2002 request for Medium Energy Nuclear Physics *(FY 2001 = $118.621 million; FY 2002 = $118.02 million)* reflects a reduction for completion of the MIT BLAST detector *(FY 2001 = $1.2 million; FY 2002 = $0.0); this and other small savings are used to maintain operation of the MIT Bates accelerator (13 weeks in FY 2001 and 14 weeks in FY 2002) and the TJNAF (27 weeks in FY 2001 and 26 weeks in FY 2002) at near FY 2001 levels.*

Heavy Ion Nuclear Physics *(FY 2001 = $155.817 million; FY 2002 = $156.295 million)* primarily funds research and operations of RHIC. Total BNL funding for RHIC, which will operate 27 weeks in FY 2001 and 20 weeks in FY 2002, increases by $1.0 million *(FY 2001 = $113.6 million; FY 2002 = $114.6 million)* while university research declines from FY 2001 *(FY 2001 = $12.0 million; FY 2002 = $11.5 million).*

Low Energy Nuclear Physics *(FY 2001 = $62.693 million; FY 2002 = $62.69 million)* has little change in funding but has minor reallocations between research and facility operations. The facilities funded by this subprogram will have relatively stable budgets but reduced operating times (HRIBF—14 weeks in FY 2001 and 13 weeks in FY 2002; ATLAS—34 weeks in FY 2001 and 23 weeks in FY 2002; 88-inch Cyclotron—33 weeks in FY 2001 and 27 weeks in FY 2002). R&D and preconceptual design for the Rare Isotope Accelerator (RIA) continues *(FY 2001 = $2.8 million; FY 2002 = $3.0 million).*

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Nuclear Theory *(FY 2001 = $23.377 million; FY 2002 = $23.505 million)* will continue theoretical research and the Nuclear Data program at essentially the FY 2001 funding level.

3. Biological and Environmental Research *(FY 2001 = $482.52 million; FY 2002 = $442.97 million)*

The Biological and Environmental Research (BER) program aims to develop the knowledge needed to identify, understand and mitigate the adverse health and environmental consequences of energy production, development, and use. The program is structured along the following four subprograms:

Life Sciences focuses on understanding and mitigating the potential effects of energy production, use, and waste cleanup. Structural Biology analyzes and predicts gene function and is concerned with recognition and repair of DNA damage. Molecular and Cellular Biology has several elements: The completed sequencing of over SO microbes for possible use in solving DOE problems in energy, waste, cleanup, and carbon management; microbes will be used for methane and hydrogen production from carbon sources and for carbon sequestration; the microbial cell project, which sought a complete understanding of a single cell, has evolved into the Genomes to Life project which will look at multi-cellular systems to predict their behavior and response to environmental cues; and, research on biological effects of low dose radiation will determine safe radiation exposure levels for clean-up workers and the general public. The Human Genome program had a major milestone in June 2000 when the President announced completion of a working draft of human DNA sequence, and in February 2001, the draft sequence was published. Much work remains, including understanding biological systems, gene function and variation and how they affect human disease, comparative sequencing, and understanding the role of the "junk" DNA. The Health Effects subprogram seeks an understanding of normal human development and disease processes. Construction continues on the Laboratory for Comparative and Functional Genomics at ORNL.

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Environmental Processes represents DOE's contribution to the U.S. Global Change Research Program (USGCRP). Working with other federal agencies, the program will continue to develop climate models with improved abilities to predict climate on regional scales. Program elements include: climate modeling; the Atmospheric Radiation Measurement program to understand the role of clouds and solar radiation in climate prediction; atmospheric chemistry and the carbon cycle; and, studying the effects of elevated carbon dioxide (CO) levels on terrestrial ecosystems. It also supports partnerships on terrestrial and ocean carbon cycles.

Environmental Remediation performs research related to remediation and restoration of the nation's nuclear weapons production sites. The Natural and Accelerated Bioremediation Research (NABR) program focuses on determining the use of bioremediation in subsurface environments. Funding is provided for operation of the William R. Wiley Environmental and Molecular Sciences Laboratory at PNNL.

Medical Applications and Measurement Science develops new medical diagnostic and therapeutic tools. Research activities include: continuation of Boron Neutron Capture Therapy and radionuclide therapies for cancer treatment, radiopharmaceutical design for disease diagnosis and treatment, non-invasive imaging techniques, and biomedical engineering.

The FY 2002 BER budget request is $442.97 million, as shown in Table 7. This is an increase of $26.933 million—or 6.5 percent—over the FY 2000 appropriation of $416.037 million, and a decrease of $39.55 million—or 8.2 percent—below the FY 2001 appropriation of $482.52 million. The majority of the reduction reflects completion of 24 Congressionally directed projects (–$43.042 million). Funding by DOE Laboratory and by universities and other performers is shown in Table 8.

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Life Sciences *(FY 2001 = $192.472 million; FY 2002 = $186.205 million)* continues funding for the biology, human genome and health effects programs at $6.267 million below the FY 2001 level. The majority of the decrease reflects FY 2001 completion of the DNA Repair Protein Complex Beamline at LBNL (–$4.5 million). The Microbial Genomics program *(FY 2001 = $14.909 million; FY 2002 = $10.928 million)* is reduced with funds redirected mainly to Genomes to Life. The Microbial Cell project *(FY 2001 = $9.591 million; FY 2002 = $19.47 million)*, which began in FY 2001, is incorporated into the new and more comprehensive Genomes to Life program. Low Dose research *(FY 2001 = $18.458 million; FY 2002 = $12.655 million)* is held to near the FY 2001 request level that was lower than the appropriation level. The Human Genome program *(FY 2001 = $86.438 million; FY 2002 = $88.238 million)* has an increase for DNA sequencing technologies and sequencing analysis *(FY 2001 = $23.95 million; FY 2002 = $28.547 million).* The Health Effects subprogram *(FY 2001 = $12.21 million; FY 2002 = $14.251 million)* terminates its Technology Development Research activity (–$3.199 million) and increases funding for functional genomics (use of model organisms to understand function of human genes).

Environmental Processes *(FY 2001 = $129.704 million; FY 2002 = $129.469 million)* continues DOE support of the USGCRP. A reduction in the Atmospheric Chemistry and Carbon Cycle subprogram of $1.725 million for completion of two Congressionally directed projects in FY 2001 is offset by increased funding for terrestrial and ocean carbon cycle research *(FY 2001 = $12.731 million; FY 2002 = $13.716 million).* There are only minor adjustments in the Climate and Hydrology subprogram *(FY 2001 = $70.326 million; FY 2002 = $70.775 million)* which includes all Atmospheric Radiation Measurement (ARM) Activity.

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The Environmental Remediation program *(FY 2001 = $61.461 million; FY 2002 = $66.137 million)* provides funding for operations of the Environmental and Molecular Sciences Laboratory (EMSL) at PNNL. EMSL funding *(FY 2001 = $31.054 million; FY 2002 = $34.054 million)* increases to lease a 2–3 teraflop computer for molecular modeling and structural genomics. Funding for Bioremediation (Natural and Accelerated Bioremediation Research) and Clean-up Research is increased by $1.48 million.

Medical Applications and Measurement Science *(FY 2001 = $96.388 million; FY 2002 = $51.159 million)* funding drops significantly due to completion of 21 Congressionally directed projects *(FY 2001 = $41.125 million; FY 2002 = $0.0). Funding for radiopharmaceutical design and synthesis also declines (FY 2001 = $26.637 million; FY 2002 = $24.445 million)* as infrastructure support is completed.

Construction *(FY 2002 = $2.5 million; FY 2002 = $10.0 million)* funding for the Laboratory for Comparative and Functional Genomics at ORNL increases as planned in FY 2002.

4. Basic Energy Sciences *(FY 2001 = $991.679 million; FY 2002 = $1,004.705 million)*

The Basic Energy Sciences (BES) program supports fundamental research to provide the foundations for new and improved energy technologies and for understanding and mitigating the environmental impacts of energy use. The BES mission includes planning, construction, and operation of major scientific user facilities serving researchers at universities, national laboratories and industrial laboratories. Research is conducted in four areas Research is conducted in four areas—Materials Science, Chemical Sciences, Engineering and Geosciences, and Energy Biosciences.

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Materials Sciences performs research to make materials perform better at acceptable cost through new methods of synthesis and processing. Research in nanoscale science has become a major focus.

Chemical Sciences seeks to understand fundamental interactions of atoms, molecules, and ions with photons and electrons, and is crucial to improving combustion systems and solar photoconversion processes. It also underpins improvements in energy systems, catalytic systems, catalysis for fuels and chemical production, waste management and environmental remediation. The program also supports nanoscale science.

The Materials and Chemical Sciences subprograms also plan, construct, and operate major scientific user facilities that include: four synchrotron light sources (Advanced Photon Source at ANL, Advanced Light Source at LBNL, the National Synchrotron Light Source at BNL, the Stanford Synchrotron Radiation Laboratory at SLAC). Also included are: (1) three neutron sources (Intense Pulsed Neutron Source at ANL; the High Flux Isotope Reactor at ORNL, Tennessee, and the Los Alamos Neutron Science Center at LANL. In addition, BES manages four electron beam micro-characterization facilities and five other specialized facilities, such as the Combustion Research Center at SNL-Livermore, that are located throughout the U.S. BES is currently supporting construction of a major new scientific user facility, the $1.4117 billion Spallation Neutron Source (SNS) at ORNL, which when completed, will be the world's most powerful spallation neutron source.

Within Engineering and Geosciences, Engineering research supports DOE's mission needs of the Department including: robotics and intelligent machines, nano-engineering, and data and engineering analysis. Geosciences research seeks to improve the fundamental understanding of earth processes that affect energy production and environmental quality.

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Energy Biosciences supports research in the formation, storage, and interconversion of energy by plants and microorganisms. This includes renewable fuel resources, agents to restore disrupted environmental sites, and photosynthesis.

The FY 2002 BES budget request is $1,004.705 million, as shown in Table 9. This is an increase of $239.648 million—or 31.9 percent—over the FY 2000 appropriation of $752.031 million, and an increase of $13.026 million—or 1.3 percent—above the FY 2001 appropriation of $991.679 million. Funding by DOE Laboratory and by universities and other performers is shown in Table 10, and major user facility funding is shown in Table 11.

Most of the increase in BES is related to construction—funding for the SNS increases from $258.929 million in FY 2001 to $276.3 million in FY 2002; and new funding of $4.0 million is requested for plant engineering and design for six Nanoscale Science Research Centers. Research and facility operations are funded at or slightly below FY 2001 levels, and small increases are offset by a transfer of funding for the High Flux Beam Reactor (–$15.341 million) to the Office of Environmental Management.

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Materials Sciences *(FY 2001 = $443.242 million; FY 2002 = $434.353) transfers responsibility for the High Flux Beam Reactor (HFBR) at BNL to the Office of Environmental Management in FY 2002 for surveillance and decommissioning (*–$15.341 million). Some of the HFBR funds made available will support increases for neutron and x-ray scattering at three existing facilities and the new SNS *(FY 2001 = $31.211 million; FY 2002 = $36.293 million).* The High Flux Isotope Reactor (HFIR) Beam Tube project at ORNL was completed in FY 2001 *(FY 2001 = $1.2 million; FY 2002 = $0.0) and provides access for, six. additional experiments at higher flux; acquisition of new and upgraded neutron scattering instruments for HFIR are initiated (FY 2001 = $0.0; FY 2002 = $2.0 million).* SNS project related costs for the Spallation Neutron Source are reduced according to schedule *(FY 2001 = $19.059 million; FY 2002 = $15.1 million).*

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Chemical Sciences *(FY 2001 = $216.526 million; FY 2002 = $218.714 million)* maintains research and facility operations funding at near FY 2001 levels. There is a small increase in operations of the Stanford Synchrotron Radiation Laboratory *(FY 2001 = $16.838 million; FY 2002 = $17.838 million)* and the High Flux Isotope Reactor at ORNL *(FY 2001 = $28.769 million; FY 2002 = $30.085 million).*

Construction *(FY 2001 = $258.929 million; FY 2002 = $280.3 million)* funding for the SNS *(FY 2001 = $258.9 million; FY 2002 = $276.3 million)* increases by $17.4 million as planned. Also, new plant engineering and design funds of $4.0 million are requested for six Nanoscale Science Research Centers.

5. Advanced Scientific Computing Research *(FY 2001 = $165.75 million; FY 2002 = $165.75 million)*

The Advanced Scientific Computing Research (ASCR) program supports world leadership in areas of scientific computing research relevant to the DOE missions, and supports the goal of providing extraordinary tools for extraordinary science. Research in Mathematical, Information, and Computational Sciences concentrates on advanced computing applications and techniques that enable researchers to analyze, model, simulate, and predict complex physical, chemical, and biological phenomena relevant to DOE. Mathematical methods are developed to model these complex systems, and software is developed to support these large applications on high performance, terascale computers. This program also provides the resources for these applications. The National Energy Research Scientific Computing Center (NERSC) at Lawrence Berkeley National Lab supports over 2,000 users, and is in the process of being upgraded to a five teraflop computer. The Energy Sciences Network (ESNET) links the Office of Science researchers and facilities, and by the year 2005 plans to have network speeds 500 times faster than today's highest speeds. The program also provides software tools for collaboratory projects that link geographically distributed research teams with experimental and computational facilities.

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The Laboratory Technology Research subprogram supports cost-shared partnerships with the private sector to transfer high-risk, long-term basic research to applied energy efficiency and utilization technologies.

The FY 2002 ASCR budget request is $165.75 million, as shown in Table 12.(see footnote 9) This is an increase of $43.412 million—or 35.5 percent—over the FY 2000 appropriation of $122.338 million, and equal to the FY 2001 appropriation. Funding by DOE Laboratory and by universities and other performers is shown in Table 13.

Mathematical, Computational and Computer Sciences *(FY 2001 = $70.654 million; FY 2002 = $70.681 million)* will continue development of the mathematics required for effective description and prediction of physical systems ($32.339 million), development of software to effectively utilize high-end performance computers ($21.051 million), software tools for high performance applications ($8.473 million), and pilot projects to apply these tools to DOE applications ($8.791 million).

Advanced Computation, Communications Research, and Associated Activities *(FY 2001 = $81.543 million; FY 2002 = $81.543 million)* will continue to conduct research on advanced networking needed to support distributed large scale scientific collaborations ($7.066 million), develop and test the software tools to support these collaborations ($16.384 million), support hardware testbeds for testing advanced hardware and software ($13.061 million), and support users with the National Energy Research Scientific Computing Center (NERSC) at LBNL ($28.244 million) and the Energy Sciences Network (Esnet) ($16.788 million).

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Laboratory Technology Research *(FY 2001 = $9.58 million; FY 2002 = $6.88) reduces support for CRADA projects by about 30 percent.*

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6. Energy Research Analyses *(FY 2001 = $0.976 million; FY 2002 = $1.3 million)*

The Energy Research Analyses program evaluates the scientific excellence, relevance, and international leadership of DOE basic science program and projects.

The FY 2002 Energy Research Analyses budget request is $1.3 million.(see footnote 10) This is an increase of $0.35 million—or 36.8 percent—over the FY 2000 appropriation of $0.95 million, and an increase of $0.324 million—or 33.2 percent—above the FY 2001 appropriation of $0.976 million.

7. Multiprogram Energy Laboratories-Facilities Support *(FY 2001 = $30.174 million; FY 2002 = $30.175 million)*

The mission of the Multiprogram Energy Laboratories-Facilities Support (MEL–FS) program is to support the infrastructure of the five Office of Science multiprogram national laboratories—ANL–East, BNL, LBNL, ORNL, and PNNL—by funding line item construction funding (*i.e.*, projects with a total estimated cost of $5.0 million or above) for general purpose facilities. The program also provides Payments in Lieu of Taxes (PILT) through the DOE Chicago Operations Office as authorized by the Atomic Energy Act of 1954, as amended, which are made to State or local governments where the DOE or its predecessor agencies have acquired property previously subject to State or local taxation (local communities around ANL–East, BNL, and ORNL qualify for PILT). Finally, the program also supports costs incurred for centralized Oak Ridge Operations Office (ORO) infrastructure requirements and general operating costs essential to maintaining a viable, functioning operations office; activities include roads and grounds maintenance, infrastructure maintenance, physical security, emergency management, support of the Oak Ridge Financial Service Center and other technical needs related to landlord responsibilities of the ORO.

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The FY 2002 request, shown in Table 14, for the MEL–Facilities Support program is $30.175 million, an increase of $0.618 million—or 2.1 percent—above the FY 2000 appropriation of $29.557 million, and an increase of $1,000—or 0.0 percent—below the FY 2001 appropriation of $30.175 million. Within this funding level, there is a shift of $3.4 million from General Purpose Projects to Environment, Safety and Health projects. Funding by DOE Laboratory/Operations Office is shown in Table 15 for the Multiprogram Energy Laboratories Facility Support.

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8. Fusion Energy Sciences *(FY 2001 = $248.493 million; FY 2002 = $238.495 million)*

The Fusion Energy Sciences (FES) program seeks to understand and control the process of fusion of deuterium and tritium that can produce an enormous release of energy. The program mission is to advance plasma science, fusion science, and fusion technology. In recent years the program has refocused its emphasis from development of a new energy source to a strong science-based program in fusion (magnetic and inertial confinement) and plasma physics.

FES has three subprograms:

(1) Science, which supports tokamak research, investigation of alternative concepts, plasma science, theory and inertial confinement fusion;

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(2) Facilities Operations, which funds operation and maintenance of the DIII–D tokamak at General Atomics (GA) in San Diego, the Alcator C–Mod tokamak at MIT, and the National Spherical Tokamak Experiment (NSTA) in Princeton, and also funds decontamination and decommissioning of the Tokamak

Fusion Test Reactor (TFTR) at Princeton; and

(3) Enabling R&D, which provides engineering and materials research support.

The FY 2002 budget request for Fusion Energy Sciences (FES), contained in Table 16, is $238.495 million.(see footnote 11) This is an increase of $0.235 million—or 0.1 percent—above the FY 2000 appropriation of $238.26 million, and a decrease of $9.998 million—or 4.0 percent—below the FY 2001 appropriation of $238.495 million. FES funding by DOE Laboratory and by universities and other performers are shown in Table 17.

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Science *(FY 2001 = $136.312 million; FY 2002 = $133.44)* will continue research at DIII–D, National Spherical Tokamak Experiment (NSTX), and the Alcator C–Mod and through international collaboration. To absorb part of the FES reduction, experimental plasma research in tokamaks and alternative concepts is reduced by $1.508 million *(FY 2001 = $31.508; FY 2002 = $30.0 million)*. Inertial Fusion Energy research *(FY 2001 = $13.792 million; FY 2002 = $13.152 million)* and Theory *(FY 2001 = $27.275 million; FY 2002 = $25.975 million)* also decline.

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Facility Operations *(FY 2001 = $77.896 million; FY 2002 = $71.994 million)* will allow: (1) the DIII–D at GA to operate 17 weeks in FY 2001 and 14 weeks in FY 2002 *(FY 2001 = $29.249 million; FY 2002 = $26.706 million);* (2) the Alcator C–Mod at MIT to operate 12 weeks in FY 2001 and 8 weeks in FY 2002 *(FY 2001 = $10.636 million; FY 2002 = $9.6 million);* and (3) the NSTX at Princeton to operate 15 weeks in FY 2001 and 11 weeks in FY 2002 *(FY 2001 = $14.366 million; FY 2002 = $13.2 million)*. Funding for the TFTR decontamination and decommissioning *(FY 2001 = $19.031 million; FY 2002 = $18.0 million)* should bring the project to completion.

Enabling R&D *(FY 2001 = $34.285 million; FY 2002 = $33.061 million)* will fund Tritium Systems Test Assembly (TSTA) *(FY 2001 = $2.163 million; FY 2002 = $3.3 million)* increases to reduce the tritium inventory in preparation for transfer of this excess facility to Environmental Management (+$1.137 million). Minor reductions and transfer of SBIR/STTR offset this to the Science subprogram (–$0.898 million).

9. Safeguards and Security *(FY 2001 = $36.447 million; FY 2002 = $50.5 million)*

The mission of the Office of Science Safeguards and Security program is to ensure appropriate levels of protection against: unauthorized access, theft, diversion, loss of custody, or destruction of DOE assets and hostile acts that may cause adverse impacts on fundamental science, national security or the health and safety of DOE and contractor employees, the public or the environment. Each site has a tailored protection program as analyzed and defined in each site's Security Plan or other appropriate plan.

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Activities performed include the following:

Physical Protection Protective Forces—provides for security guards, management, and or supervision, training and equipment needed for effective performance of protection tasks during normal and emergency conditions.

Physical Security Protective Systems—provides for equipment to protect vital security interests and government property per the local threat. Equipment and hardware includes fences, barriers, lighting, sensors, entry control devices, etc. This hardware and equipment is generally operated and used to support the protective guard mission as well.

Information Security—ensures that materials and documents, that may contain sensitive or classified information, are accurately and consistently identified, properly reviewed for content, appropriately marked and protected from unauthorized disclosure, and ultimately destroyed in an appropriate manner.

Cyber Security—ensures that sensitive and classified information that is electronically processed or transmitted is properly identified, protected, and tested and that all electronic systems have an appropriate level of infrastructure reliability and integrity.

Personnel Security—includes clearance program, security education and awareness for employees, and visitor control. This is accomplished through initial and termination briefings, re-orientations, computer based training, special workshops, publications, signs, and posters.

Material Control and Accountability—provides for the control and accountability of special nuclear materials, including training and development for assessing the amounts of material involved in packaged items, process systems and wastes. Additionally, this activity documents that a theft, diversion or operational loss of special nuclear material has not occurred. Also included is on-site and off-site transport of special nuclear materials in accordance with mission, environmental and safety requirements.

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The FY 2002 budget request for Safeguards and Security, contained in Table 18, is $50.5 million. This is an increase of $13.197 million—or 35.4 percent—above the FY 2000 appropriation of $37.303 million, and an increase of $14.053 million—or 38.6 percent—above the FY 2001 appropriation of $36.447 million. Safeguards and Security funding by site is shown in Table 19.

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Safeguards and Security increases $14.053 million over the FY 2001 level to fully fund all activities at the Office of Science laboratories and field sites. The largest part of the increase is for protective forces (salaries, etc.) (+$4.389 million), security systems (+$2.183 million), cyber security (+$3.93 million), and program management (+$1.984 million).

10. Program Direction *(FY 2001 = $126.906 million; FY 2002 = $144.385 million)*

Science Program Direction consists of three subprograms: Program Direction, Science Education, and Field Operations.

Program Direction is the funding source for the Office of Science (SC) Federal staff that directs and administers a broad spectrum of scientific disciplines and provides technical and administrative support directly related to Science in Headquarters, the Chicago and Oak Ridge Operations Offices, and the Berkeley and Stanford Site Offices. It provides funding for salaries and benefits, travel, support services, and other related expenses, including the Working Capital Fund.

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Science Education sponsors programs that enable college and university students and faculty to take advantage of fellowship and research opportunities at the National Laboratories and user facilities, all designed to promote interest in science, math, engineering, and technology fields. These include: (1) the Energy Research Undergraduate Laboratory Fellowship Program (ERULF), which is designed to provide educational training and research experiences at DOE laboratories for highly motivated undergraduate students; (2) the National Science Bowl Program, a highly-publicized academic competition among high school students who answer questions on scientific topics in astronomy, biology, chemistry, mathematics, physics, earth, computer and general science; (3) the Albert Einstein Distinguished Educator Fellowship Program, which supports outstanding science and mathematics teachers, who provide insight, extensive knowledge, and practical experience to the Legislative and Executive branches; and (4) the DOE Community College Institute (CCI) of Biotechnology, Environmental Science, and Computing, collaboration among DOE National Laboratories and the American Association of Community College that provides 10-week educational human resource development experiences at several DOE National Laboratories for highly motivated community college students.

The FY 2002 budget request for Program Direction, contained in Table 20, is $144.385 million.(see footnote 12) This is an increase of $23.894 million—or 19.8 percent—above the FY 2000 appropriation of $120.491 million, and an increase of $17.479 million—or 13.8 percent—above the FY 2001 appropriation of $126.906 million.

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11. Technical Information Management

The Technical Information Management (TIM) program collects, preserves, organizes, and disseminates scientific and technical information resulting from DOE R&D and environmental programs. The program provides worldwide energy scientific and technical information to DOE, U.S. industry, academia, and the public through a set of Internet based information products for technical reports, scientific journals and preprints—the three main sources in which scientific and technical information is recorded. The TIM program also coordinates technical information activities throughout the DOE complex, maintains a classified information program, and serves as DOE's leader in the international exchange of scientific and technical information. The Science and Energy and Commerce Committees share TIM program jurisdiction.

Report literature is disseminated via the Information Bridge *(http://www.osti.gov/bridge/),* which provides free, full-text access to over 70,000 technical reports. For journal literature, TIM has developed PubScience *(http://pubsci.osti.gov/),* which provides searchable bibliographic records with links to full-text journal articles in over 1,400 journals at publishers' web sites. The PrePrint Network *(http://www.osti.gov/preprint/)* provides searchable access to over 2,400 preprint sites worldwide. The TIM program also represents DOE and the U.S. in the International Energy Agency's Energy Technology Data Exchange (EDTE), which includes 18 industrialized nations. TIM has also established electronic subscription arrangements with publishers.

The FY 2002 budget request for TIM, contained in Table 21, is $8.97 million. This is an increase of $0.219 million—or 2.5 percent—above the FY 2000 appropriation of $8.751 million, and an increase of $0.238 million—or 2.7 percent—above the FY 2001 appropriation of $8.732 million.

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In FY 2002, an increase of $0.234 million is requested to support the 83 FTEs. All other program activities are essentially unchanged.

Chairman **BARTLETT.** We will now convene the hearing. Today we will consider issues and opportunities at the Department of Energy, Office of Science. With the current year budget of over $3.1 billion, the DOE Office of Science is the largest single program under our Subcommittee's jurisdiction. The Office of Science is also the largest Federal funder of scientific facilities and the physical sciences such as physics and chemistry and also plays a major role supporting other scientific fields, including life sciences, mathematics, computation, engineering, and environmental sciences.

The Office provides the largest share of funding for ten DOE laboratories and also funds programs at other DOE labs, as well as at a number of research facilities located at universities. In addition, two DOE Operations Offices, Chicago and Oak Ridge, report to the Office of Science and the Office also manages DOE's Technical Information Management Program.

The Office of Science funds six major programs—High Energy Physics, Nuclear Energy Physics, Biological and Environmental Research, Basic Energy Science, Fusion Energy Sciences, and Advanced Scientific Computer Research. Each of these programs also has an advisory committee to provide independent advice regarding the complex, scientific, and technical issues that arise in their planning, management, and implementation, and we are pleased to have the chairs of each of these advisory committees here today on our first panel. We will also hear from a distinguished panel of outside witnesses after the DOE Advisory Committee Chair Panel has concluded.

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Panel one includes the following witnesses representing the DOE Office of Science Advisory Committees: Professor Fred Gilman of the Department of Physics at Carnegie Mellon, who chairs the Department of Energy High Energy Physics Advisory Panel; Dr. James Symons of the Nuclear Sciences Division at Lawrence Berkeley National Laboratory, who chairs the DOE/NSF Nuclear Science Advisory Committee; Dr. Geraldine Richmond of the Department of Chemistry at the University of Oregon, who chairs the DOE Basic Energy Sciences Advisory Committee. And Dr. Richmond has her priorities straight. She must leave at about 11:30 today because she has a child who is doing a piano concert—two children doing a piano concert and she needs to be there this evening. Thank you for showing us what proper priorities are.

Dr. Keith Hodgson of the Department of Chemistry at Stanford University, who is Director of the Stanford Synchrotron Radiation Laboratory and who chairs DOE's Biological and Environmental Research Advisory Committee; Professor Richard Hazeltine of the University of Texas at Austin Institute for Fusion Studies, who chairs DOE's Fusion Energy Sciences Advisory Committee; Dr. Margaret Wright of Lucent Technologies' Bell Laboratories, who chairs DOE's Advanced Scientific Computing Advisory Committee.

In the second panel, we will also hear from the following witnesses: Dr. Robert Richardson, who is Vice Provost for Research at Cornell University, and the recipient of the 1996 Nobel Prize in Physics; Dr. Charles Shank, who is Director of DOE's Lawrence Berkeley National Laboratory; and Professor James Drake of the University of Maryland's Institute for Plasma Research.

I look forward to hearing today's testimony on the current status of the DOE Office of Science programs, future opportunities, and major issues that confront the Office. Before we get started here, I would like to remind the members of the Subcommittee and our witnesses that this hearing is being broadcast live on the Internet, so please keep that in mind during today's proceedings.

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I would also like to ask for unanimous consent that all members who wish might have their opening statements entered into the record. Without objection, so ordered.

I am one of two Ph.D. scientists in the Congress. I came here from a career in basic research, but then moved into the engineering area. I was—have been awarded 20 patents in the engineering area. I came here with a major concern that the importance of basic research was underappreciated in our country.

When I first came, I was told that the Congress had a new focus, that we were only going to fund basic research that was going to have a societal payoff. And I asked them how they were going to do that. Because when you begin basic research, you have no idea whether or not it will have a societal payoff. I doubt that

Madam Curie had any idea as to the societal benefits of her early discoveries in radiation.

They asked me then, if that wasn't the right thing to do, what should the Congress do and how would we make sure that the taxpayers' dollars were properly spent. I told them that if we invested enough money to support good scientists without any concern as to whether or not the research they were doing would have societal payout, that they could be assured that there would be societal benefits from the research that we supported. But there is no way of knowing before you begin the research, or even during the research, whether or not there is going to be societal payoff. That is not the reason you do research. You do research to advance the frontiers of knowledge. And when you advance the frontiers of knowledge and push the envelope, there will be opportunities for societal benefit.

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As you all know, better than most people in our country, as a large nation, we invest a smaller percentage of our GDP in basic research and R&D than any other nation in the world. In the short term, I am concerned that this is going to impact our economic superiority. We will not continue to be the world's premier economic power unless we are turning out the world's best scientists, mathematicians, and engineers.

I worked for IBM Corporation, and this was a number of years ago, and we knew that we were at risk in IBM and we were at risk in our country of losing our superiority in computers to Japan for a very simple reason. At that time, Japan was turning out more and better scientists, mathematicians, and engineers than we were in this country. That very nearly came to be true. If you look in our technical schools today, most of the graduate students there are foreign graduate students. We are the envy of the world when it comes to our graduate schools and they flock here from all over the world. But the best minds in our country are not going into science, math, and engineering.

In the longer term, it is a threat to our national security. We will not continue to have the world's best military unless we have the world's best scientists, mathematicians, and engineers. So your contribution to our society is maybe greater than even you realize. We welcome you to our hearing today. We hope that America, through all of our combined voices, gets the message that you can't eat your seed corn—if you don't make the proper investments in basic science, tomorrow will not be a bright tomorrow. Let me turn now to my Ranking Member, Ms. Woolsey, for her opening remarks.

[The prepared statement of Mr. Bartlett follows:]

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PREPARED STATEMENT OF CHAIRMAN ROSCOE G. BARTLETT

Today, we will consider issues and opportunities at the Department of Energy (DOE) Office of Science.

With a current year budget of over $3.1 billion, the DOE Office of Science is the largest single DOE program under the Subcommittee's jurisdiction.

The Office of Science is the also largest Federal funder of scientific facilities and the physical sciences—

such as physics and chemistry—and plays a major role supporting other scientific fields, including life sciences, mathematics, computation, engineering, and environmental sciences.

The Office provides the largest share of funding for 10 DOE Laboratories, and also funds programs at other DOE labs, as well as at a number of research facilities located at universities.

In addition, two DOE Operations Offices—Chicago and Oak Ridge—report to the Office of Science and the Office also manages DOE's Technical Information Management Program.

The Office of Science funds six major programs: (1) High Energy Physics; (2) Nuclear Physics; (3) Biological and Environmental Research; (4) Basic Energy Sciences; (5) Fusion Energy Sciences; and (6) Advanced Scientific Computing Research. Each of these programs also has an advisory committee to provide independent advice regarding the complex scientific and technical issues that arise in their planning, management, and implementation, and we are pleased to have the chairs of each of these advisory committees here today on our first panel. We will also hear from a distinguished panel of outside witnesses after the DOE Advisory Committee Chair panel has concluded.

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Panel one includes the following witnesses representing the DOE Office of Science Advisory Committees:

Professor Frederick J. Gilman of the Department of Physics at Carnegie Mellon University, who chairs the DOE High Energy Physics Advisory Panel;

Dr. T. James Symons of the Nuclear Sciences Division at Lawrence Berkeley National Laboratory, who chairs the DOE/NSF Nuclear Science Advisory Committee;

Dr. Geraldine L. Richmond of the Department of Chemistry at the University of Oregon, who chairs the DOE Basic Energy Sciences Advisory Committee;

Dr. Keith O. Hodgson of the Department of Chemistry at Stanford University, who is Director of the Stanford Synchrotron Radiation Laboratory, and who chairs DOE's Biological and Environmental Research Advisory Committee;

Professor Richard D. Hazeltine of the University of Texas at Austin Institute for Fusion Studies, who chairs DOE's Fusion Energy Sciences Advisory Committee; and

Dr. Margaret H. Wright of Lucent Technologies' Bell Laboratories, who chairs DOE's Advanced Scientific Computing Advisory Committee.

In the second panel, we will hear from the following witnesses:

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Dr. Robert C. Richardson, who is Vice Provost for Research at Cornell University, and recipient of the

1996 Nobel Prize in Physics;

Dr. Charles V. Shank, who is Director of DOE's Lawrence Berkeley National Laboratory; and

Professor James F. Drake of the University of Maryland's Institute for Plasma Research.

I look forward to hearing today's testimony on the current status of the DOE Office of Science programs, future opportunities, and major issues that confront the Office.

Ms. **WOOLSEY.** Thank you very much, Mr. Chairman. I, too, am pleased to have this opportunity to hear from our witnesses. In looking over the group, such well-versed and wonderfully knowledgeable people, it is going to be a pleasure today. And the part of your willingness to share your expertise with us is a good opportunity for everybody on this Subcommittee. And also we will learn a lot about the Department of DOE. I am going to keep my remarks short. I want instead to have plenty of time to hear from everybody. And what I hope I will be hearing about is a good understanding of how priorities are set and what it takes to fully support efforts undertaken by the Department.

I am hoping to hear about perceived impediments to the full realization of science potential. And because the Subcommittee has already heard from DOE regarding the level of funding for Fiscal Year 2002, I hope that today's hearing and all of you will feel free to comment on the levels of funding and the effect it will have on your programs because your scientific priorities have to be funded if, indeed, your priorities are going to go forward.

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Personally, I feel that there are areas within the Office of Science that work well, but I also feel that there are areas that need serious review. And on the positive side, I am encouraged by the Department's commitment to multidisciplinary research within the Office. I am convinced, however, that a path to true understanding of many complex problems will take a level of coordination and cooperation between the different entities that we may not have. And I would like, if you can, to talk to me about that so that we understand where there is breakdowns and where we are—there is overlap.

Among one of my major concerns is the frequency that I hear about, about reduced support for operations and maintenance at DOE labs. Federal support of our state-of-the-art user facilities sometimes are completed, and sometimes as close as a year ago, cannot be waning. I mean, we have to have that support, but we have to have that support used in the right ways. And I need you to talk to me about that so that I don't feel like we are jumping on to the next program that is popular like a child that gets rid of a toy and goes on to the next toy after we have already invested in the first toy thinking that was going to satisfy.

So please let me know how that is working in your areas. And know that I feel strongly that science is key to solving many of our societal problems—our energy supply, our diseases, cancer, Parkinson's, all that need basic science to start the beginnings of some of the major research that is going to go on. Our limited natural resources—that is an area that we have to be responding to and focusing on. And I view it as one of this Committee's responsibilities, Mr. Chairman, to make sure that we are really charting a mature, responsible, and well-planned path that goes forward.

So with that, I said I was not going to say a lot. I said way more than I intended. Let me say that I am eager to hear from about—from your testimony today and I thank you very much for being here.

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[The prepared statement of Lynn Woolsey follows:]

PREPARED STATEMENT OF LYNN WOOLSEY

Thank you very much, Mr. Chairman. I am pleased to have the opportunity to hear from nine witnesses that are very well versed in their particular area and willing to share their expertise and their views on issues and opportunities that exist within the Office of Science at DOE. I will keep my remarks brief in deference to the witnesses that have prepared testimony intended to help Congress better understand the priorities, opportunities, and obstacles related to research and development within the Office of Science.

My hope for today is that we will come away with a better understanding of how priorities are set and what it takes to fully support efforts undertaken by the Department. I hope to hear about perceived impediments to the full realization of our scientific potential. And since the Subcommittee has already heard from DOE regarding the level of funding for Fiscal Year 2002, I see today's hearing as an opportunity to hear how these levels might effect the realization of these scientific priorities.

Personally, I feel that there are areas within the Office of Science that work well and those that need serious review. On the positive side, I am encouraged by the Department's commitment to multidisciplinary research within the Office of Science. I am convinced that this is the path to true understanding of many complex scientific problems.

However, I am curious as to the level of coordination between Office of Science programs and other programs such as Energy Efficiency and Fossil Energy and hope our witnesses could speak to the level of communication that exists.

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Among my concerns are the frequency with which I am hearing about reduced support for operations and maintenance at DOE labs. Federal support of our state-of-the-art user facilities, some completed as recently as a year ago, must not wane in the face of the next bigger-better project, like the affections of a child that discards one toy for the excitement of a brighter-shinier new one.

I feel very strongly that science is the key to solving many of our societal problems—energy supply, cancer, Parkinson's disease, limited natural resources—and I view it as the responsibility of this Committee and others to make sure that we charting a mature, responsible, and well-planned path forward.

With that let me say that I am eager to hear external witnesses testify to the exciting science being done at the Department, and the steps that need to be taken to fully support the investment we've made to science and society.

Chairman **BARTLETT.** Thank you very much. I was very interested to see that the six of you have coordinated your testimony. So let me just ask that you proceed in any way you wish. Your full written testimony will be made a part of the record without objection. We would encourage you, as far as possible, to limit your remarks to 5 minutes now, with the assurance that there will more than ample time to expand on anything that you want to expand on during the question and answer exchange after your formal remarks. Thank you very much and proceed as you had planned.

[The prepared statement of Dr. Hodgson, Dr. Wright, Dr. Richmond, Mr. Hazeltine, Mr. Gilman, and Dr. Symons follows:]

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PREPARED STATEMENT OF THE DOE OFFICE OF SCIENCE ADVISORY COMMITTEE CHAIRS

Introduction and Overview of the DOE Office of Science Programs

We are the chairpersons of the six external Advisory Committees that provide strategic guidance and advice to the Director of the U.S. Department of Energy (DOE) Office of Science (SC) and help set scientific priorities. We appreciate very much the opportunity to testify at this hearing of the Subcommittee on Energy of the Committee on Science of the U.S. House of Representatives. Besides introducing briefly each of our six programs, we would like to share our views on DOE Science and its future. To begin, we would point out that

DOE SC is the principal supporter of physical sciences research and a major supporter of research in biological sciences, mathematics, and computing in our country.

DOE SC plays a major role in maintaining and building the scientific workforce needed to sustain the U.S. scientific enterprise and meet challenging opportunities in the future.

DOE SC supports a large amount of basic peer-reviewed research at our universities and National Laboratories, especially in the physical sciences.

DOE SC plans, builds, and operates our Nation's large user facilities, including synchrotron light sources, neutron sources, fusion energy science facilities, particle physics accelerators, supercomputers and environmental research centers.

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The DOE has broad and deep involvement in our Nation's scientific enterprise. Effective scientific research requires a sustained commitment: to ensure that the U.S. is among the world leaders in the areas of science supported by the DOE Office of Science; to support the ongoing programs; to ensure the maximum availability of facilities to support the research; to train future scientists; and to seize new research opportunities as soon as they emerge. To accomplish these missions, the DOE Office of Science supports highly successful, peer-reviewed basic research programs at universities in every state in our Nation. These programs involve 4,900 Ph.D. level researchers, 3,200 graduate students, and 1,000 other technical and supporting staff. In addition to being a major supporter of basic peer-reviewed research in our universities and National Laboratories, the DOE Office of Science plans, builds, and operates the Nation's large scientific user facilities, including synchrotron light sources, neutron sources, fusion energy science facilities, particle physics accelerators, supercomputers and environmental research centers. These facilities are jewels in our Nation's science infrastructure and models for the international research community. Roughly b of the more than 16,000 scientists using these unique facilities are from universities, about & are graduate students or postdoctoral candidates. Much of their research depends critically on the effective and sustained operation of the facilities.

The FY 2001 budget for the DOE Office of Science reverses a trend of several years of level or declining funding and allows continuing ongoing construction projects (most notably the spallation neutron source, SNS), beginning several new initiatives (for example in nanoscience/technology and scientific computing) and continuing core programs (though generally only at or below inflationary levels). We hope that in FY 2002 and beyond, DOE Science can be even better recognized for the major role it has in the Federal R&D portfolio, thus building upon past investments and strengthening its role as the largest single supporter of research in the physical sciences in the U.S. (and the 3rd largest overall supporter of basic research).

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To recognize this potential, the Office of Science budget should aim for a better balance between the physical sciences and engineering, on the one hand, and the life and biomedical sciences on the other. Indeed, in view of the role of physical science as the foundation for research in life sciences, DOE Office of Science funding should keep pace with the growth in the National Institutes for Health (NIH). In this way the Office of Science can continue its current world-class work while capitalizing on new opportunities in areas that include scientific computing, nanoscale science, engineering and technology, and post sequence-genomics research.

Hence, given the unique and irreplaceable role that the DOE Office of Science plays in our Nation's scientific enterprise, we hope efforts can be made to sustain significant growth in FY 2002 and beyond. In particular, the following actions seem to us essential to the health of U.S. scientific research:

Continue the trend begun in FY 2001 to reverse the significant erosion in the base research and facility operations programs, where it has occurred; during the past 5 years and prevent irreparable damage.

Complete facilities and major equipment projects already started and then fund their operation so as to realize the scientific return on the investment already incurred.

Sustain a critical (although small in proportion to the total) investment in areas of advanced R&D where there are unique and talented teams of researchers and technical staff that will enable DOE to develop and deliver the extraordinary tools needed for tomorrow's science.

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Provide new funding (incremental above the base) that will enable DOE-funded science to be a player in new initiatives in FY 2002—*e.g.*, nanoscience, advanced scientific computing and the genome to life (GTL) initiative.

In conclusion, and speaking collectively for our Advisory Committees and large DOE scientific user community, we strongly urge:

Recognition that DOE science plays a unique role in the Nation's scientific enterprise and in the age of discovery that is in front of us.

Recognition that a balanced portfolio in basic research, that includes the physical as well as biological and biomedical sciences, is essential if the U.S. is to sustain its world preeminence in science and technology.

Recognition that DOE SC-funded science and facilities are complementary to that of other Federal agencies.

Funding for FY 2002 for the DOE Office of Science at a level that will capitalize on the unique potential and opportunities of DOE SC and move the Nation strongly forward in science and technology.

In the following section of this testimony are six sections discussing each of the programs within the DOE Office of Science that we represent.

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Advanced Scientific Computing

Overview. Computing and mathematics are the cornerstone of modern science, engineering, and medicine. The stunning images of new molecules on the cover of Science, splashy films depicting the dynamics of creating a new star, prediction of the patterns of nuclear waste seepage into the environment—all of these depend on sophisticated computing and mathematics, working together with science.

Mathematics is a foundation for science through models—mathematical descriptions of complex real-world phenomena such as plasma turbulence, interacting chemical species, the spread of pollutants in water, the collision of subatomic particles, shocks in a heart attack, overload on the Internet, and tomorrow's stock prices. Combined with intuition, experience, and data, the abstraction and generality of mathematics allow models to be created that can be analyzed, tinkered and computed with, and visualized. Experimental data invariably reveals that nature is more complicated than expelled; mathematics provides the tools—analysis, perturbation, generalization—leading to deeper insights and quantum jumps in understanding, predictability, and controllability.

Mathematical models advance in close partnership with the science they represent. Starting with simple models that provide crude estimates, increasingly sophisticated mathematics is required to capture the behavior of small-scale, highly nonlinear details. Nature reads and interacts on vastly differing scales—accurate global weather analysis includes scales ranging from thousands of miles to a few feet—and the same issues of multi-scale interactions arise in understanding manmade artifacts such as the Internet. Part of the challenge of modeling is a careful analysis of which scales matter and which can be ignored, when, and how.

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Numerical methods are a second essential ingredient in today's scientific explorations. Contrary to portrayals in popular films, there is never a single formula that gives the answer. New algorithms—ways to solve problems—are constantly needed as the science becomes larger, more complex, and more nonlinear, and as answers are needed ever more quickly, even in real time. Solution techniques that are perfectly reasonable when analyzing experimental data at leisure are unacceptable when deciding how to control a nuclear explosion or judging where and how deeply to cut in brain surgery. One of the beauties of mathematics and computing is that they are general-purpose—their advances carry over to other, sometimes unexpected, application areas. For instance, the well-known Web search engine Google relies on a numerical method that has been refined and improved for more than 30 years in physical applications.

The final element in scientific computing research is computing itself, with software in at least two roles: the incarnation of numerical methods and the infrastructure that makes computing possible. Everyone knows about the spectacular gains in computing power during the last 25 years. Unfortunately, however, gains in raw speed, memory, and access do not translate into comparable gains in our ability to solve problems. As computer architectures become more complicated, including, for example, distributed computational elements and multilevel cache memory, it simply does not work to apply the algorithms and software developed for earlier configurations. As a simple analogy, consider an early version of a railway system in which a single train travels from location to location, collecting and distributing freight. If the managers of that system were suddenly given 100 trains of varying capacities and varying peak speeds, they would have to rethink the entire system to achieve substantial improvements in efficiency.

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Translating gains in raw computer power to comparable advances in scientific computing requires serious, deep attention to issues of software. One often reads general assertions that the greatest challenge in technology today is software; this statement is unquestionably true in advanced scientific computing. A rule of thumb in software development is to take the best estimate of time needed to complete the software and multiply by ten—and sometimes even this is a serious underestimate! Writing reliable software is extremely complicated, even for straightforward problems and simple computer architectures, as anyone who has ever written a program can attest.

Given the complexity of the underlying science, modeling codes themselves are inherently complex, typically requiring years of effort to get the mathematics and the numerics right. Hence the software lasts much longer than the typical three-year lifetime of a generation of computer hardware. The "Gaussian" computational chemistry code for which John Pople shared the Nobel Prize in chemistry in 1998 began its existence in the early 1970s, and has continued to evolve ever since. Creation of software should be tightly coupled with mathematical modeling and numerical methods; failure to conned them is a recipe for inefficiency, inaccuracy, and (consequently) less-than-optimal science.

The performance gap between raw speed (measured by the theoretical maximum number of calculations per second) and actual performance is already large and, more seriously, is increasing with no end in sight. Closing this gap can be achieved only by major, coordinated investments in research on scientific modeling codes and the underlying systems software; the gap will not disappear if left to its own devices.

Opportunities. Addressing these multiple issues in advanced scientific computing involves meeting the rapidly growing needs of scientists for good models, accurate and fast numerical methods, and reliable, easy-to-use software infrastructure. To achieve these goals, the Office of Advanced Scientific Computing Research has wisely recognized the need for close ties among mathematicians, computer scientists, and disciplinary scientists, and is creating programs that build on the historic strengths of scientific computing within the Office of Science. For more than 50 years, the Department of Energy has been a leader in effective use of the latest, best computing and mathematics to serve the needs of science. The challenges and opportunities today and in the foreseeable future are even more compelling, dramatic, and exciting. At the most basic level, the scientific mission of the Department of Energy cannot flourish without thoughtful attention to advanced scientific computing. The Department of Energy should be supporting the world's leading research efforts in this area because of its unparalleled array of experimental facilities, top-quality scientists, and, most important, its unity of focus.

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Advances in computing technologies during the past two decades have set the stage for major steps in modeling and simulation. By 2005, computers 1,000 times faster than those available to the scientific community today will be at hand, leading to the promise of spectacular advances in science. However, recent technology trends and business forces in the U.S. computer industry have resulted in radically reduced development and production of the high-end systems necessary for meeting the most demanding requirements of scientific research. Thus investments in advanced scientific computing must be made by DOE and other government agencies whose missions depend on the highest end of computing hardware. Science will not keep up with computing unless hardware gains can be translated into increases in modeling and solution capabilities. This requires a spectrum of research in mathematical modeling and analysis, numerical methods, simulation codes, and computing systems software (operating systems, compilers, runtime environments, high-speed data communication and access, and mathematical libraries).

The Office of Science has developed an integrated strategy for taking advantage of these opportunities, "Scientific Discovery through Advanced Computing" (SciDAC), a plan for significant increases in coordinated, multidisciplinary efforts in key areas. SciDAC includes research in applied mathematics and computer science coupled with theoretical and computational science programs in Basic Energy Sciences, Biological and Environmental Research, Fusion Energy Sciences, and High Energy and Nuclear Physics. Ideally, enhancements will occur in both research and computing facilities, and SciDAC will be only the beginning. DOE's admired and successful graduate fellowship programs complement the research program by training the future leaders of U.S. science and engineering to excel in tomorrow's interdisciplinary world.

Basic Energy Sciences

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The Basic Energy Science Advisory Committee (BESAC), that I Chair, advises the Director of the Office of Science on matters relating to Basic Energy Sciences. BESAC has a diverse membership including academic, industrial, and government laboratory researchers. Many of is members are members of the National Academy of Sciences and the National Academy of Engineering. Two of the members are Nobel Laureates. The membership includes physicists, chemists, engineers, biologists, and geologists reflecting the diverse portfolio of BES. Over the last several years, we reviewed all of the user facilities supported by BES, including new facilities such as the Spallation Neutron Source, and the research done at the facilities. BES management has acted quickly and decisively on the advice we have provided. We have also been briefed extensively on BES's research programs research initiatives such as nanoscale science. BESAC has consistently found high quality, exciting research and compelling new research directions.

The Basic Energy Sciences (BES) program is one of the Nation's largest sponsors of fundamental research, encompassing more than 2,400 researchers in nearly 200 U.S. institutions. In FY 2000, the program funded research in more than 160 academic institutions located in 48 states and in 13 DOE laboratories located in 9 states. BES supports a large extramural research program, with approximately 40% of the program's research activities sited at academic institutions. This investment in academic research has been a constant fraction of the BES research portfolio for more than a decade. This program supported 2,900 graduate students and postdoctoral investigators in FY 2000 through grants or contracts; 3,680 graduate students and postdoctoral investigators used the BES science user facilities in FY 2000.

The BES program also supports outstanding scientific user facilities, providing world-class capabilities for imaging and characterizing materials. Experiments at these facilities are conducted on a host of different types of samples, including ceramics, metals, and alloys; polymers and soft materials; gases and liquids; and fragile biological specimens and crystals. The BES synchrotron radiation light sources, the neutron scattering facilities, and the electron beam characterization centers represent the largest collection of such facilities supported by a single organization in the world. Annually, 8,000 researchers from universities, national laboratories, and industrial laboratories perform experiments at these facilities. The BES program also supports the vast majority of the federally funded research in the physical sciences at these facilities.

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Activities supported by the BES program are a significant part of the national research effort, providing particular strength to the Nation's science enterprise in the physical sciences and in facilities planning, construction, and operation.

BES supports five major research areas: materials sciences, chemical sciences, biosciences, geosciences, and engineering. It is one of the few organizations that supports all of the natural sciences. The Materials Sciences subprogram supports basic research in condensed matter physics, metal and ceramic sciences, and materials chemistry. This research seeks to understand the atomistic basis of materials properties and behavior and how to make materials perform better at acceptable cost through new methods of synthesis and processing. Basic research is supported in magnetic materials, semiconductors, superconductors, metals, ceramics, alloys, polymers, metallic glasses, ceramic matrix composites, catalytic materials, surface science, corrosion, neutron and x-ray scattering, chemical and physical properties, and new instrumentation.

Ultimately the research leads to the development of materials that improve the efficiency, economy, environmental acceptability, and safety in energy generation, conversion, transmission, and use. This subprogram is the largest supporter of basic research in materials in the world, is the primary supporter of the BES user facilities, and is responsible for the construction of the Spallation Neutron Source. Closely associated with materials sciences is the engineering part of the Engineering and Geosciences subprogram is integrated with activities in the materials sciences subprogram and focuses on nanotechnology and microsystems, multicomponent fluid dynamics and heat transfer in materials, and nonlinear systems.

The Chemical Sciences subprogram supports basic research in atomic, molecular and optical science; chemical physics; photochemistry; radiation chemistry; physical chemistry; inorganic chemistry; organic chemistry; analytical chemistry; separation science; and heavy element chemistry. This research seeks to understand chemical reactivity through studies of the interactions of atoms, molecules, and ions with photons and electrons; the making and breaking of chemical bonds in the gas phase, in solutions, at interfaces, and on surfaces; and energy transfer processes within and between molecules. Ultimately, this research leads to the development of such advances as efficient combustion systems with reduced emissions of pollutants; new solar photoconversion processes; improved catalysts for the production of fuels and chemicals; and better separations and analytical methods for applications in energy processes, environmental remediation, and waste management. This subprogram provides support equal to that of the National Science Foundation for basic research in chemistry. It provides the Nation's primary support for homogeneous and heterogeneous catalysis, photochemistry, radiation chemistry, gas-phase chemical dynamics, and separations and analysis. It is the Nation's sole support for fundamental research in heavy element chemistry. This subprogram also provides support for a number of the BES user facilities.

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The geosciences activity in the Engineering and Geosciences subprogram supports basic research to understand the Earth's crust, including mineral-fluid interactions; rock, fluid, and fracture physical properties; and new methods and techniques for geosciences imaging from the atomic scale to the kilometer scale. The activity contributes to the solution of problems in multiple DOE mission areas, including reactive fluid flow studies to understand contaminant remediation; seismic imaging for reservoir definition; and coupled hydrologic-thermal-mechanical-reactive transport modeling to predict repository performance. This activity provides one third of the total federal support for individual investigator basic research in solid earth sciences.

The energy biosciences subprogram supports basic research in the molecular and cellular mechanisms to understand the capture and conversion of solar energy via natural photosynthesis. The research defines—at the molecular level—the structure, synthesis, and assembly of cellular components involved in the light-driven production of chemical energy. Ultimately, this research will aid the development of renewable biomass resources. This subprogram is the prime provider for molecular research on plants not focussed on traditional crop and agricultural interests and a major supporter of research on microbial systems that have broader importance than the model systems used in the biomedical community. This subprogram is one of the Nation's prime interfaces between bio- and physical sciences, promoting multi- and cross-disciplinary research activities jointly with all of the other BES subprograms.

I am pleased to say that regular peer review and merit evaluation is conducted for all activities, except those Congressionally mandated, based on published procedures and criteria. New projects are selected by peer review and merit evaluation. In addition, BES regularly conducts external reviews of its construction projects to ensure that they are on time and within budget. In FY 2001, BESAC has been charged to evaluate the proposal review and selection process and provide advice on subprogram portfolios on a rotating basis, completing the entire BES program portfolio approximately triennially.

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Every year BESAC hears of the principal investigators funded by BES that win dozens of major prizes and awards sponsored by professional societies and by others. In addition, many are elected to fellowship in organizations such as the National Academy of Sciences, the National Academy of Engineering, and the major scientific professional societies. Paramount among the honors are four Nobel Prizes awarded to BES principal investigators during the 1990s.

We have found that BES is a dynamic program with significant accomplishments in all areas of research. There are many examples of these accomplishments. When information is written to a computer hard drive, local magnetic moments associated with atoms in a small region of the surface reverse direction like sub-microscopic compass needles. A new theory has helped explain these dynamical processes. This work recently received the Gordon Bell Award for the fastest real supercomputing application and was named to the Computerworld Smithsonian 2000 collection for being the first supercomputing application to surpass one teraflop. A newly developed class of nanostructured materials can selectively filter molecules by their size and chemical identity. These remarkable materials are made from a solution of molecular building blocks that spontaneously arrange themselves into a porous solid as the solvent evaporates. This achievement involved creating the self-organizing precursors, controlling the pore size, and employing a novel evaporation process that promotes self-assembly. These materials hold the promise for significant industrial applications for separations processes. A theoretical method was invented by which one can first specify the properties desired in a semiconductor and then work backward to predict the structure of the material that will show those properties, which was featured in *Fortune Magazine.* Arabidopsis thaliana, a small weed belonging the mustard family, became the world's "model" plant for research because of its small physical size, small genome size, low level of junk and repetitive DNA, short life cycle, large number of mutations, and ease in genetic analysis. An international collaboration involving scientists from the U.S., Europe, and Japan announced the completion of the complete sequence of this plant genome in December 2000. The Arabidopsis genome is entirely in the public domain, making the results available to scientists worldwide. The Energy Biosciences subprogram has been a partner in this project since its inception; support for research on Arabidopsis dates to the early 1980s.

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Often the work in BES crosses disciplines. For example, it is increasingly evident that living processes play a fundamental role in determining the geochemistry of groundwater, near-surface sediments, and deeper rocks. Microbes affect the weathering of rocks and minerals, and microbial metabolism affects the accumulation of heavy metals in soils or their release to groundwater. These and other processes determine how soils, sediments, and ore bodies form and how water quality is affected. Work identifying how microbes affect the fate of zinc released to groundwater percolating through lead-zinc mines and other biogeochemistry work recently led to the award of MacArthur Foundation Fellowship to a BES supported researcher. Biogeochemistry, which links three BES subprograms, is expected to play an increasingly important role in addressing DOE missions.

BES has a remarkable record of completing major scientific fatalities on time and on budget. It built the Advanced Light Source and the Advanced Photon Source. It is responsible now for the Spallation Neutron Source, which is a $1.4 billion facility that will provide a next-generation short-pulse spallation neutron source for neutron scattering. This project is on track, making substantial progress. The SNS will be used by researchers from academia, national labs, and industry for basic and applied research and for technology development in the fields of condensed matter physics, materials sciences, magnetic materials, polymers and complex fluids, chemistry, biology, earth sciences, and engineering. When completed in 2006, the SNS will be significantly more powerful than the best spallation neutron source now in existence—ISIS at the Rutherford Laboratory in England. The facility will be used by 1,000–2,000 scientists and engineers annually. Scientists will use the SNS to study the physical, chemical, and biological properties of materials by determining how atoms and molecules are arranged and how they move—knowledge needed to understand and "engineer" materials at the atomic level so that they have improved macroscopic properties and perform better in new applications. Neutron scattering will play a role in all forms of materials research and design, including the development of smaller and faster electronic devices; lightweight alloys, plastics, and polymers for transportation and other applications; magnetic materials for more efficient motors and for improved magnetic storage capacity; and new drugs for medical care. The high neutron flux (i.e., high neutron intensity) from the SNS will enable broad classes of experiments that cannot be done with today's low-flux sources. For example, high flux enables studies of small samples, complex molecules and structures, time-dependent phenomena, and very weak interactions.

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BES also explores novel ways to build large projects. Traditionally projects have been built by assembling at one laboratory all of the skill needed to build the project. This way can be wasteful if the skills needed for construction are different than those needed for operation. The SNS Project partnership among six DOE laboratories takes advantage of specialized technical capabilities within the laboratories: Lawrence Berkeley National Laboratory in ion sources; Los Alamos National Laboratory in linear accelerators; Thomas Jefferson National Accelerator Facility in superconducting linear accelerators; Brookhaven National Laboratory in proton storage rings; Argonne National Laboratory in instruments; and Oak Ridge National Laboratory in targets and moderators.

I would like to close with a personal observation. Based on my 3-year tenure and chair of BESAC and 2 years as a member of BESAC, I have seen much exciting science that BES cannot fund with its current budget. Indeed, over the last 10 years BES has had to retrench in many important areas and needs to recover. The number of scientists supported at the DOE laboratories has declined by 20% during this period. The average grant size has not changed during this period despite and increase in cost of living of over 25%. User facilities operate very close to the margin, and even a small decrease—such as absorbing inflationary increases in a flat budget year—will have major impacts. The Nation has made a multi-billion dollar investment in these unique facilities, and they must be operated efficiently to take advantage of that large capital investment. I have seen much exciting work presented by BES that cannot be done with the current budgets. The interagency working group on Nanoscale Science, Engineering, and Technology recommended an increase of twice the increase appropriated in FY 2001. I went to a BES sponsored workshop on complex systems that was part of their strategic planning that outlined a very exciting research program for the future in physics, chemistry, and biology that would have broad impact on energy technologies, electronics and chemical industry, and on harnessing nature's own mastery to make better materials and to control chemical reactions.

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Biological and Environmental Research

Overview. The DOE Biological and Environmental Research Advisory Committee (BERAC) recently completed an assessment of the current state of the BER portfolio, including its recent accomplishments and potential. This testimony for the Science Committee in the U.S. House of Representatives is drawn from a report delivered to the DOE Office of Science in March 2001. The full text of the report can be found at http://www.sc.doe.gov/ober/berac/Reports.html

The Office of Biological and Environmental Research (BER) has three broad program elements which closely couple to DOE missions—life sciences (including the genome program), environmental sciences (including global change) and medical sciences (including biomedical imaging). The BER portfolio includes such efforts as: advanced medical imaging technology and radiopharmaceuticals; biologically based strategies for cleaning up environmental contamination at former weapons sites; understanding of global climate change to predict future energy needs and impacts of energy use on the ecosystem; developing capabilities to understand health risks from human exposures to energy-related by-products; and operation of user facilities and resources for the broad biomedical and environmental scientific communities. BERAC finds that BER funds cutting edge, high quality, peer-reviewed science consistent with, and guided by, the recommendations of the BER Advisory Committee. This research is highly relevant to DOE missions and supports and advances issues that are of broad importance to the health and well being of our Nation's citizens in a way that is very complementary to the goals of NIH and NSF.

The BER research programs require a broad range of specialized scientific facilities spanning a range from traditional "Bricks and Mortar" facilities to widely distributed field research sites. They include unique state-of-the-art beam lines and instrumentation to investigate macromolecular structures on the DOE–BES funded synchrotron sources, the Joint Genome Institute's Production Sequencing Facility for high throughput DNA sequencing, the Environmental Molecular Sciences Laboratory (EMSL) at Pacific Northwest National Laboratory, the new Laboratory for Comparative Genomics at the Oak Ridge National Laboratory (now under construction), and globally distributed facilities including Cloud and Radiation Testbeds (the Atmospheric Radiation Measurement or ARM sites), Free-Air Carbon Dioxide Enrichment facilities and the AmeriFlux Carbon Dioxide flux measurement sites. These facilities collectively serve more than 5000 researchers and provide truly unique resources that are an essential part of the Nation's scientific infrastructure. Comments on several specific program elements follow.

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Life Sciences Research (including the genome program). The BER contribution to the human genome project and to genome science has been spectacular. BER had the vision to first articulate the value of this bold new venture culminating in one of the greatest accomplishments of the 20th century—the sequencing of the human genome. BER also developed many of the key technologies necessary for success from sequencing technologies to enzymes to cloning strategies to key gene-finding algorithms. The BER Joint Genome Institute (JGI) made major contributions to the human DNA sequence that was published this past February in Nature. BER promoted and supported sequencing of the first microbial genome, and has provided support for more than g of the 70 or so sequences now near completion. BER is developing key technologies for the next phase of genomics research, represented by BER's Genomes to Life program, that will focus on understanding the structure, function and higher level organization of complex biological systems. Methodologies include very advanced mass spectrometric methods for proteome analysis, advanced computational methodologies and new approaches for imaging.

The genome effort has set a substantial foundation for pursuit of DOE missions. The accumulated genome sequences are the raw material for taking advantage of biology to develop novel methods for dealing with toxic clean up problems, with carbon sequestration, for clean energy and with global warming. This information opens many opportunities for commercialization of biologically engineered new products in both a safe and economically effective manner. Notable throughout these early years of genome science has been the close collaboration between the DOE and other federal agencies. The effort of each federal agency has been maximized through cooperative ventures and agreements. This has not always been easy but the success is clear.

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BERAC finds that the BER genome effort is excellent science, is a model for success of future DOE life science endeavors and serves DOE missions exceptionally well. It is world class and competitive with any similar effort. It takes advantage of the unique capabilities of the DOE laboratories and effectively engages academic science to pursue the broad program goals established in partnership with other agencies. This program is a model of success to which DOE, and the whole Nation's scientific enterprise, should look for how to effectively manage such a complex endeavor and coordinate its efforts within a much broader National framework.

The BER structural biology program supports research and develops and operates major national user facilities on DOE's four synchrotron light sources. Through these user facilities, scientists are provided the specialized infrastructure, training and support for their experiments. (NIH and a few other private entities also provide such resources but DOE–BER is the largest single supporter of these efforts). The increased utilization, productivity and impact of these facilities over the past decade have been nothing short of remarkable—leading to forefront research from fundamental biology of the complex macromolecular machines of the cell to drug discovery enabled by study of the structure of integral membrane proteins, key targets for new drugs. These BER operated facilities provide the foundation upon which new initiatives in the post-sequence genome will be based. They will have a direct and significant impact on BER initiatives and core research, including DNA repair and low dose radiation effects, microbial cell function, bioremediation and more broadly the new Genomes to Life initiative. It is essential that BER be provided the means to continue to effectively support the operation of these resources, expanding capacity as appropriate and needed and investing in instrumentation upgrades that are necessary to maximize productivity, advance capability and maintain international competitiveness.

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BER has a low dose radiation research program to understand the risks to people from exposure to low-dose, low-dose-rate, low-LET (linear energy transfer) radiation. The information generated by this program is intended to provide a scientific base that underpins the development of future radiation risk regulatory policy. This research is important since most of the projected non-medical, man-made radiation exposures over the next 100 years will be from waste clean-up and environmental isolation of materials associated with nuclear weapons production and will be in the form of low-LET radiation delivered at low doses and low dose-rates: At this early stage of the program, what the science will tell us is unknown but in the end, it is essential that the regulations for clean-up standards and appropriate radiation protection practices be founded on the best science possible. This is a strong and important research program that will make useful contributions to DOE's mission needs in environmental cleanup and worker and public protection from radiation risks. Moreover, it will help improve the science base for national debate on how to address potential risks of low-level exposure to radiation as well as other agents.

Environmental Sciences Research (including Global Change). The DOE–BER program has a long history of making significant contributions to basic environmental research, including the improved understanding of energy-related impacts on air quality, climate, and ecological systems. DOE is the third largest contributor to the U.S. Global Change Research Program (USGCRP) budget following NASA and NSF and has taken the lead Federal role in several key areas. There is increasing concern about mankind causing changes in the climate system. BER has taken a leadership role to improve scientific knowledge about the carbon cycle, the role of clouds and radiation in the climate system, and in building state of art climate models that can be used for climate prediction. The Intergovernmental Panel of Climate Change (IPCC) recently released its Third Assessment Report. This assessment states that mankind is changing the earth system in many different ways and the changes will increase in the 21st century. These changes make it imperative that policy decisions about the environment must be based on credible scientific information and predictions.

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The BER program has great breadth and strength in several key areas. BER has a unique Federal and world leadership role to address the role of clouds and radiation on the climate system. Cloud and radiation measurements are important for understanding how the climate system responds to changes in radiation forcing due to increasing concentrations of greenhouse gases and aerosols in the atmosphere. BER designed and built an elaborate ground measurement system as part of the Atmospheric Radiation Measurement (ARM) program. This research has led to improvements of the radiative aspects of climate models. BER is a world leader in carbon cycle research and has taken the lead in quantifying the magnitude and variation of carbon uptake by terrestrial ecosystems. Because of the role carbon dioxide plays as a climate change forcing variable, it is mandatory that understand the complete carbon cycle. This research builds the groundwork on which carbon related energy policies are based. BER research over the last few years has led to substantial improvement in understanding of the regional and global sources and sinks of carbon. BER has been a long-time leader in ecosystem research, especially in areas of how terrestrial organisms and ecosystems respond to changes in climate and atmospheric composition, and the role that biological and ecological processes play in controlling observed responses. The unique research supported by this program has improved our understanding of how terrestrial ecosystems respond to various environmental changes. To make progress in this area there must be an expansion of long-term, distributed field studies combined with well-calibrated measurement systems, as well as data archiving and retrieval systems. BER is the Federal government leader in the development of state-of-the-art climate models for climate system predictions on time scales of decades to centuries. Using its computational capabilities vested in the national laboratories and the scientific expertise of these labs plus the academic community, new and improved climate models are being developed and used to estimate energy related impacts on the environment. BER's integrated assessment research evaluates interactions between all components of the climate system, including human socioeconomic systems providing an important link between policy makers, climate science, and economics.

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BER has been a leader in research on atmospheric processes that control the transport, transformation, and fate of energy related chemicals and particulate matter and in the development of models to describe these processes. These processes cover regional, national, and global aspects of air quality and climate change. The results, at the core of many of the energy related science issues found only in DOE, have important implications for energy policies.

BER operates the Environmental Molecular Sciences Laboratory (EMSL) as a National user facility. EMSL provides a unique suite of research tools to investigate molecular interactions important to DOE and the scientific user community. EMSL provides world-class research capabilities for both experimental and theoretical investigations at the molecular to meso-scale. This work is highly relevant to DOE missions. EMSL's research tools are precisely those needed to address major complex problems such as post-genome sequence biology, nanoscience, and technology and environmental sciences. EMSL also provides unique educational opportunities for students and postdoctoral fellows who are the next generation of researchers in the molecular sciences. EMSL receives high marks as a national user facility and has the opportunity to play an important role in future directions of BER research, including the Genomes to Life program.

BER's Natural and Accelerated Bioremediation Research Program (NABIR) is the government's only basic research program focused on the science needed for more effective cleanup of environmental pollutants, especially those resulting from past DOE activities. Remediation of environmental contaminants is among the most complex technical challenge facing society and requires basic research to provide the information to make wise decisions for solutions for other than the simplest problems. DOE's problems of mixed wastes in a variety of subsurface environments are among the most complex challenges. In the past three years, the NABIR program has built a strong science base to understand the potential for bioremediation of metals and radionuclides, attracting many of the leaders in the field of environmental microbiology. Many of those studies have been laboratory based, using contaminated sediments and soils from DOE sites. With the initiation of the Field Research Center at Oak Ridge National Laboratory (ORNL) in 2000, the program can now move into an exciting new phase: field-scale hypothesis testing. The NABIR program is carefully coordinated with other federal science and technology programs including those at the EPA, DoD, USDA, NSF, in the SERDP and others. The NABIR program is unique among bioremediation research programs with its focus on metals and radionuclides. No other agency is addressing or plans to address the problem of radionuclide contamination.

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Medical Sciences Research (including Nuclear Medicine). The BER Medical Sciences program funds radiopharmaceutical and radiation detector imaging research that provides the foundation for using radioisotopes in a broad range of diagnostic and therapeutic applications. The program laid the foundations for the establishment of nuclear medicine as a major clinical specialty. Today, millions of nuclear medicine procedures are performed annually worldwide to diagnose cancer metastases, localize infections, and assess heart and lung performance using technologies developed in this program. BER developed the original detection systems for positron emission tomography (PET) used today by more than 260 centers around the world.

New molecular radiotracers and biological imaging technologies developed through the Nuclear Medicine Program are bringing revolutionary changes to molecular nuclear medicine: these high precision guiding tools permit previously unimaginable insights into brain and heart physiology and pathophysiology, providing improved diagnosis and treatment of patients with diverse illnesses such as cancer, Alzheimer's disease, and coronary artery disease. New PET reporter probes have been developed to imaging gene expression in animals in real-time. The pioneering research on mapping dopamine brain biochemistry related to cocaine abuse, alcoholism, cigarette smoking and addiction treatment (reported in *Time Magazine* and published in top scientific journals including *Nature*) is already influencing medical science around the world. The Nuclear Medicine Program is recognized for its research in the development and application of new radiotracers to understand the biology of neurological and psychiatric disorders, particularly addiction and aging, and for its research on imaging gene function *in vivo.*

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New Opportunities in FY 2002. Within the framework of this broad research portfolio comes the opportunity to address the next grand challenge in the biological and biomedical sciences that comes from understanding the sequence of the human (and many other) genomes. That is to answer the question, "how do living things actually function and what factors—genetic, environmental, and others—influence life in positive as well as negative ways?" The researchers, tools and infrastructure supported by the BER program are uniquely positioned to tackle this problem of enormous complexity that has the potential to profoundly influence our approaches to a range of challenges from developing new biologically-based strategies for mitigating the effects of global climate change, such as carbon sequestration or the development of new clean fuel options, to understanding risks from low doses of radiation, to cleaning up our environment. This proposed new initiative, "Genomes to Life," is described in detail (http://www.DOEGenomestoLife.org) and here we simply emphasize the opportunity and how it will build upon the strengths of many elements in the BER portfolio.

Conclusion. At the BERAC meeting on December 11–12, 2000, Committee Members discussed the BER program elements, agreed unanimously, and voted upon the following statement as the explicit recommendation to come from this assessment: "Based on scientific accomplishments, unique intellectual capital and resources, and the promise of new discovery in the BER portfolio (global change, environmental remediation, biomedical and genomics and structural biology research) summarized in this assessment, BERAC urges that DOE seek to:

Double the budget for the DOE–BER program beginning in FY 2002, continuing for the next five years and, within this framework that:

Increases be used to adequately support core capabilities and facility operations in addition to new initiatives

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$50M per year be allocated beginning in FY 2002 to the new initiative "Genomes to Life"

Further, BERAC lends it strong endorsement and support to the doubling of the DOE Office of Science budget over the next 5 years.

Fusion Energy Sciences

Program Goals. The mission of the Fusion Energy Sciences program is to "Advance plasma science, fusion science and fusion technology—the knowledge base needed for an economically and environmentally attractive fusion energy source."

Fusion, the energy source of the sun and other stars, is the joining of light atomic nuclei to produce energy. Fusion researchers view their product as part of the mix of improved energy sources that will begin to dominate the global economy during the 21st century. The energy yield from fusion reactions is impressive; for example, the amount of deuterium (an isotope of hydrogen that is prone to fusion) in one gallon of sea-water would yield the same energy as 300 gallons of gasoline. Indeed fusion offers a safe, long-term energy option with important environmental advantages.

The fusion mission statement begins with a reference to plasma, often called the fourth state of matter. A plasma is an ionized gas—a gas comprised of electrons and positively charged ions that can move independently of one another. Although plasmas are rare on the surface of the Earth, they constitute most of the visible universe. Plasmas make up the atmosphere and interior of stars, supernovas and quasars, the vastness of interstellar and intergalactic space, and the Earth's magnetosphere. More commonly visible plasmas include those in lightning bolts, fluorescent lights, and the aurora borealis.

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Fusion scientists need to understand plasma behavior, because any gas that is heated sufficiently to fuse is necessarily in the plasma state. Plasma physics is famous for its demanding complexity—this is the primary fusion challenge. However, because plasma is so pervasive in the universe, understanding its rich and varied dynamics would be an enormous boon to several areas of science and technology. Thus the fusion quest is linked to numerous deep questions about the natural world.

Status and Recent Progress. Fusion progress over the past decade has been enormous, and exemplified by the production of megawatts of fusion power at laboratories in Oxford in the United Kingdom, and at the Princeton Plasma Physics Laboratory in New Jersey. These advances (along with others that missed the headlines) have brought fusion research to a watershed: its central challenge is no longer to demonstrate that fusion reactors are feasible, but rather to show that they can be practical. The present focus of fusion research is to establish the scientific and technological reality of a fusion power source with operational features (including competitive cost and size) that would attract commercial investment.

Underlying the progress toward fusion energy—and, to the working scientists, just as exciting as that progress—has been a dramatic advance in scientific understanding. Aspects of plasma behavior once considered nearly beyond description are now being unraveled and predicted by first-principles theory and advanced computation, on a regular basis. The stability of various plasma configurations, the level of heat conductivity of a hot plasma, and the natural formation of coherent structures in the plasma—phenomena that bear on stellar and astrophysical plasmas as well as those in the laboratory—are becoming understood at a level hardly expected even a decade ago. And of course these advances in understanding are showing benefits in scientific areas outside of fusion. One example is the very fundamental advance that fusion research has brought to the science of fluid turbulence and its effects; another, more practical, example is the development of improved models for stellar sub-storm activity, which can dramatically affect long-distance communication on the earth.

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Scientific and Technological Opportunities. Understanding a natural phenomenon usually allows one to control it. Thus the improved understanding of plasma physics has led to substantial advances in our ability to manipulate fusion plasmas. In particular, the means have been found to influence plasma turbulence externally—even in certain situations, to stop turbulence. Since a non-turbulent plasma has much better properties for sustained fusion reactions, this level of control is extremely significant.

Such achievements have allowed the theoretical and experimental exploration of a wider variety of potential reactor configurations. We are finding cheaper and simpler ways to make fusion work. Indeed the prospect of plasma control opens truly exciting vistas, promising important steps forward for both science and fusion power development. In this regard, a troubling question is whether program resources will allow exploiting such opportunities for major advance.

A class of experiments that is certain to advance scientific understanding, while bringing fusion closer to the power grid, comprises the so-called "burning plasma" experiments, in which fusion reactions are sustained at a relatively high level and for long periods of time. A burning plasma experiment can be said to create a star in the laboratory, allowing analysis of its behavior. Because of the scientific progress described previously, a burning plasma experiment is within our reach, and it could be constructed at lower cost and higher confidence than would have been possible a decade or so ago. The European community, Russia and Japan are expected to begin joint work on such experiments very soon, and they would welcome our participation. However, an effective U.S. role in an international burning plasma experiment would require us to enter negotiations with the other participants very soon. It is another exciting opportunity that is threatened by limited program resources.

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Health of the Program. The fusion program has been examined in recent years by several independent agencies, including the President's Committee of Advisors on Science and Technology (PCAST), the Secretary of Energy's Advisory Board (SEAB) and the National Research Council (NRC), the research arm of the National Academy of Science. Although each panel had a somewhat different scope and purview, all came to similar conclusions about the value of fusion research. Thus SEAB remarks that "In light of the promise of fusion and the risks arising from increasing the worldwide energy demand and from eventually declining fossil energy supply, it is our view that we should pursue fusion energy aggressively." PCAST describes fusion as "an attractive and possibly essential new energy source for this country and world" while the NRC states that "the quality of the science funded by the US fusion research program in pursuit of a practical fusion power source (the fusion energy goal) is easily on a par with other leading areas of contemporary physical science." Thus there is every reason for fusion scientists to feel very good about the importance and quality of their work.

Yet fusion research has two nearly opposing aspects. First one sees the excitement of its recent dizzying advances and its exhilarating scientific outlook: new challenges, new areas for exploration, new stepping-stones to fusion power. On the other hand, one finds deep concern about the condition and future of the program. Now funded at less than half its peak a few decades ago, U.S. fusion research is increasingly constrained and threadbare. For example, it is rapidly falling behind the fusion programs in Europe and Japan. Compelling initiatives can be funded only by removing support from existing efforts, with the result of under-utilized experimental fatalities and over-committed scientists. This issue also is recognized in the recent examinations of the program. The SEAB report states that "in light of the promise of fusion, the Task Force concludes that the funding is now subcritical," while PCAST remarks "there is a strong case for the funding levels for fusion. . .increasing from $366 million in FY 1996 to about $860 million in FY 2002." In fact fusion funding was severely cut in FY 1996 and remains today at approximately $250 million.

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Wanting to strengthen the enterprise—to build a more powerful device, to hire another research assistant—is a natural hunger for a scientist. But what one sees in the fusion program (as well as other federally supported programs in physical science) goes beyond that traditional urge; it is a serious concern about whether the enterprise can be sustained. If a program is starved to the point at which it cannot attack its central challenges, it risks losing its driving force and its talent base. Because of the rapid scientific progress seen in the last decade, fusion research is not yet at that point. But the fear, expressed by outsiders and insiders alike, that fusion is heading in that direction is real and growing.

High Energy Physics

Overview of High Energy Physics—The Science of Matter, Space, and Time. High-energy physicists seek to understand what the universe is made of, how it works, and where it has come from. They investigate the most basic particles and the forces between them. Experiments and theoretical insights over the past several decades have made it possible to see deep connections between apparently unrelated phenomena, and to piece together more of the story of how a rich and complex cosmos could evolve from just a few kinds of elementary particles.

A new periodic table of the fundamental particles has been found, which is the analogue of the periodic table of the chemical elements established in the 19th century. This began with the discovery of the electron in 1897 and was completed in the last decade with the experimental confirmation of the existence of the top quark and the tau neutrino. The new periodic table has twelve fundamental building blocks of the universe, six quarks and six leptons. The deep questions now are why there are twelve of these particles, why they are arranged in a pattern, and why do they have a wide range of masses. But the agent for the generation of mass is now confidently predicted to be observable in near-future experiments. The potential for discovery of this new physics gives great promise to the next stages of experiment at high-energy colliders.

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Non-accelerator experiments also provide understanding of the fundamental particles and of the universe itself and often complement those at accelerators. Both can look back to the earliest moments of the universe after the Big Bang. Those involving astroparticle studies see remnants from an earlier era, while those at accelerators recreate directly the conditions of the Big Bang in a controlled environment.

The U.S. has been at the forefront of high-energy physics since the field formed in the 1950s. A 1998 study by the National Research Council noted that 18 physicists won the Nobel Prize for research in this field from 1973 to 1998, 14 of whom did their breakthrough research in the U.S.

Status of the Field. The field of high-energy physics is entering what is expected to be an era of discovery. The Higgs boson, which is a particle of a entirely new kind, and the signature of the mechanism by which all the fundamental particles acquire the property of mass, is predicted to itself have a mass that is at most a few hundred times the mass of a proton. The lower part of that range has been explored by the LEP collider at CERN, which found a tantalizing hint at the end of its run. Now LEP has been decommissioned in order to build the Large Hadron Collider (LHC) in the same tunnel. The search has passed to U.S. physicists from the DOE laboratories and from universities supported by the DOE and NSF, together with their international partners from Europe and Asia, who form the CDF and D0 collaborations at Fermilab's Tevatron collider. They will have a unique opportunity to search for the Higgs boson and make other potential discoveries at the energy frontier from now until the LHC produces its first major results around 2007.

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Thereafter, CERN will have the only accelerator capable of studying the new energy frontier. U.S. groups comprising over 500 physicists are playing important roles in each of the two worldwide collaborations that are building the large LHC detectors, and will be participants in producing the physics from that new frontier machine.

The PEP-II electron-positron collider (or B–Factory) at SLAC operates at the high intensity frontier. The BaBar experiment at SLAC, built by an international collaboration of over 500 physicists, together with a competing experiment in Japan, are on the verge of providing critical data to answer another of our basic questions: What is the source of the difference in the behavior of matter and antimatter? A tiny effect was observed in earlier experiments. We also know that shortly after the big bang there were equal amounts of matter and anti-matter, but the universe we observe now is almost completely made out of matter. Something happened in between to make our matter dominated universe, and the B–Factories should give us important clues as to whether we are on the right track to understanding how this happened.

Modest upgrades will be needed at both these facilities over the next few years to get optimal scientific benefit from them. In addition, the Neutrinos at the Main Injector (NuMI) project now under construction at Fermilab is going to send neutrinos produced at the Main Injector to an experiment 450 miles away in northern Minnesota starting in 2004. Each of the experiments above has a unique opportunity to make new discoveries that could change our understanding of the nature of matter, but in each case there is a relatively narrow window in time to make those discoveries.

To take advantage of these opportunities while preparing to continue a strong U.S. program into the end of this decade and into the next requires an improvement in high-energy physics funding from the present level. The field today receives the same funding level in constant dollars as in 1973. However, the costs to do competitive research has steadily gone up, as they have in other fields. European support for HEP has steadily increased over that period until it is much greater than in the U.S. Not only do the U.S. accelerator laboratories need increased support to achieve this goal, but also the large number of university physicists who form the experimental collaborations that produce the physics from these fatalities. Within the budget proposed for the high-energy physics program of the DOE in FY 2002, the strategy of trying to run the colliders in order to produce the data needed to potentially make great discoveries has also meant that other parts of the program have had to endure painful cuts, with the university-based high-energy program in particular cut by 5%. Faced with this cut, most of the university groups, which include most of the scientists and all of the students in the field, would need to reduce scientific staff, often by reducing the number of younger scientists. Not only does this have an immediate effect on the research produced next year, but many of these young people would be lost to the field permanently.

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Planning for the Future of U.S. High-Energy Physics. The High-Energy Physics Advisory Panel (HEPAP), composed of a broad and diverse group of leading physicists from both the universities and national laboratories, acts as the advisory body on the subject to the DOE and the NSF. Planning for the field typically involves subpanels of HEPAP that have the particular membership and intensive schedule needed to deal with the issues at hand.

The 1998 Subpanel of the High-Energy Physics Advisory Panel (HEPAP) laid out a strategy for U.S. high-energy physics for a decade with a central budget scenario of a constant-level-of-effort. That strategy balanced exciting near-term opportunities with preparations for the most important discovery possibilities in the longer-term. Difficult choices were made to end several highly productive programs and to reduce others.

Since the 1998 Subpanel, there were a number of important developments and many of that Subpanel's recommendations were implemented. Notably, construction of the B-factory at SLAC, the Main Injector at Fermilab, and the upgrade of CESR at Cornell were all finished on schedule and on budget. Great confidence was gained in the performance of these accelerators and the associated detectors. The B-factory at SLAC has already operated above design luminosity and plans are in place to reach three times the design in the next few years. As emphasized above, physics developments also lead us to believe that these completed projects are guaranteed to produce frontier physics results and they have enhanced potential for a truly major breakthrough.

In 2000, HEPAP took the plan given in the 1998 Subpanel's report and updated it in a White Paper. It provides an assessment of where the field stands in a world context and indicates the next steps in the intermediate term. (The 1998 Subpanel report and the White Paper are found at http://hepserve.fnal.gov:8080/doe-hep/hepap–reports.html .) The White Paper's principal conclusion about the near-term high-energy program was to reaffirm as the highest priority need the 1998 Subpanel's recommendation for optimum utilization of the recently completed facilities through funding their operations and supporting the groups extracting physics from them.

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With respect to the long-term future, the White Paper reasserted the conclusion of earlier subpanels that research at the energy frontier is essential for the sustained excellence of the U.S. high-energy program. Accelerator R&D has become ever more important with the long lead-times and new technologies employed. It is essential as well in order to drive the costs down. New accelerator technology, developed originally for high-energy physics, has had broad applicability in other fields of science and has also been one of the main societal benefits that flow from particle physics. A substantial increase in such R&D was recommended in the White Paper to ensure that the U.S. remain among the leaders in high-energy physics and to allow this nation to be the host for an international facility that will address the questions which will be most important a decade from now.

A new HEPAP subpanel has begun work this year, charged by DOE and NSF with producing a long-range plan with a twenty-year time horizon. The report of this subpanel is due by the end of 2001. For the near-term, the situation seen by the 1998 HEPAP subpanel and the 2000 White Paper remains: The field of high-energy physics is entering an exciting era of discovery in which we will get answers to some of our deep questions, such as the origin of mass and the asymmetry between the behavior of matter and anti-matter. Facilities in the U.S. have a window of opportunity over the next several years to make these major discoveries, but we need the corresponding budgets to run these facilities and to support the university researchers who are the essential partners in this enterprise.

Nuclear Physics

Mr. Chairman, Ms. Woolsey and Members of the Subcommittee, my name is James Symons, and I am the Chair of the Nuclear Science Advisory Committee (NSAC). I very much appreciate this opportunity to share with you some of the many exciting opportunities that are open to the Nuclear Physics Program in the

Office of Science.

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First let me make some remarks about the role of NSAC. This committee advises both the National Science Foundation and the Department of Energy on their nuclear science programs. These two agencies support essentially all of the Nation's federally-funded, basic research in nuclear science, with the Office of Science providing the lion's share of the funding (90%). On request from the Department of Energy, NSAC has reviewed many aspects of the nuclear physics program in the Office of Science and, when necessary, has set scientific priorities which have been used to guide difficult funding decisions within the program. In addition, NSAC prepares, on a periodic basis, a comprehensive long-range plan for our field. As part of its planning process, NSAC consults widely in the scientific community in order to achieve consensus on the highest priorities for the field, including new construction. The most recent plan was prepared in 1996 and we are currently preparing a new one, which will become available later this year. This process is sufficiently well advanced that I can share with you some of the most exciting opportunities that we have identified.

I would like to describe briefly the scientific goals of our field and the essential role played by the Office of Science in attaining them. Nuclear Physics research encompasses some of the most fundamental problems in all of science. We wish to understand both the structure of nuclei and other strongly interacting systems and their creation in the stars. In recent years, the intellectual boundaries of our field have broadened considerably to encompass problems at the interface of nuclear physics, particle physics and astrophysics. Nuclear physicists are now using complex experimental tools and sophisticated theoretical methods to elucidate the structure of strongly interacting matter as it existed in the first few seconds after the big bang and as it exists today both in the cores of nuclear stars, and within protons and neutrons in the nucleus. Finally, the nucleus is a unique environment for studies of fundamental processes that are at the frontier for many areas of modem physics.

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The importance of nuclear science to our nation is not limited, however, to basic research. Our field provides crucial scientific underpinning for many important aspects of the DOE mission such as nuclear energy, nuclear waste remediation and national security. Applications of nuclear science first developed in basic research programs are widespread in other fields such as medical imaging, nuclear medicine, and materials testing. Even more importantly, basic research supported by the Office of Science is the training ground for the next generation of nuclear physicists and chemists who will enter these applied fields. A steady supply of talented and well-trained nuclear scientists is of strategic importance to the Nation.

The Office of Science carries out its nuclear physics mission in a number of different ways. First it operates facilities at National Laboratories and Universities. These include the flagship facilities of our field: the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory and the Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility. RHIC and CEBAF are extraordinary facilities that provide capabilities that are unique an the world with exceptional opportunities for scientific discovery. In addition, the Office of Science supports a number of smaller facilities at other National Laboratories and on University Campuses, including Duke University, MIT, Texas A&M, the University of Washington and Yale. These facilities also provide unique research opportunities, and are especially effective in the training of young scientists. Finally, almost one third of the Office of Science budget supports research through peer-reviewed grants to University research groups, and research programs at the national laboratories. The importance of the Office of Science in funding research directly has sometimes been overlooked. Modern nuclear physics research is a partnership between the Universities and National Laboratories with the Office of Science taking a leading role in funding both facility operations and research.

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Turning to the principal opportunities ahead of us in the coming decade, let me say a few words about the long range planning process. In partnership with the American Physical Society, NSAC has made a comprehensive survey of the field, its achievements and the opportunities ahead of us. These have been summarized in four white papers submitted to NSAC by different parts of our scientific community. On the basis of these studies, one can make some general comments on the competitiveness of our program on the international scene. At the present time, it is unarguable that the U.S. has world leadership in the frontier areas of nuclear science carried out at CEBAF and RHIC. We are also among the leaders in the study of nuclear structure and astrophysics, but this leadership is threatened by the aging of our own fatalities and by substantial investments that are being made in Europe and Japan. In the area of fundamental symmetries, many of the key experiments have to be carried out in laboratories deep under ground. At the present time, we do not have a dedicated laboratory for this work in the United States.

After reviewing the scientific opportunities that are available to us, we are committed to maintaining a balanced program that includes forefront fatalities in each of these areas. We believe that this commitment to a balanced program is justified not only by the merit of the science, but also by the national need to train the next generation of nuclear physicists and chemists. Without forefront research fatalities in nuclear structure and astrophysics, we will not train scientists with the skills necessary to support other mission areas of DOE or applications in the life sciences.

Unfortunately, the current level of funding for Nuclear Physics in the DOE Office of Science is inadequate to meet these goals. Insufficient funds are provided to exploit the investments we have made, and there is no chance at these budget levels to exploit new opportunities. As an example, with constant dollar funding, the Relativistic Heavy Ion Collider will operate at less than fifty percent of its potential in the coming year. This is a serious problem for the scientific community and especially for the graduate students and postdoctoral fellows who are relying on results from this facility to advance their careers. It is also a wasted opportunity for the nation which has invested so heavily in the construction of the facility. The funding problems are not confined to RHIC. All of the DOE fatalities face similar challenges. Given the urgency of this situation, NSAC as part of its long-range planning process has drafted the following prioritized recommendations on budgets for the field. The aspects of these recommendations that pertain to Office of Science Programs follow.

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First, recent investments by the United States in new and upgraded facilities have positioned the Nation to continue its world-leadership role in nuclear science. The highest priority of the nuclear science community is to exploit the extraordinary opportunities for scientific discoveries made possible by these investments. Increased funding for research and facility operations is essential to realize these opportunities. Specifically, it is imperative to: increase support for facility operation, increase investment in university research and infrastructure, and significantly increase funding for nuclear theory.

Secondly, the Rare Isotope Accelerator (RIA) is our highest priority for major new construction. RIA will be the world-leading facility for research in nuclear structure and nuclear astrophysics. The exciting new scientific opportunities offered by research with rare isotopes are compelling. RIA is required to exploit these opportunities and to ensure world leadership in these areas of nuclear science. RIA will require significant funding above the nuclear physics base. This is essential so that our international leadership positions at CEBAF and at RHIC be maintained.

Thirdly, we strongly recommend the upgrade of CEBAF at Jefferson Laboratory to 12 GeV as soon as possible. The 12 GeV upgrade of the unique CEBAF facility is critical for our continued leadership in the experimental study of the inner structure of protons and neutrons, the basic building blocks of matter.

In addition, NSAC strongly recommends that an underground laboratory be built in the United States and supports the proposal which has been submitted to the National Science Foundation. There is a unique opportunity to build such a facility at the Homestake Mine in South Dakota, which will help ensure United States leadership in studies of fundamental particles and symmetries for the coming decade.

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In summary, the Nuclear Physics Program funded by the Office of Science is at a taming point. It is clear that funding above the level of the FY 2002 budget is essential to exploit the investments that the nation has made in new facilities for nuclear physics and to ensure that the nation has a balanced program in nuclear science in the coming decade. As you have heard, this is an urgent issue that is common to all of the programs in the Office of Science. However, I would like to end on a positive note. Mr. Chairman, thanks to the investments have been made over the last decade, this is a most exciting time to be a young nuclear scientist, with extraordinary opportunities to advance our knowledge. Thank you for your support of the physical sciences, and for the opportunity that each of us has been given to share some of that excitement with you today.

STATEMENT OF DR. KEITH O. HODGSON, CHAIR, BIOLOGICAL AND ENVIRONMENTAL RESEARCH ADVISORY COMMITTEE; DIRECTOR, STANFORD SYNCHROTRON RADIATION LABORATORY, DEPARTMENT OF CHEMISTRY, STANFORD UNIVERSITY

Dr. **HODGSON.** Chairman Bartlett and distinguished Members of the Subcommittee, on behalf of my colleagues—and we are getting the visual up—good. On behalf of my colleagues, the six of us first would like to express our appreciation for the invitation to come and testify before the Committee on behalf of the DOE Office of Science, the role that it plays, and the role it can play in the future.

Chairman Bartlett, you have said, much better that we can, I think, what, in fact, is important about science in this nation and in the future. Perhaps, I can just amplify a few—graphically amplify a few of your remarks in this introductory few comments, and then you will hear from each of us about the six programs that we represent.

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You mentioned the important role that DOE plays. And here we see that DOE is, indeed, a science agency. If one looks at total basic and applied research or basic research, HHS is by far, through NIH, the strongest supporter in these areas, but NASA and DOE and DoD are very strong partners in supporting the Nation's national scientific enterprise in Research and Development.

If one looks in the physical sciences, one sees that the Department of Energy is almost twice the size of the nearest other agency, NASA, in supporting research in the physical sciences. In the area of R&D facilities you have mentioned already the importance of DOE in supporting infrastructure and user facilities. And here you see, again, DOE is a very large player in supporting this important infrastructure for science R&D.

I would like to just then make a few more points. We have talked about the first one. DOE plays an important role in maintaining, supporting our scientific workforce and building for the future. It currently supports, through the Office of Science, about 4,900 Ph.D. students at our universities in postgraduate training and research, and about 3,200 graduate students are currently supported by the Department of Energy, Office of Science. The DOE Office of Science also supports a large amount of basic peer-reviewed research at our universities and national laboratories, especially in the physical sciences. This amounts to more than—about a quarter of a billion dollars investment in basic research through this peer-reviewed grant research mechanism.

And then, finally, DOE plans, builds, and operates many of our nation's large-user facilities. There are actually 27 of them. They support about 60 research—about 16,000 scientists use these each year. About 8,000 of those scientists come from the academic sector. Many of them also come from industry and they represent every state in the nation as users of this large collection and unique collection of user facilities which are so important to enabling the science.

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Let me then re-emphasize the point about the support of basic research, and, in particular, the notion and the point that has been made about the underpinning of the biomedical sciences, more broadly by the physical sciences. You heard about the complexity of problems that are being attacked today and will be attacked in the future, requiring interdisciplinary approaches. Those approaches are very strongly dependent upon strength across all of the disciplines.

And here you see, as a function of the last three decades, the roughly constant trend in funding and constant dollars for the physical sciences over this three-decade period. And that is certainly beginning to, and will have, an impact on investment that is important to fuel the economy, as you heard also the 21st century.

In terms of DOE itself, we see a similar trend and that is, DOE science has remained or, in fact, declined somewhat in constant spending power over this period. The workforce supported by the DOE science programs is about 21,000 strong. It has lost as much as 25 percent of its workforce over even the last decade as a result of this trend. And I think it is something that we are concerned about, again, as it relates to the future of support for the physical sciences and, more broadly, sciences in the future.

And so, with this, I would like to end with a quote, which I am sure you have all heard, from Harold Varmus, a Nobel Prize winner, and was also the Head of the National Institutes of Health for many years, where he pointed out, among other things, that the importance of the balance among the science is essential to progress in all spheres, including medicine and biomedical research.

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So with that, I would like to turn this over to Margaret Wright, who will say a few words then about the specifics of the computing initiative and science program in DOE science.

BIOGRAPHY FOR KEITH OWEN HODGSON

Chair, Biological and Environmental Research Advisory Committee

Born: Hampton, Virginia.

Education:

B.S., University of Virginia, 1969
Ph.D. (chemistry), University of California, Berkeley, 1972

Professional Experience:

1972–73, NATO Fellow, Chemistry, Swiss Federal Institute of Technology;
1973–78, Assistant Professor, Stanford University;
1979–84, Associate Professor, Chemistry, Stanford University;
1984– , Professor, Chemistry, Stanford University;
1998– , Director, Stanford Synchrotron Radiation Laboratory, Stanford University.

Memberships:

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American Chemical Society

American Crystallography Society
American Association for the Advancement of Science

Research:

Inorganic, bio-inorganic and structural chemistry, application of x-ray absorption spectroscopy for investigation of molecular structure of metalloenzymes and proteins. Use of synchrotron radiation in structural molecular biology including crystallography and small angle scattering.

Mailing Address:

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STATEMENT OF DR. MARGARET H. WRIGHT, CHAIR, ADVANCED SCIENTIFIC COMPUTING ADVISORY COMMITTEE, BELL LABORATORIES/LUCENT TECHNOLOGIES

Dr. **WRIGHT.** Thank you, Chairman Bartlett, distinguished members of the Subcommittee. I am honored to be here today and I want to whisk very quickly through some of the highlights that I see in the advanced scientific computing research. This is a selection of wonderful things that you are used to seeing on the cover of Science Magazine and in the press. If I had my way, I would impose some complex mathematics and some hundreds of thousands of lines of computer source code on top of these pictures, but, of course, many people would not be as excited about that as I am. But those are the underpinnings of science and engineering as we know it today.

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The Office of Advance Scientific Computing Research funds mathematics, numerical methods, and computing, and I want to talk very briefly about those. The other five chairs are from the physical sciences. I am the one that is from this other different agency—part of the agency. I want to mention the distinguished history of the Department of Energy. It has been in advanced computing since the beginning of advanced computing and it has been in mathematics for longer than that.

The first thing I want to talk about is the mathematics. Mathematical models, again, are something that not everybody appreciates. They are a foundation for science and engineering. They are absolutely standard in physics. If we go back to some of the science like Keplar, who certainly didn't have a model of the universe to experiment with, there was some mathematics there. In biology and medicine, these are becoming more important. They work together with scientists very closely, experience, intuition, and experiments. They are the source of leaps of understanding that would not be possible otherwise.

I just want to mention two examples—pollutants seeping into the environment. It is not possible for anyone to run experiments and say, let us see if we did this at this rate, what would happen. Oh, dear, it pollutes everything. Let us not try it. You would do this with a mathematical model. There is very interesting work in medicine, for example, modeling heart attacks—what happens to them. You can't take people and watch them during heart attacks and try things. You need the mathematical models. So these allow very important things to be done that cannot be done otherwise in the real world.

The second part of that is numerical algorithms. In the movies, people always say, ah-ha, the secret formula. This is how we will get the answer. In real science, it is done with numerical methods, which are a separate category of research that is closely coupled to the models and to the science. Algorithms have accounted for as much speed up as Moore's Law if not more, in the speed with which we can solve problems today. This is another thing that is not always appreciated. As science becomes more complex, more interconnected, more nonlinear, we need better algorithms.

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And they are essential for real-time applications. An interesting one I heard about recently was real-time brain surgery where the surgeon is deciding where to cut based on computations that are being performed. And if that is you on the table, you certainly don't want to wait a week for the answer.

The best algorithms generalize and can be applied in other areas. As you all know, this is one of the beauties of science—that something that comes up here can be applied elsewhere. I just have a couple of charts about algorithms. The one on the left is showing that as problems get larger—this is the "Y" axis, the vertical line—it is not always true that we can solve them faster and faster. The nearly flat line on the bottom shows how many operations it takes to solve problems of a certain size. And if you look at the flattest line, you will see that for the hardest problems with the algorithms we have today, you can solve it with as much computing power as you have, and you cannot solve a very large problem. What you want to do is move to the more nearly vertical line, which says, as the problems get larger, you can solve them better.

And the second chart shows this so-called performance gap, which is, as computing is getting faster, the performance that we can get on scientific problems is not growing that fast. So we need a combined program —in particular, better algorithms to deal with that.

Now, let us just talk about challenges for software. This is something I work on all the time. And if you read any business page, you will find people bemoaning the fact that software is this hard problem, and it is a hard problem. Algorithm shifts demand you rethink software; you cannot just leave it alone. So you have to constantly adapt the software infrastructure to deal with new algorithms, new science, and so on. At its best, software is tied to the mathematical modeling and the numerical methods development. But for scientists today, to use the high-speed Internet, massive data sets, more data than you can conceive, they need better computing.

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And the last chart I have is simply a schematic provided by the Department of Energy showing the hardware, the mathematics and numerical methods, the science, all feeding in together, feeding from advanced scientific computing research, to the other parts of the Office of Science. It should be an integrated, unified whole, and I think the Department has a proud history of doing that and is continuing that. Thank you very much.

BIOGRAPHY FOR MARGARET H. WRIGHT

B. San Francisco, California, February 18, 44; d 1. SCIENTIFIC COMPUTING AND APPLICATIONS. *Educ:* B.S., Mathematics, Stanford University, 64; M.S., Computer Science, Stanford University, 65; Ph.D., Computer Science, Stanford University, 76. *Prof Exp:* GTE Sylvania, Development engineer, 65–71; Operations Research Department, Stanford University Research associate, 76–81; Senior research associate, 81–88, Bell Laboratories Member of technical staff, 88–93; Distinguished member of technical staff, 93–97; Head, Scientific Computing Research Department, 97–present. *Concurrent Pos:* Visiting lecturer, Computer Science Department, Princeton University, 89; Society for Industrial and Applied Mathematics (SIAM) Council, 87–89, Vice-President-at-Large, 90–93; President-Elect, 94; President, 95–96; Past-president, 97; Advisory Committee, Directorate of Mathematical and Physical Sciences, National Science Foundation, 94–98; (chair, 97–98). *Honors & Awards:* National Academy of Engineering, 97; SIAM Award for Distinguished Service to the Profession, to be awarded 2000, *Mem* SIAM; Mathematical Programming Society; American Mathematical Society. *Res:* Optimization, especially numerical methods for nonlinear problems; linear algebra; scientific computing. *Mail Add:* Bell Laboratories, Room 2C–462, 600 Mountain Avenue, Murray Hill, New Jersey 07974–0636.

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Business Address

Computer Science Department, New York University, 251 Mercer Street, New York, New York 10012; Telephone: 212–998–3056; Fax: 212–995–4121; E-mail: mhw@cs.nyu.edu

Education

Stanford University, Stanford, California

B.S., Mathematics (with distinction)
M.S., Computer Science
Ph.D., Computer Science
Dissertation: "Numerical Methods for Nonlinearly Constrained Optimization"
Advisors: Gene H. Golub, Walter Murray

Employment (since 1978)

2001–present:
Professor of Computer Science and Mathematics
Chair, Computer Science Department
Courant Institute of Mathematical Sciences
New York University

1988–2001:

Bell Laboratories, Murray Hill, New Jersey
(AT&T through 1995, Lucent Technologies after 1996)
Head, Scientific Computing Research Department, 1997–2000
Distinguished Member of Technical Staff, 1993–2001
Member of Technical Staff, 1988–1993

1976–1988:
Department of Operations Research, Stanford University
Senior Research Associate, 1981–1988
Research Associate, 1976–1981

Honors

Award for Distinguished Public Service, 2001, American Mathematical Society

American Academy of Arts and Sciences, 2001

Special Award for Distinguished Service to the Profession, 2000, Society for Industrial and Applied Mathematics (SIAM)

Forsythe Lecturer, 2000, Computer Science Department, Stanford University

Emmy Noether Lecturer, 2000, Association for Women in Mathematics

Bell Labs Fellow, 1999

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National Academy of Engineering, 1997

First George E. Forsythe Award for Student Contributions to Education, 1972, Computer Science Department, Stanford University

Editorial Activities

Editor-in-Chief, *SIAM Review*, 1999–present
Associate Editor, *SIAM Journal on Scientific Computing*, 1981–present
Associate Editor, *Mathematical Programming*, 1986–present
Associate Editor, *SIAM Journal on Optimization*, 1990–present
Area Editor for Optimization, *Computation in Science and Engineering*, 1994–present

Society Memberships

Society for Industrial and Applied Mathematics

American Mathematical Society
Mathematical Programming Society

Selected Professional Activities (since 1990)

Co-chair, "SIAM50", SIAM's 50th Anniversary Meeting, Philadelphia, 2002
Member, NSF Blue Ribbon Panel on Cyberinfrastructure, 2001–present
Chair, Advanced Scientific Computing Advisory Committee, Department of Energy, 2000–present

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Peer Committee, Computer Science and Engineering Section, National Academy of Engineering, 1999–2002 (chair, 2001–2002)
Scientific Advisory Committee, Mathematical Sciences Research Institute, Berkeley, California 1996–2001 (co-chair, 1999–2001)
Society for Industrial and Applied Mathematics (SIAM)—Board of Trustees, 2000–present; President, 1995–1996 (President-elect, 1994; Past-president, 1997); Vice-President-at-Large, 1990–91, 1992–93; Council, 1987–1989
Blue Ribbon Panel, Accelerated Strategic Computing Initiative (ASCI), Department of Energy, 1999 and 2000
Advisory Committee, Mathematical and Physical Sciences Directorate, National Science Foundation, 1994–1998 (chair, 1997–1998)
Program Committee, SIAM Conference on Optimization, Atlanta, Georgia, 1999
Advisory Committee, Computational Science Graduate Fellowship Program, Department of Energy, 1992–present (chair, 1998–present)
IFIP Working Group 2.5 (Numerical Software), 1983–2000 (chair, 1997–2000)
United States Delegation, International Congress of Mathematicians, 1998
Committee to Benchmark U.S. Mathematics, National Research Council, 1997
Review Committee for Canadian Mathematics, Natural Sciences and Engineering Research Council, Canada, 1996
Co-chair, SIAM Conference on Optimization, Victoria, British Columbia, 1996
Co-chair, Workshop on Women in Mathematical Sciences Connected with Industry, Institute for Mathematics and its Applications, Minnesota, 1996
Advisory Committee, Division of Mathematical Sciences, National Science Foundation, 1991–1994
Nicholson Student Paper Prize Committee, Operations Research Society of America, 1993, 1994
Review Panel on Linear Algebra, Mathematical Sciences Program, Department of Energy, 1993

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Federal Policy Subcommittee, Committee on Science Policy, American Mathematical Society, 1993–1994
Board of Visitors, Mathematical Sciences Research Program, Office of Naval Research, 1989, 1990, 1993
Co-chair, Workshop on Progress in Mathematical Programming, Asilomar, California, 1990

Plenary and Invited Talks, Named Lectures (since 1988)

2000 State-of-the-field speaker on "Scientific computing" (plenary), Supercomputing 2000, Dallas, Texas

2000 SIAM Conference on Applied Linear Algebra (plenary), North Carolina State University, Raleigh-Durham

2000 Distinguished Speaker on High-Performance Computation for Engineered Systems, Massachusetts Institute of Technology

2000 Australian and New Zealand Industrial and Applied Mathematics (ANZIAM) (plenary), Bay of Islands, New Zealand

1999 Olga Taussky Todd Celebration of Careers for Women in Mathematics, Mathematical Sciences Research Institute, Berkeley

1999 International Congress on Industrial and Applied Mathematics (plenary), Edinburgh, Scotland

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1999 Workshop on Computational Methods in Engineering (plenary), Department of Scientific Computing, Uppsala University, Sweden

1999 Frontiers Lecture Program, Texas A&M University, College Station, Texas

1998 European Postdoctoral Forum (plenary), Institut des Hautes Études Scientifiques, Bures-sur-Yvette, France

1998 The Gentry Lectures, Wake Forest University, Winston-Salem, North Carolina

1998 First Pacific Rim Conference in Mathematics (plenary), Hong Kong

1997 International Symposium on Mathematical Programming (talk in invited session), Lausanne, Switzerland

1997 International Conference on High-Performance Software for Nonlinear Optimization (plenary), Ischia, Italy

1997 The Lonseth Lecture in Mathematics, Oregon State University, Corvallis, Oregon

1996 SIAM Conference on Sparse Matrices (plenary), Coeur d'Alene, Idaho

1996 International Conference on Nonlinear Programming (plenary), Beijing, China

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1995 Theory Center 10th Anniversary Symposium (plenary), Cornell University

1995 AMS/SIAM Summer Seminar in Applied Mathematics (plenary), Park City, Utah

1995 Dundee Biennial Conference in Numerical Analysis (plenary), Dundee, Scotland

1995 Conference on Linear Algebra and its Applications (plenary), University of Manchester, England

1994 International Symposium on Mathematical Programming (talk in invited session), Ann Arbor, Michigan

1993 SIAM Annual Meeting (plenary), Philadelphia, Pennsylvania

1993 Symposium on Parallel Optimization (plenary), Madison, Wisconsin

1993 Pure and Applied Linear Algebra Conference (plenary), International Linear Algebra Society, Pensacola, Florida

1992 Symposium on High-Performance Computing for Flight Vehicles (plenary), Washington, DC

1992 Cissy Patterson Lecture in Mathematics, William and Mary College, Williamsburg, Virginia

1992 NATO Advanced Study Institute, "Linear algebra for large-scale applications" (plenary), Leuven, Belgium

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1992 SIAM Conference on Optimization (plenary), Chicago, Illinois

1991 SIAM Conference on Applied Linear Algebra (plenary), Minneapolis, Minnesota

1991 Dedication Symposium, Theory and Engineering Center Building (plenary), Cornell University

1991 International Symposium on Mathematical Programming (talk in invited session), Amsterdam, Netherlands

1990 25-Year Anniversary Symposium (plenary), Computer Science Department, Stanford University

1990 Workshop on Very Large Scale Computing (plenary), Cape Cod, Massachusetts

1989 Workshop on Large-Scale Numerical Optimization (plenary), Cornell University

1989 European Meeting of the Psychometric Society (keynote address), Leuven, Belgium

1989 SIAM Conference on Sparse Matrices (plenary), Gleneden Beach, Oregon

1988 Distinguished Women in Operations Research Series (Inaugural lecture), Massachusetts Institute of Technology

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1. Gill, P.E., Murray, W., and Wright, M.H. (1981). *Practical Optimization,* Academic Press, London and New York.
2. Gill, P.E., Murray, W., and Wright, M.H. (1991). *Numerical Linear Algebra and Optimization,* Volume 1, Addison-Wesley.

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3. Smith, F.W. and Wright, M.H. (1971). Automatic ship photo interpretation by the method of moments, *IEEE Transactions on Computers C–2.*
4. Gill, P.E., Murray, W., Picken, S.M., and Wright, M.H. (1979). The design and structure of a Fortran program library for optimization, *ACM Transactions on Mathematical Software* 5, 259–283.
5. Friedman, J.H. and Wright, M.H. (1981). A nested partitioning procedure for numerical multiple integration, *ACM Transactions on Mathematical Software* 7, 76–92.
6. Gill, P.E., Murray, W., Saunders, M.A., and Wright, M.H. (1981). Aspects of mathematical modelling related to optimization, *Applied Mathematical Modelling* 5, 71–83.
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STATEMENT OF DR. GERALDINE L. RICHMOND, CHAIR, BASIC ENERGY SCIENCES ADVISORY COMMITTEE, DEPARTMENT OF CHEMISTRY, UNIVERSITY OF OREGON

Dr. **RICHMOND.** Gerri Richmond from the University of Oregon. I represent the basic energy sciences group. Basic Energy Sciences is one of the Nation's largest sponsors of fundamental research. It operates on tenants of excellence, relevance, and stewardship. Its mission is to foster and support fundamental research that provides the basis for energy technologies and provides the tools needed for research through user facilities and instrumentation.

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I am honored to be here to be able to share with you some ideas about what we have been thinking about in BES. BES supports five major areas of research—if we can have—and this is an eye chart. This actually is to give you some idea of the depth and breadth of the science that is conducted in BES.

Five major areas of material science, chemical sciences, geosciences, engineering sciences, and biosciences. The work is intovative and innovative and extremely multidisciplinary, crossing boundaries that 10 or 15 years ago would not have been crossed. It is a scientific portfolio that reflects the diversity of issues and needs of our country in the area of energy research.

From the development of better magnetic materials, for electric generators and motors, to solar energy devices, to understanding what processes make combustion more effective and efficient, and issues of environmental remediation and waste management. It funds the best science in this country, as evaluated by an extensive peer-review process in BES. This allows the best science to emerge, killing off areas that are old and mature and allowing us to evolve into new areas. This is a natural part of the peer-review process. It funds the best scientists in the country with world-class science.

It has, indeed, been an honor for me to have served as Chair of the Basic Energy Science Advisory Committee, BESAC for the last 3 years, and to have been a committee member for the last 6 years. The 20 BESAC members that are some of the most active players in the physical science research in this country. Many are National Academy of Science and National Academy of Engineering members. Two of my committee members are Nobel laureates. It is a feisty group. One might say that my job is like herding cats. I would say it is more like herding cougars. This group has no patience for mediocrity in research or in its facilities and it works diligently to make certain that only the best science is funded and money is not wasted.

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In my time on BESAC we have reviewed all the DOE-user facilities. Where we have identified problems, BES management has acted swiftly to make the needed changes. And, in some case, that means significant cuts in budgets. When we have identified particularly stellar programs, BES management has followed our advice to shift resources.

But as much as BES is about first-class research, it is also about people. There are 2,400 scientists funded by BES with creative ideas of how to solve, in the long term, energy problems of this country. There are chemists, physicists, biologists, who are working across the disciplines to develop devices that mimic the efficiency of plants and humans, the chemistry that goes on in these very efficient systems.

About 3,000 graduate students from 48 states around the country are supported by BES funds. The hardest part about being BESAC Chair has been to see many phenomenal new ideas shelved or stalled because of the lack of funding. It is particularly painful for me, personally, as an educator, to watch some of our brightest new post-docs and faculty in the physical sciences struggle to figure out how they can possible put their ideas into reality.

Many of us know that to do science in the physical sciences, we require not just one funding agency, but several. That is why DOE, along with NSF, must both play a strong role in the funding of the physical sciences. And without adequate funding, we are stalling again many of these ideas, bypassing new ideas, that we desperately need to solve energy and the environmental and economic problems that we have up ahead, that my children will have in spades, much more than we have now. What we are getting this year, with regards to the energy crisis, only a peak at what we will have in the next 10, 20, 30 years if we don't invest now.

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For BES, in the past 10 years, the average grant size has not changed, despite a 25 percent cost-of-living increase. And the number of scientists supported at the DOE labs has dropped by 20 percent. I must admit, personally, that I have difficulty recommending that my own best graduate students go work at a DOE lab because of the uncertainty of their future, and that is really sad.

So I am hopeful, with the science and the new ideas that we see coming down the pike, and, in fact, I am excited about the new science that I see. But I worry, as an educator, that if we don't continue to fund the physical sciences and, in fact, increase the funding for the physical sciences, that the workforce issues will become dominant and we will not only have a problem with not having the science done, but we will not have the scientists to do it. So thank you, again, very much for listening to my concerns, but also the excitement that I feel for the programs in BES.

STATEMENT OF PROFESSOR RICHARD D. HAZELTINE, CHAIR, FUSION ENERGY SCIENCES ADVISORY COMMITTEE, UNIVERSITY OF TEXAS AT AUSTIN, INSTITUTE FOR FUSION STUDIES

Mr. **HAZELTINE.** I am Richard Hazeltine. I am Chair of the Fusion Energy Sciences Advisory Committee. And my first slide—yeah—my first slide summarizes what fusion research is all about. The sun —that is a picture of the sun and it—the sun is a fusion reactor. Indeed, all stars are powered by fusion. So one can say that the objective of the fusion program is to build a small star on the earth as a clean, safe, and enduring energy source.

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But the picture is helpful for a second reason. It shows matter that is so hot, so energetic, that it is unlike any ordinary solid, liquid, or gas. This fourth state of matter is called plasma. So from the point of view of a physicist, the sun is a large ball of plasma kept hot by fusion reactions. Although plasmas are rare on the surface of the earth, they constitute most of the visible universe. Plasmas make up the atmosphere and interior of stars, most of interstellar space, and the earth's magnetosphere. More commonly visible plasmas include those in lightening bolts, and in the lights in this room.

Fusion scientists need to understand plasma behavior, because any gas that is heated sufficiently to fuse is necessarily in the plasma state. Plasma physics is famous for its demanding complexity, and that is the primary fusion challenge. However, because plasma is so pervasive in the universe, understanding its rich dynamics would be an enormous boon to several areas of science and technology. Thus, the fusion quest is linked to numerous deep questions about the natural world. It also offers short-term rewards, since plasmas are used in many industrial applications. Next slide please.

Fusion progress over the past decade has been rapid and exemplified by the production of megawatts of fusion power at laboratories in the United States and Europe. You see those two squares on the upper right—one corresponding to a European experiment and one in the United States. The production of fusion power—the growth in that production has been truly phenomenal and comparable to Moore's Law, which has already been mentioned here.

Such advances have brought fusion research to a watershed. Its central challenge is no longer to demonstrate that fusion reactors are feasible, but rather to show that they can be practical. The present focus of research is to establish the scientific and technological reality of a fusion power source with costs and operational characteristics that would attract commercial investment. It should be emphasized that this challenge is just as serious and demanding as the previous demonstration of feasibility. Next slide please.

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Underlying the progress toward fusion energy and, to me, just as exciting as that progress, has been a dramatic advance in scientific understanding. You needn't worry about the details of this picture, but it simply shows the theoretical prediction compared to detailed experimental observations and tries to make the point that, hey, we are—we understand what is going on now in hot, fusion-oriented plasmas.

The next slide tries to convey two simultaneous trends in fusion research. On the one hand, looking at the triangle to the right, armed with new understanding and knowledge, we are focusing on the key remaining challenges to practical fusion energy. One the other hand, looking at the left triangle, our increased understanding leads to an intellectual broadening of the field, in which its applications to other areas of science and technology are increasingly appreciated and used. So there is a lot of opportunities on both of those triangles.

A class of experiments that is certain to advance scientific understanding, while bringing fusion closer to the power grid, are the so-called burning plasma experiments, in which fusion reactions are sustained at a relatively high level for long periods of time. The European community, Russia and Japan, are expected to begin work on such experiments soon and it is an exciting opportunity that is clouded by limited program resources.

Or there is another sense in which there is two aspects to fusion program. On the one hand, the exciting opportunities I have mentioned, on the other hand, concern about whether deep future support will be sufficient to sustain scientific momentum. We are now funded at less than half our peak of a few decades ago, and, as a result, increasingly stretched and threadbare.

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The last slide shows one result of this. It is the utilization of our major facilities in weeks per year. And you can see, in all cases, the utilization is far below the full level.

Let me just summarize with a final remark. All scientists want to make their programs bigger. That is very natural. But worries about the fusion program and other programs you will hear about today go beyond that traditional urge. There is serious concern about whether the enterprise can be sustained. If a program is starved to the point at which it cannot attack its central challenges, it risks losing its driving force and its talent base. I don't think fusion is at that point yet because of its exciting recent advances, but there is a real fear that fusion is heading in that direction. Thank you.

BIOGRAPHY FOR RICHARD D. HAZELTINE

Address: Physics Department, University of Texas at Austin, Austin, Texas 78712; Phone: 512–471–1322; Fax: 512–471–6715; E-mail: rdh@physics.utexas.edu

Education:

Harvard College 1960–64 A.B. (Physics)
University of Michigan 1964–66 M.S. (Physics)
University of Michigan 1966–68 Ph.D. (Physics)

Employment:

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1968: Lecturer in Physics, University of Michigan
1969: (summer) Research Scientist, US Naval Research Lab
1970: (summer) Visiting Scientist, Aspen Center for Physics
1969–1971: Member, Institute for Advanced Study, Princeton

The University of Texas at Austin:
1971–1975: Research Scientist Associate, Fusion Research Center
1975–1983: Research Scientist, Fusion Research Center
1982–1986: Assistant Director, Institute for Fusion Studies
September 1, 1986–present: Professor of Physics
September 1, 1987–June 1, 1988 and July 1, 1991–August 31, 1991: Acting Director, Institute for Fusion Studies
September 1, 1991–present: Director, Institute for Fusion Studies

Awards and Representative Present Activities:

Sigma XI; Phi Kappa Phi; Harvard College Scholar; Horace H. Rackham Pre-doctoral Fellow
Fellow, American Physical Society
Teaching Excellence Award, College of Natural Sciences, University of Texas at Austin
Board on Physics and Astronomy, National Research Council, National Academy of Science
Councilor, American Physical Society
Chair, Theory Coordinating Committee, U.S. Magnetic Fusion Program
Chair, Program Advisory Committee, General Atomic Company
Chair, Fusion Energy Sciences Advisory Committee, U.S. Department of Energy

International Advisory Committee, International Conference on Plasma Physics
Integrated Program Planning Activity, U.S. Department of Energy
Steering Committee, Transport Task Force, U.S. Department of Energy
Board of Directors, Fusion Power Associates
Co-Director, Joint Institute for Fusion Theory

Representative Past Activities:

Editorial Boards: Reviews of Modern Physics (1989–1997); Physical Review A (1978–1979); The Physics of Fluids (1978–1980)
Chair, Division of Plasma Physics, American Physical Society
Chair, Theory Advisory Board, Plasma Fusion Center, MIT
Chair, Program Advisory Committee for Theory, Princeton Plasma Physics Laboratory
Chair, Nominating Committee, Division of Plasma Physics, APS
Chair, Executive Committee, Controlled Fusion Theory Conference
Chair, FASAC Panel on Western European Controlled Fusion Program
Chair, Excellence Award Committee, American Physical Society (APS)
Chair, Program Committee, Division of Plasma Physics, APS
Co-Chair, FASAC Panel on Comparative Assessment of International Controlled Fusion Programs
Chair, Budget Council Advisory Committee, Physics Department, University of Texas at Austin
Steering Committee, Technical Planning for Magnetic Fusion Program Plan, U.S. Department of Energy
Steering Committee, International Thermonuclear Experimental Reactor, U.S. Home Team
Program Advisory Committee, Princeton Plasma Physics Laboratory
Strategic Planning Panel for Fusion Theory Program, U.S. Department of Energy
Advisory Committee, Fusion Energy Postdoctoral Research and Professional Development Programs

Subpanel on Role of Universities in Magnetic Fusion, Magnetic Fusion Energy Advisory Committee
Program Committee, Division of Plasma Physics, European Physical Society
Subpanel on Role of Theory in Magnetic Fusion, Magnetic Fusion Energy Advisory Committee
Science Advisory Board, La Jolla International School of Physics

Consulting:

Austin Research Associates, Austin, Texas
Los Alamos National Laboratory, Los Alamos, New Mexico
General Atomic Company, San Diego, California
Lawrence Livermore National Laboratory, Livermore, California
Science Applications International Corporation, San Diego, California; Boulder, Colorado; McLean, Virginia
McGraw-Hill Publishing Company, New York
Macmillan Publishing Company, New York

Addison-Wesley Publishing Company, California
Lodestar Research Incorporated, Boulder, Colorado
IOP Publishing Limited, Bristol, England
Educational Testing Service, Princeton, New Jersey
Saunders College Publishing, Fort Worth, Texas

Publications:

Two books; approximately 120 technical papers.

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STATEMENT OF PROFESSOR FREDERICK J. GILMAN, CHAIR, HIGH ENERGY PHYSICS ADVISORY PANEL, DEPARTMENT OF PHYSICS, CARNEGIE MELLON UNIVERSITY

Mr. **GILMAN.** Mr. Chairman, thank you for the opportunity to be here today. I am Fred Gilman, Chair of the High Energy Physics Advisory Panel. High-energy physicists try to understand what the universe is made of, how it works, and where it has come from. In the last decades, we found deep connections between apparently unrelated phenomena and, from a few particles, are able to explain a very complex cosmos.

Experiments at accelerators create conditions like those in the Big Bang, but under controlled experimental conditions, and they are complimented by astroparticle experiments that look for relics of the Big Bang. Next.

In the course of the last 100 years, high-energy physicists have developed a new periodic table. The upper left-hand corner illustrates the old periodic table, the periodic table of the chemical elements. And the next, to the right on the viewgraph, shows a picture of J.J. Thompson, the discoverer of the first of our fundamental building blocks, the electron, in 1897. And that was followed by the discovery of the atomic nucleus, by the theory of relativity, by quantum mechanics, and a journey inward that resulted finally in the last of our building blocks, the top quark and tau neutrino, that were found in the last decade. And that periodic—new periodic table of 12 fundamental building blocks is in the middle of the bottom line.

But deep questions now confront us. Why are there 12? Why is there a pattern? Why do they have a wide range of masses? And, in particular, the mechanism for the generation of the masses of these fundamental particles, should be able to be seen in near-term experiments. And that gives great promise to the next stages of experiment at high-energy colliders.

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So the next transparency, we, in fact, then go from that to the fact that high-energy physics is entering an area of discovery in which U.S. facilities will play the lead role until the Large Hadron Collider at CERN starts in 2007. In fact, the search for the Higgs boson, which has been long sought, was—that most recently explored by the LEP Collider at CERN, they found a tantalizing hint, but, in fact, have now turned off that machine preparatory to the construction of the Large Hadron Collider. So the Tevatron Collider at Fermilab will have a unique opportunity to find that long-sought Higgs boson, as well as make other discoveries at the high-energy frontier.

Another facility, the B–Factory at SLAC will give us crucial information on another basic question of why does matter behave differently from antimatter and how did the universe become composed of matter, and to tell us whether we are, indeed, on the right track with some ideas that we have on that issue.

The next transparency, in fact, just shows those facilities. In the center in the upper right is the Fermilab accelerator and the CDF, one of the big detectors at Fermilab. On the left is the BaBar detector at SLAC and end view and simulated event in that detector that will look for the difference between matter and antimatter.

So on the next transparency, we come to, in fact, the central point, that to take advantage of the nation's investment in these facilities and the corresponding opportunities requires an improvement in funding. For the Fiscal 2002 budget, the strategy has been to run those colliders to produce the data that is needed. But that has meant painful cuts in other parts of the program, especially the smaller labs and the university-based program. And there the cuts will mean cuts in people and, in particular, cuts that will result in the loss of our younger scientists, perhaps, permanently.

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So how are we planning for high-energy physics and taking into account the budgets that we have had and will have in the future? It is done through the High-Energy Physics Advisory Panel that I chair. It reports both to the Department of Energy and to the National Science Foundation. In '98, there was a sub-panel, which is the mechanism by which we make long-range plans. It made a decade long plan and set priorities for the field. In the last year we produced a white paper, which takes into account developments worldwide and the need to provide some intermediate term guidance for the next few years. It reaffirmed the '98 sub-panel's priority on funding, the operation, and the groups using the facilities for those big facilities that have just been completed—the Main Injector at Fermilab for the Tevatron Collider and the B-factory and BaBar detector at SLAC.

It also reasserted the importance of accelerator R&D for the United States to continue to be a leader in the field long term. And it is in an accelerator R&D incidentally that many of the societal benefits of high-energy physics come to be. Thank you.

BIOGRAPHY FOR FREDERICK J. GILMAN

Department of Physics, Carnegie Mellon University, Pittsburgh, PA 15213

THEORIST; ELEMENTARY PARTICLE PHYSICS

Born: Lansing, MI; October 9, 1940

Education:

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B.S., Michigan State University, 1962
Ph.D., Princeton University, 1965

Professional Experience:

1965–66 National Science Foundation Research Fellowship, California Institute of Technology

1965–67 Research Fellowship, Theoretical Physics, California Institute of Technology

1967–69 Research Associate, Stanford Linear Accelerator Center

1969–73 Associate Professor, Stanford Linear Accelerator Center

1973–90 Professor, Theoretical Physics, Stanford Linear Accelerator Center

1990–94 Associate Director and Head of the Physics Research Division, Superconducting Super Collider Laboratory

1994–95 Deputy Director of the Physics Research Division, Superconducting Super Collider Laboratory

1995–Present Buhl Professor of Theoretical Physics, Carnegie Mellon University

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Societies, Committees and Honors:

Fellow, American Physical Society

Chairman **BARTLETT.** Thank you very much. As you heard from the bells, another vote is on. About 10 minutes remains in that—well, as a matter of fact, the bells you now hear is the 10-minute call to the vote. So we will recess the hearing briefly so that we can go and vote and we will return as quickly as possible. Thank you.

[Recess]

Chairman **BARTLETT.** We will reconvene our hearing. And now our last witness, Dr. Symons.

STATEMENT OF DR. T. JAMES SYMONS, CHAIR, DOE/NSF NUCLEAR SCIENCE ADVISORY COMMITTEE, NUCLEAR SCIENCES DIVISION, LAWRENCE BERKELEY NATIONAL LABORATORY

Dr. **SYMONS.** My names is James Symons, and I am Chair of the Nuclear Science Advisory Committee, NSAC. I very much appreciate this opportunity to share with you some of the many exciting opportunities that are open to the Nuclear Physics Program in the Office of Science.

NSAC advises both the National Science Foundation and the Department of Energy on their nuclear science programs. These two agencies support essentially all of the nation's federally funded basic research in nuclear science, with the Office of Science providing the lion's share of the funding.

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Chairman **BARTLETT.** Will you excuse me, Dr. Symons.

Dr. **SYMONS.** Yes.

Chairman **BARTLETT.** If I could just interrupt you very briefly. I didn't know that Dr. Richmond was still here. What I would like to do is take advantage of the 5 minutes that we have remaining of her time. Thank you for coming so far. What I would like to do is to ask my colleagues if they have—and I have only one of them here—specific questions for Dr. Richmond. And they will ask for her any comment she has. Ms. Woolsey.

Adequate Energy Research Funding to Address Energy Needs

Ms. **WOOLSEY.** Thank you, Mr. Chairman. Well, we are sorry you are leaving, but thank you for your input. Could you discuss the impact of research in material science and the other sciences that you are talking about, as it applies to fossil fuels, energy supply, and fossil energy, as it relates to the energy situation we have going on in this nation right now? I—is there enough emphasis on that subject?

Dr. **RICHMOND.** So the question is, is there enough funding currently to be able to——

Ms. **WOOLSEY.** That is right.

Dr. **RICHMOND** [continuing]. Fund the kind of research that necessary to solve many of the energy needs of the country?

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Ms. **WOOLSEY.** That is a great question. Thank you. You made me look like a good student.

Dr. **RICHMOND.** And the answer to that is obviously no. But let me expand on that. There are many areas in BES, in the last 10 or 15 years, that have basically had to be put aside. In solar energy research, for example, a lot of that has been slowed down. In catalysis and combustion science, all those areas have basically had flat funding, and, yet, they are the research that underpins everything with regards to energy uses.

In material science, in particular, we have seen incredible advances in making of new magnetic materials that are the basis behind energy generators and motors. Where would we be if we had seen some increases in funding in those areas? Those are critical to updating our power plants, to making new generators. If we could just get some of those ideas into use, make that additional step, that would be great. But there just isn't that funding to sort of get the fundamental research done and then take it further.

And you can, you know, name me any area of any energy technology and I can do the same for any of them, whether it be a better catalyst in your car or a combustion engine, or getting more fuel—more oil out of the ground, better surfactants to get it out, better processes. You know, when you have had flat budgets for the last 10 years, just imagine where we would be with regards to the energy crunch we are in now. And so much of it is the heart and backbone of BES science.

Ms. **WOOLSEY.** Thank you. I am going to stop so that other people can have a chance before Dr. Richmond leaves, Mr. Chairman.

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Overlap Between Chemical and Biological Sciences

Chairman **BARTLETT.** Thank you. I noticed that you listed photosynthesis as a chemical science and fermentation microbiology as a biological science. And I was struck with the reality that all biological science is ultimately a chemical science. Is it not?

Dr. **RICHMOND.** Well, it is really true. And I often—when I teach freshman chemistry, I say to my students, your body is an incredible chemical machine. It is. Think about it. It does all these incredible reactions at 98.6 and it does it with catalysis and the—can I say this—the byproducts aren't so bad to deal with. And it is amazing. If we could just do in a—what a plant or a body does in terms of making chemicals efficiently, taking in sunlight like plants do, and produce an amazing array of chemicals, it would be remarkable. And that is why this wonderful merging of the chemical science and the biological science is so important.

Chairman **BARTLETT.** Yes. Thank you. Just one quick question about—I understand that we have now bioengineered an organism that can split cellulose into its glucose molecules. Are you familiar with that technology and what potential does it have for making fuels from cardboard and newspaper?

Dr. **RICHMOND.** That I am not so much. Keith?

Dr. **HODGSON.** No.

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Dr. **RICHMOND.** No? That is not my particular area. So I would have to get back to you on that.

Chairman **BARTLETT.** Okay. Okay. Thank you. Let us see if there are other members on our Subcommittee who would like to ask questions of Dr. Richmond, because she must leave very shortly for a more important engagement——

Dr. **RICHMOND.** Back in Eugene, Oregon.

Chairman **BARTLETT** [continuing]. Two of her children are doing piano recitals this evening. Okay.

Basic Energy Sciences Funding Opportunities

Mr. **MATHESON.** Thank you. If I could just—that is very important priority, so I don't want to take too much of your time. But I am concerned about where we are going in terms of our funding for this Basic Energy Research. And I appreciate the concerns you have raised and particularly the concern about that the younger students coming up and your post-docs—that we are discouraging them from moving into this field, or at least we are creating some disincentives. And I think that as we look at the energy issues which are certainly the topic of the week, and we are looking at a lot of short-term solutions, that this is where the real—if we take the longer view of this panel, and your office, in particular, is really an important component of that. So I really appreciate the fact that you highlighted those issues in your opening testimony

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My question for you is, as the funding situation has been rather limited, as you touched upon in your response earlier, for various programs, where do you think, if we were to increase funding, what—if you could prioritize items that we have been lacking to this point in Basic Energy Research, where would you try to focus additional funding?

Dr. **RICHMOND.** Right now, with regards to the science, and I am very much directed towards, you know, what are the emerging science issues, I would say right now nanoscience. And that may sound like a buzzword. But these new ideas, with regards to nanoscience really revolutionize the way we think about making materials and doing chemistry. It is—the way you can think about this is many chemists and material scientists in the past have made new materials by heat-and-beat methods and cook-and-shake-them-up and shake-and-bake they call it. You basically throw a lot of stuff together and you pound on it and you look what comes out at the end and you hope it is what you wanted.

But now, with nanoscience and the new tools that we have to look at things as we make them, we can now do molecular architecture rather than shake-and-bake. We can take the tinker toys and put a few together, look at it, and see where we are, the put a few more together. And so you are building something as—you watch it as you build it. And that is only within the last 5 years that that has happened. And that will have huge impacts with regards to catalysis, energy storage, solar cells, sensing, optical communication, a wide range of topics. So in terms of science, I am strongly supportive of the areas of nanoscience.

Mr. **MATHESON.** And do you have a sense of—you are suggesting that area is underfunded today.

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Dr. **RICHMOND.** Absolutely.

Mr. **MATHESON.** And do you have a sense of the magnitude to which you would like to see that funding level placed in terms of our—looking out over the next—not just the next fiscal year, but looking out over the next few years?

Dr. **RICHMOND.** No. I don't know the numbers, but I can get back to you, because I am not one that carries those numbers in my head, because I tend to focus on the science. But let me give you an example, and then—and someone from BES would have to correct me. But I believe at the last BESAC meeting, they put out an initiative for an invitation for proposals in the nanoscience area. And they got more proposals than they had ever gotten for any program, something like 800 proposals. Eight hundred proposals—and they could only fund a handful of those—10 percent—hardly any. And these proposals were from the most exciting young people in the field that are trained differently than many of us in terms of not only interested in the basic science, but they know the device that they want it to go into to make an impact in the end.

Mr. **MATHESON.** Let me ask one final question along this line. And that is, I am very supportive of trying to promote this type of activity. And it seems to me that this is an item where public funding is a critical component. Would you share with me your thoughts about—to the extent that if the public funding component isn't there, that private sector funding is going to be involved in this basic research of this area you are talking about?

Dr. **RICHMOND.** In terms of industrial support, for example——

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Mr. **MATHESON.** Any——

Dr. **RICHMOND** [continuing]. Taking up some of the slack.

Mr. **MATHESON.** Yeah. Do you—will this happen from the private sector? I guess that is what I am asking you.

Dr. **RICHMOND.** What I see when I—when my students go out and get jobs and look for jobs in companies that want to do basic research in these areas, what I see is very little interest in that. Many companies would prefer to have a startup company do the basic science with their little bits of funds and then they go buy the company. And so I don't see very much going on in the industrial setting with regards to basic science. And I also don't see a huge amount of funding coming from industry into our government or academic labs to help.

Mr. **MATHESON.** Well, I really appreciate your testimony. And, Mr. Chairman, I will yield back the balance of my time.

[The prepared statement of Mr. Matheson follows:]

PREPARED STATEMENT OF CONGRESSMAN JIM MATHESON

One of the many exciting lines of research that the Department of Energy, Office of Science is engaging in is Biological and Environmental Research. Biological and Environmental Research performed under DOE addresses multiple national priorities including methods for cleaning up contaminated environments, medical imaging technologies, and fast, accurate DNA sequencing. In the area of DNA sequencing, the Human Genome Project intends to discover all of the human genes and determine the complete sequence for all of the 3 billion DNA subunits. One goal of this project is to be able to break down waste at the microbial level. In addition to this sequence mapping, the Humane Genome Project coordinates with the National Institute of Health to address other overarching questions related to genetics. Both DOE and NIH genome projects set aside 3% to 5% of their total budgets for research in the ethical, legal, and social issues surrounding the study of the human genome.

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The Utah Center of Genome Research has been developing technology for large scale sequencing of DNA. This research is focused on determining the function of specific genes and their interactions in human disease. One exciting area of research under this program is part of the work on ethical and social issues involved in genetic research. The University of Utah and the Huntsman Cancer Institute in Salt Lake City are leading the way in some of this research, designed to "bring the genome to life." This collaboration project with the Huntsman Cancer Institute utilizes the Utah Population Database containing computerized genealogies of the founders of Utah and all their descendants. This data is then connected to other data on births and deaths, cancer records, census records, and HCFA data. Because these interconnected data sets are well developed and rich with information they offer the opportunity for researchers who identify genetic component of disease processes to track familial clusters. Identification of these clusters allows the understanding of the degree of relatedness between people and the identification of families to potentially study.

One area of focus presently is on the behavioral and ethical results of testing for BRCA1 and BRCA2 mutations connected with susceptibility to breast and ovarian cancers. This research examines the implications of molecular biology on social behaviors. It explores how to construct appropriate clinical protocols for dealing with genetic information, such as cancer susceptibility in order to maximize outcomes for patients. This research is testing huge populations of Utah-based kindred who are known to carry this BRAC1 gene mutation. Numerous projects coordinated with the National Cancer Institute work to address issues such as decreased psychological stress, compliance with recommended medical regimens, and insurance discrimination.

The genome research project being carried out in Utah is one of the largest internationally addressing these issues. Continued support of the DOE Office of Science and basic research is critical to furthering these issues in the future. As this hearing progresses today I hope that we will be able to explore the future of such research projects conducted under the Office of Science.

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Chairman **BARTLETT.** Thank you. Dr. Richmond, if you have another moment, Mr. Wu is very anxious to ask you a question. We don't want to have on our conscious missing your plane. So you tell us if you have time to answer his question.

Dr. **RICHMOND.** Okay.

Mr. Wu. Thank you very much, Mr. Chairman. And I will only take a second to say hello to you, Dr. Richmond. And as a fellow Oregonian, say hello to Eugene for me. And I also wanted to say hello to Dr. Hodges—Hodgson. I don't know if you remember, but Dr. Hodgson, I think that you were just out of your post-doc and I was a freshman and I took physical chemistry from you. It seems like just yesterday. And it is a delight to see you both and I look forward to more substantive contact over time.

Dr. **RICHMOND.** Thank you. Thank you very much.

Chairman **BARTLETT.** Thank you. And, Dr. Symons, thank you very much for your patience and proceed now with your testimony.

Dr. **SYMONS.** Thank you very much, Mr. Chairman. As I was saying, NSAC works closely with both DOE and NSF to set scientific priorities which guide funding decisions within their programs. In addition, NSAC prepares, on a periodic basis, a comprehensive long-range plan for our field, consulting widely in the scientific community in order to achieve consensus on the highest priorities for the field. We are currently preparing a new long-range plan, which will become available later this year.

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Nuclear Physics research encompasses some of the most fundamental problems in all of science. We wish to understand both the structure of nuclei and their creation in the stars. Nuclear physicists are now using complex experimental tools and sophisticated theoretical methods to elucidate the structure of matter as it existed in the first few seconds after the big bang and as it exists today both in the cores of neutron stars and within protons and neutrons in the nucleus. Finally, the nucleus is a unique environment for studies of fundamental processes that are at the frontier of many areas of modern physics.

The importance of nuclear science to our nation is not limited, however, to basic research. Our field provides crucial scientific underpinning for many important aspects of the DOE mission, such as nuclear energy, nuclear waste remediation, and national security. Applications of nuclear science first developed in basic research programs are widespread in other fields such as medical imaging, nuclear medicine, and materials testing. Even more importantly, basic research supported by the Office of Science, is the training ground for the next generation of nuclear physicists and chemists who will enter these applied fields. A steady supply of talented and well-trained nuclear scientists is of strategic importance to the industrial health and the security of our nation.

Modern nuclear physic research is a partnership between the universities and national laboratories for the Office of Science taking a leading role in funding both research and facility operations. Approximately one-third of the nuclear physics budget in the Office of Science supports peer-reviewed grants to university research groups and research programs at the national laboratories.

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The remainder supports operational facilities, including the Relativistic Heavy Ion Collider, RHIC, at Brookhaven National Laboratory and the Continuous Electron Beam Accelerator Facility, CEBAF, a the Thomas Jefferson National Accelerator Facility. These are extraordinary facilities with exceptional opportunities for scientific discovery. In addition, the Office of Science supports a number of smaller facilities at other national laboratories and on university campuses which are especially effective in the training of young scientists.

At the present time, it is unarguable that the United States has world leadership in the frontier areas of nuclear science carried out at CEBAF and RHIC. We also are among the leaders in the study of nuclear structure and astrophysics. But this leadership is threatened by the aging of our own facilities and by substantial investments to be made in Europe and Japan.

In the area of fundamental symmetries, many of the key experiments have to be carried out in laboratories deep underground. At the present time, unlike Europe and Japan, we do not have a dedicated laboratory for this work in the United States. In these latter areas, new investments must be made to maintain a balanced program which will train scientists with the skills necessary to support other missionaries of DOE in the applications in life sciences.

Unfortunately, the anticipated Fiscal Year 2002 budget for nuclear physics in the DOE Office of Science is inadequate to meet these goals. Insufficient funds are provided to exploit the investments we have made, and there is no change at these budget levels to prepare the university infrastructure or to exploit new opportunities. As an example, with constant dollar funding, the Relativistic Heavy Ion Collider will operate at less than 50 percent of it potential in the coming year. Clearly, this is a pressing issue facing the Office of Science and members of NSAC, but it is even more pressing for the graduate students and post-doctoral fellows who are relying on results from this facility to advance their careers.

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Facing this situation, what are priorities for Office of Science funding? The highest priority of the nuclear science community must be to exploit scientific discoveries made possible by the investments we have already made at CEBAF and RHIC. Increased funding for research and facility operations is essential to realize these opportunities without irreversibly damaging other parts of the field.

Secondly, the Rare Isotope Accelerator, RIA, is our highest priority for major new construction. RIA will be the world-leading facility for research in nuclear structure and nuclear astrophysics.

Thirdly, we strongly recommend the upgrade of CEBAF at Jefferson Laboratory to 12 GeV as soon as possible. The upgrade is critical for our continued leadership in the experimental study of the inner structure of protons and neutrons, the basic building blocks of matter.

In addition, NSAC strongly recommends that a deep underground laboratory be built in the United States and supports the proposal which will be submitted to the National Science Foundation. There is a unique opportunity to build such a facility at the Homestake Mine in South Dakota. There is also an important role for shallower sites, such at WIPP in New Mexico.

In summary, the Nuclear Physics Program funded by the Office of Science has many opportunities. We do face funding issues in common with all of the programs in Office of Science. However, I would like to end on a positive note, emphasizing scientific opportunity rather than budget constraints. Mr. Chairman, thanks to the investments which have been made over the last decade, this is the most exciting time to be a young nuclear scientist. Thank you for your support of the physical sciences in general and nuclear physics, in particular, and for the opportunity that each of us has had been given to address you today. Thank you.

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BIOGRAPHY FOR T. JAMES M. SYMONS

Nuclear Science Division, Lawrence Berkeley National Laboratory

EXPERIMENTAL NUCLEAR PHYSICS

Born: Southborough, England; August 4, 1951

Education:

B.A., Oxford University, 1972
Ph.D., Oxford University, 1976

Professional Experience:

1976–1977 Fellow, Oxford University
1977–1979 Fellow, Lawrence Berkeley National Laboratory
1979–1983 Division Fellow, Lawrence Berkeley National Laboratory
1983–1985 Associate Director, Lawrence Berkeley National Laboratory
1985–1995 Division Head, Nuclear Science, Lawrence Berkeley National Laboratory
1995–Present Nuclear Science Division, Lawrence Berkeley National Laboratory

Societies:

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Fellow, American Physical Society

Research:

Study of nuclear physics using high energy heavy ion beams.

Biological and Environmental Research at DOE

Chairman **BARTLETT.** I want to thank all the witnesses for their testimony. Oh. Okay. I am sorry. Dr. Hodgson did the introduction and now you need to do the specifics of your area. Thank you very much.

Dr. **HODGSON.** Thank you for indulging me. I will try to be very brief with a few remarks about the Biological and Environmental Research Program at the DOE. Some of you may wonder why DOE is involved in biology or biological research. And, indeed, the mission of this program is to identify, understand, and mitigate adverse health and environmental consequences of energy production development and use. And it does this in very close partnership with other Federal agencies in a very cooperative way to support interdisciplinary programs that stretch across all of the research portfolio of the U.S. Government.

I would like to briefly say that our committee has recently just finished an assessment. The web site for this is in the written testimony and details can be found in that written document, and I would be happy to provide copies, as well, to read at your leisure.

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What I would like to do in really about 3 minutes or less is to just highlight some of the areas of research of DOE biological and environmental research and just say a little bit about where my committee foresees as where we can go in the future and where are the opportunities.

The life sciences area, one of three that are supported broadly programmatically within DOE-BER, has had some remarkable achievements in the past few years. Perhaps a little known fact is that DOE-BER initiated the human genome project. Subsequent to that, it became a strong partner. NIH came in. And you all know of the remarkable success. Perhaps one of the greatest achievements that has been done in science was the sequencing of the human genome.

A little less known is perhaps that DOE-BER and its scientists developed a number of the tools and the technologies that allowed this remarkable success to be achieved. The DOE-BER program through its sequencing center in Walnut Creek, the JGI, actually completed a sequence of three of the human chromosomes.

A further remarkable achievement was the verification of the new branch of life. Indeed, DOE–BER, through its life science programs, has positioned the nation well through new technologies and instrumentation and methodologies for taking the next step, and I will tell you about that next step at the very end.

Finally, DOE–BER, in this area, supports new facilities for determining the structure of biomolecules. And, Chairman Bartlett, indeed, your comment is very well taken. At some level, in fact, biology is chemistry. And you have heard—many of you have heard the recent remarkable, again, success of this drug Glivec, which is said to be the first drug to target cancer at the molecular level. That information comes from understanding structure and physical methodologies, something called protein crystallography. A hallmark of the DOE and its facilities will enable that kind of success well into the next century in a much larger way.

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DOE–BER has a strong role in the environmental sciences. It partners, again, with other agencies through the U.S. Global Change Program. It has programs in advanced modeling of climate and climate prediction, of measuring experimentally some of the main uncertainties in what controls climate and climate in the future, and that is the role of clouds in the atmosphere. It has strong programs in areas of aerosol research and also is heavily involved in finding solutions, biological solutions, to helping mitigate the long-term problems that have been created by the legacy of the Manhattan Project.

Finally, BER has a Medical Sciences Program, perhaps again, little known. In fact, in the United States, the BER research has set the foundation for a very, very strong program in the area of nuclear medicine. About 35,000 procedures are performed each day using nuclear medicine in our hospitals. A lot of the fundamental research in radio pharmaceuticals and in imaging comes from investments made by DOE-BER over the past three decades. It has significant work in future directions, including imaging, use of computational tools to improve the radioisotope and other use of radiation in treatment of tumors and a variety of things, which, again, relate to DOE's energy mission in strong complementarity to NIH.

And so, finally, let me say that DOE-BER sees a number of opportunities with our partners to understand complex living systems to make further advances in medical imaging, to work with partners in climate modeling, to leverage the investments in biological solutions, to clean up, to carbon sequestration, to try to better understand the role of CO2, how the environment interacts with that CO2.

And, finally, and let me end by saying that to expand in new directions. And that is the last program I will mention, which is something which has come to be known as Genomes to Life. And here we understand the sequence of the human genome. We understand the words that are written in our genes. The question is, how do those words give the cells the instructions to carry out what they do, to carry out the processes of life. And simply stated, the Genomes to Life Initiative is to take the next step, to understand, at the molecular level, at the level of chemistry, what the gene incurrents for, what these proteins do, what they catalyze, how they interact, how they signal. And this is the next grand challenge, which, again, DOE-BER is well-positioned to make an investment in, given, again, adequate budgets to do so.

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So, Mr. Chairman, and, members of the Committee, let me then end this on BER and on behalf of all of my colleagues to say thank you for hearing from us on behalf of the DOE Office of Science. We would be very pleased to respond to your questions now or in a written form if we don't know the answers. Thank you very much.

Science Education

Chairman **BARTLETT.** Thank you all very much for your testimony. This was a very short half hour. You did a very good job. And the better job you do, the shorter time it appears for us, and you did a very good job. Thank you very much. I would just like to note that the empty seats up here and the empty seats behind you are indicative of the problem we face in attracting the attention of America to the importance of what you are doing. It is not just out there that we need to project. It is also, from the empty seats up here, obviously, inside the Congress also that we need to be able to better communicate. Let me turn now to my Ranking Member for questions and observations.

Ms. **WOOLSEY.** Thank you. I echo my Chairman's comments on appreciating you very much. And one of the reasons these seats aren't full is we are in the middle of reauthorizing elementary, secondary education. And that is going to bring me to my questions to you. I am one of three members, I think, in the House, both on the Science Committee and the Education Committee. And in a minute I might have to leave and go down on the floor. But I am curious from everyone of your disciplines' perspective, how are we doing in educating scientists of the future? Given the best of all worlds, say that we totally fund your—each of your disciplines, would we have the talent we need to carry out the projects? So we can just go down the line. And also let me know if you think we are—how we are doing in training girls because they aren't going into the science, math, and technology fields. And we are going to start with Dr. Symons.

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Dr. **SYMONS.** Well, thank you. Of course, that is prior to the funding you send to the nuclear science ——

Ms. **WOOLSEY.** Do you have that on? Your——

Dr. **SYMONS.** Yeah. I just put it on.

Ms. **WOOLSEY.** Okay.

Dr. **SYMONS.** As we do the research—but we can't do the research with the balance of—we don't have people coming into the field. And so K–12 education is obviously important to us, to ensure that we have the right balanced, diverse workforce for science of the future. We are certainly—this is certainly a big issue for us and something we have put a lot of thought and time into. I could give you a couple of examples. Recently, at the Lawrence Berkeley Laboratory and some other institutions we put together a wall chart, which I will send you a copy of——

Ms. **WOOLSEY.** Okay.

Dr. **SYMONS** [continuing]. If you don't already have it, which is in high schools and so on——

Ms. **WOOLSEY.** Uh-huh.

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Dr. **SYMONS** [continuing]. And this is part of our outreach program to get the message out. There are careers in science and there are careers in nuclear science, in particular, and we are working on that. We also, of course, welcome young people for summer camps and other education activities and internships at the laboratories and universities to really get high school students excited——

Ms. **WOOLSEY.** Uh-huh.

Dr. **SYMONS** [continuing]. About the work we are doing and involved in it. So I agree with you that this is a crucial issue and something we have to continue to work on. Thank you.

Ms. **WOOLSEY.** Thank you. Professor.

Mr. **GILMAN.** Yes. Let me start at the level of post-doctoral and on faculty members of laboratories. We do have the people in the field to do the projects, including the potential future projects. Let me emphasize the international nature of high-energy physics. That it is a science that is conducted all over the world. That, in fact, Europe is, in particular, putting into this area considerably more resources and people, but the United States itself still has the people to do the science. The worry is rather that the people who are already in the field will start to leave in increasing numbers if there is not a future for the field.

At the graduate level, I would echo the Chairman's remarks that the American universities in general are the envy of the world in terms of graduate education. We still are attracting U.S. students. It isn't that everybody is going to other things besides, for example, high-energy physics. We are still getting excellent U.S. students, as good as they ever were, less of them, but still we are getting them. And then we are getting a considerable number of foreign students who are coming to America because of the excellence of our programs.

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At the undergraduate level, I believe that nationally this downtrend in the number of physics students, if I remember correctly, has leveled off. I know in my own university we have had a massive effort to recruit people into physics with some success, in fact, in the last few years. They increased the enrollments by about 50 percent. That is just one university and one very intense effort. But the potential is certainly there if there is a future for these people in science.

Ms. **WOOLSEY.** Professor.

Mr. **HAZELTINE.** Yes. I would also comment separately on the K–12 situation and the——

Ms. **WOOLSEY.** Okay.

Mr. **HAZELTINE** [continuing]. More advanced situation. K–12, I think, science education in this country at that level is terrible. All of us in our programs try to be helpful to it, but none of us, as far as I know, are equipped to really get into that in a major way, nor is that really part of our official role. Well, in Fusion, we have a program, similar to what James mentioned. We have a teachers' day at all our meetings. We have the local teachers come with their students and we try to engage them. But I think this has a small effect and I think there is a real problem with teaching science to our youngest students.

At the graduate level, I have seen the number of graduate students who want to get into my field fluctuate. Graduate students are very smart at knowing what is hot, what looks exciting, and what has interesting job opportunities. They are extremely smart and they are pretty tough-minded. They are pretty tough minded. And so when they see something growing and something that is taking on new challenges, they get excited. When they see something that has been level for year after year, they get very discouraged and we lose them.

Ms. **WOOLSEY.** My time is up. Can I—can the other two answer? Oh. Thank you. Thank you. Dr. Wright.

Dr. **WRIGHT.** Let me just——

Ms. **WOOLSEY.** No.

Dr. **WRIGHT.** No? Oh. Sorry. A mathematician and a computer science and actually in both those fields, students are remaining steady, going into the more—I think, interdisciplinary mathematics is becoming more exciting. Let me mention that advanced scientific computing research has, for 10 years, had a fellowship program for graduate study and computational science, which is the envy of every other agency and every other part of the world. And they did this, you know, 10 years ago. And the students in that must be U.S. citizens. And on the bright side, if you could see them—actually, we are meeting in Washington this summer. They are amazing students. So I am hopeful about that.

I am not so hopeful about getting girls into science. It is something I personally do. I think the Department of Energy's programs have a component to attract women and minorities into scientific careers with outreach into K-12. But, as Richard said, it is a giant problem and a few people going around can't really deal with it. I actually think the web is helpful because so many kids now log on. And if you can find an exciting web site, a hands-on one, where you can do something interesting—since people don't have television shows about science and they don't really know what scientists do, I think this is a way to go forward, but we need more, definitely.

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Dr. **HODGSON.** I will be also brief. I make two comments. One is that I think in the broadly defined biomedical research area, clearly the strong funding for biomedical research has helped that area significantly. The problem is, and comes, when one looks at the, again, interdependence of the sciences and the recognition that we have to continue to train and strengthen the areas of physical science. Because after all, magnetic resonance imaging, CT X-ray scans—in fact, even drug design, using protein structures—all of these things come from advances in physical sciences. Mr. Rutkin was a physical scientist. He wasn't a biological scientist. So I think that is an important point.

The other point is a trend—again, an international trend. And I don't know whether the gentleman can turn the screen back on—the projector back on, just to share with you one interesting statistic. And here you see the ratio of bachelors in science and engineering by country over a period from '75 to '97. And you notice the U.K. was around three per hundred back in '97. Look at where it is now. It is up to almost nine. The United States has grown a little bit, but it is not even close to the shift in this emphasis over some of the other countries.

Now, it is hard to make quantitative things from these trends, but they are indicators. They come to the attention of many people, including the National Science Board. And I think they do indicate and reinforce just your very important point, that we need to be vigilant. We need to find ways to work harder to attract the most talented young people into science and engineering.

Ms. **WOOLSEY.** And I can assume that 50 percent of our population, the females, should not be left out.

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Dr. **HODGSON.** Indeed. And, in fact, I think here, one sees that in the more biologically oriented aspects of the research, for reasons that I don't know, it has always been an area where one has tended to see a larger population of females. So very good.

Ms. **WOOLSEY.** Well, off the board we want them. Thank you. Thank you very much.

Value of Major Research Facilities

Chairman **BARTLETT.** Thank you. Mr. Grucci has joined us. He is not a member of our Subcommittee, and he presumably is here expressing his interest in your areas of concern because he has a very large laboratory, Brookhaven National Laboratory, in his district.

Mr. **GRUCCI.** That is correct, Mr. Chairman. And thank you for giving me the opportunity to join you today and to listen to this distinguished panel. I do have a very important facility in the district that I represent. It is the Brookhaven National Laboratories and they do outstanding work in a couple of major areas with the RHIC and the National Synchrotron Light Source. And not being a scientist or having those many year of experience in those worlds, I find it very fascinating every time that I go out there, learning and watching how this operation works.

And the question that I asked out there, and I am going to ask it to the panel again because I think it is important to be put on the record as to why we are investing in these types of projects. I would like to hear from you, the panel, or whoever you think on the panel would be the best to respond to the question, why is it important to have a project like the RHIC underway and why is it important for the National Synchrotron Light Source to be a source of research dollars and a source of research product that comes out of it? Explain to us, on the record, if you will, the importance to mankind of these two very important projects.

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Dr. **HODGSON.** We will do RHIC first.

Dr. **SYMONS.** Well, let me just—there are various quotes at different times. And I think the quest to understand the world around us has always been one that attracts the brightest minds in the history of mankind and these are deep problems. And the problems that RHIC—I will speak to RHIC. The light source, other people can talk about.

But RHIC has the possibilities to create energy densities that are unprecedented since the earliest few microseconds of the universe. This is a—has implications for how the universe evolved after that time, if we understand it. And we don't make a big bang, but we make a little bang every time one of these ions collides inside that accelerator and we want to understand what happened inside that collision. And this is a fundamental exciting question. It is an exciting question to young people, and we feel that is justification for that.

Mr. **GRUCCI.** And I concur with you it is exciting. But the question that I keep getting asked and I respond to the best that I can, is what does mankind get from knowing this, other than the excitement of—and—of seeing these atoms colliding with each other? The information that is obtained from these helps us to do what?

Dr. **SYMONS.** Well, I am going to rely on the Chairman to help me out a little bit there. In his introductory remarks this morning, he mentioned that it maybe was not clear to Madam Curie, when she did her first experiments on nuclear radiation, what would come out of those experiments. She was fascinated by the science involved. The same was true when people were studying the early days in nuclear physics in the 1930s. The same was true with molecular biology in the 1950s. You cannot predict precisely what will come out of it. But if you use history as a guide, forefront science opens new areas and in the new areas, the unexpected things come.

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I will say one last thing, if I may. I would like to——

Mr. **GRUCCI.** Well——

Dr. **SYMONS** [continuing]. Give other—my colleagues an opportunity to respond also. But you could have asked precisely the same question in 1899, okay, with exactly the same implications behind it. At that time, it appeared that physics was pretty much done. Everything was understood. We had the electromagnetic theory. We had—and so on. All of a sudden, a few key results came out of basic research and the whole field changed. And it may happen again. I can't guarantee to you that a similar change will come from RHIC, but if we don't do these experiments and we don't explore these frontiers, we have no chance of opening new areas. Thank you.

Mr. **GRUCCI.** Thank you.

Dr. **HODGSON.** Maybe I could respond briefly to the point or the question about the National Synchrotron Light Source. I will say that the National Synchrotron Light Source is one of four such light sources in the world actually supported by the DOE Office of Science. The other three are the Advanced Light Source at Berkeley, the Advanced Photon Source at Oregon, and the Stanford Synchrotron Radiation Laboratory.

Collectively, these four light sources serve about 6,000 users per year. And these are users who are working in a variety of fields, from physics to medicine to basic biology to chemistry. And, again, our Chairman put it extremely well in his introductory remarks. These facilities and the light that is produced by these facilities allow us to look down at a level of detail where we can begin to understand how to make things, how chemistry occurs, how to design new things, which ultimately are going to mean we are going to be much more efficient in discovering new ways to more effectively use energy to find better drugs, to really understand at the level of individual atoms how science occurs and how to control it even better. And this is true across all fields of science.

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The 6,000 users include many people who are funded by other Federal agencies, NIH, NSF, DoD, and, as well as NASA. And so in this context, they are really a unique facility to serve all of science, and the National Synchrotron Light Source is one of those facilities. And so, in part, it is important because it enables science across a broad range of disciplines through its user program in these ways which I have described and, in part, because it provides frontier opportunities for new discoveries, some of which are very hard to predict where they will lead.

But I commented earlier about the example of drug discovery. And here is an example in the HIV proteases. These proteases came directly from using this tool, X-ray synchrotron light, to design better drugs. And I think this is the way in the future that we are going to see in that particular area—a competitiveness by the U.S. science and technology community.

Mr. **GRUCCI.** Thank you. And that research goes on into areas of diabetes, cancers, and Parkinson's, and etcetera, etcetera, etcetera.

Dr. **HODGSON.** Absolutely.

Mr. **GRUCCI.** And those are the reasons why we have to continue to invest into this kind of research and that is the reason why facilities like the Brookhaven National Laboratory will be continuing to lead the way in those types of research areas. And, Mr. Chairman, I thank you for giving me the opportunity to be with you today and to have an opportunity to speak to this distinguished panel. And I yield back the remainder of whatever time I have.

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Chairman **BARTLETT.** Thank you very much. I appreciate Mr. Grucci's question because it is a question asked by many people in America, why are you funding this with my taxpayers' dollars? What good is it going to do me? And you gave exactly the right answers. We just have to look back through history. And I think that there is almost no research that was vigorously pursued that did not have a societal payoff and there was no way of knowing when that research was being pursued, if there was going to be a societal payoff or what it would be. And the role of science is not to look for societal payoff; it is to advance the frontiers of knowledge. And if we do that, you can be assured there will be a societal payoff. So thank you for your question. It gave us another opportunity to get on the record the importance of basic science. Ms. Lofgren.

Fusion Research

Ms. **LOFGREN.** Thank you, Mr. Chairman. And thank you for allowing me to participate in this hearing, even though I am not a member of the Subcommittee and to ask at least one question. As you know, and many of the panelists know, recently I and several dozen other Members of the House have been pursuing increased funding in a new direction for fusion research. And we are hopeful that that effort will prove successful. Clearly, the energy crisis in California has focused the attention of the public on the need to explore long-term solutions for the energy crisis.

And I am wondering, Professor Hazeltine, we know that the long-term success of the Fusion Energy Science Program is linked, in part, to greater collaboration between scientists in the fusion community and their peers in the greater scientific community. As a matter of fact, last year's National Research Council report made a recommendation that there be stronger ties and better connections between the fusion community and a greater scientific community. How, in addition to funding resources—what further can we do to support that effort, in your judgment, if anything?

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Mr. **HAZELTINE.** Okay. That is an interesting question that I hadn't thought about. In fact, the fusion community has been grappling with the issue of how much could be gained by improved ties to other areas of physics. And we consider that something that we can benefit from very much and that other areas of physics could also benefit. So it is something that is taking up a lot of time at our meetings. We view it as something that we have to address as individual scientists more than something to go whining to the government about.

But there is one area in which government policy might have an effect, and that has to do with not the level of funding, which, of course, is always inadequate, but the nature of it. Almost all fusion research is funded by the Department of Energy and it is possible that if that funding base were broadened, including, for example, NSF, and other organizations, that just that broadening would also have an intellectual counterpart. That is, it would have—it would cause a broadening of the contacts, you know, amongst the scientists themselves.

But I think I would have to repeat, in my answer to your question, that I think this is something for the scientific community to deal with and not something that the government should think it has to solve.

Ms. **LOFGREN.** Other than, perhaps, the suggestion you have made that would have an outcome that would be supportive of that effort.

Mr. **HAZELTINE.** Right.

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Ms. **LOFGREN.** It looked like Dr. Hodgson had an eagerness—no.

Dr. **HODGSON.** No. No. That is fine.

Ms. **LOFGREN.** Let me just—I don't want to go on it too greatly. But are we, in your judgment, Professor Hazeltine, attracting the necessary student talent to the fusion science and plasma physics programs and are we getting the best and the brightest in these fields and what further do we need to do if the answer is—needs to improve?

Mr. **HAZELTINE.** Okay. I think that is an extremely important question. And I would rather answer it from the point of view of all of this, so to speak, rather than just fusion. I think that the sorts of physical science that we represent, which provides, as you have heard, an infrastructure for many other sciences, is not getting the talent flow that it needs. And I think all of us are concerned about that.

And I think that, you know, on top of all our other problems, is what worries us the most, is that the—as Fred said, we are getting very bright students still, but we are not getting the numbers that will needed to—that will be needed to do our jobs. And what—if I could just finish my sentence, what I see over and over is students are aware of growth and students see when an area is growing and attacking new challenges and when it is healthy and they also see an area that is not doing that—that funding has become static. And even as it discovers new challenges, is unable to attack those new challenges. Students are amazingly perceptive of things like that and it is very scary to see how they are reacting.

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Ms. **LOFGREN.** That is very interesting. So the issue of the funding disaster we have had here relates not just to—I mean, there are incredibly exciting and interesting challenges for scientists, but the funding has had a deleterious impact on the energy level of the students coming in.

Mr. **HAZELTINE.** Most certainly.

Ms. **LOFGREN.** I know that the bells are over and I don't want to monopolize your time. Thank you, Mr. Chairman. And I—perhaps I can submit the rest of my questions in writing.

[The prepared statement of Ms. Lofgren follows:]

PREPARED STATEMENT OF CONGRESSWOMAN ZOE LOFGREN

Mr. Chairman, today we have the opportunity to better understand the issues affecting the U.S. Department of Energy's Office of Science.

This is the office charged with promoting the policy, research and development so the nation can move forward on its short-range and long-range objectives for energy, technology and the environment.

Currently, scientists funded through the Office of Science are working on such diverse problems as high-speed computer modeling, climate change, nuclear waste cleanup, the Human Genome and ways to develop new energy sources.

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As a Member from energy-strapped California, I have a real interest in the mission of the Office of Fusion

Energy Sciences and its ability to affect a long-range solution to developing fusion as a commercially viable energy source.

We know that to take fusion from the laboratory to the power plant we must first achieve a burning plasma experiment.

Last week, Rep. George Nethercutt and I introduced bipartisan legislation that increases resources for the Fusion Energy Sciences program and directs the Secretary of Energy to develop a roadmap for a burning plasma experiment.

To date, we have been encouraged by our 28 House colleagues and particularly by the 9 House Science Committee colleagues who have cosponsored the Fusion Energy Sciences Act of 2001 (H.R. 1781).

Today the President is unveiling Vice President Cheney's Energy Task Force Recommendations. Two days ago, House Democrats put forth their own plan. We should marshal the best of these ideas into a single national energy strategy.

It is worth noting that under the Administration's proposed budget 100 positions in the Fusion Energy Sciences program would be eliminated. It is my hope that we can work in a bipartisan way to increase funding and move this program toward a burning plasma experiment.

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Chairman **BARTLETT.** Without objection, the panel has volunteered that they will be happy to respond to written questions. They just called the vote. We do have time for another questioner. And Mr. Matheson is here and hopefully—I know he will return because our Ranking Member has to go to the Education Committee, so he will be sitting in her chair. We would like to give him an opportunity now before we run to vote to ask his series of questions and make his comments.

Funding for the Genomes to Life Program

Mr. **MATHESON.** Well, thank you, Mr. Chairman. And I want to associate with the Chairman's remarks in complimenting this panel. The testimony was very interesting, very well-organized, and, indeed, the 30 minutes went by very quickly. I am just going to ask a real quick question, because I recognize we need to be going to vote in a few minutes. But I guess I direct this question at Dr. Hodgson. In terms of the BER budget, it is my understanding that you are facing about an 8 percent decrease as has been proposed for this year.

Dr. **HODGSON.** That is correct.

Mr. **MATHESON.** And I am curious how that is going to affect the Genomes to Life project.

Dr. **HODGSON.** It is our belief and our committee discussed this at some length. But it is so important that the beginning of that project, under the auspices of the microbial cell initiative, which evolved into the Genome to Life, has such important potential that we must look within the program to re-prioritize to try to begin that effort in a larger way. But undoubtedly it will mean slower start. It will mean a less rapid return on investment.

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But, again, when faced with hard decisions, we have to look at them and we have to make those decisions. But we believe that it is so important, we will try to begin that program at a larger level.

Mr. **MATHESON.** Is it safe to say that in terms of the priority of this program, you are going to possibly be making cuts in other areas——

Dr. **HODGSON.** Yes.

Mr. **MATHESON** [continuing]. Relative to this program?

Dr. **HODGSON.** Yes. In fact, we will probably share with you a copy of this, you will see that we have an explicit recommendation from the committee in terms of this program, and that will have to come in a constant or decreasing budget from other places in the portfolio.

Mr. **MATHESON.** Mr. Chairman, I yield back the balance of my time right now.

Building Support for Major Research Facilities

Chairman **BARTLETT.** Okay. We have about 5 minutes remaining before we have to leave to run to vote. I had a number of questions and observations to make, and let me spend these last 5 minutes abbreviating that. And then we will excuse this panel and convene our next panel when we return. We have had more votes than was anticipated this morning.

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Dr. Gilman, in high-energy physics, I voted for the Superconducting Super Collider. And the reason I did that was because I felt that how exciting it would be if we discovered something there that would aid Stephen Hawking in attempt to mathematically synthesize the great mysteries of the universe. What do we need to do to convince our people who have representative—our people voted the way their constituents would have liked them to have voted on that, I am sure voted wrong, when we killed that project—but what do we have to do so that projects like that in the future, that hold such exciting potential won't be killed?

Mr. **GILMAN.** Mr. Chairman, I agree that it was a matter of convincing the Members of the Congress and the public at large of the importance of that part of science. And we need to understand, and I refer back to a previous question, that there—sitting before you are people who deal with questions that are at the deepest level—and the Superconducting Super Collider was such a project—that will have impact 50 years from now, all the way thorough questions that will give results that have practical implications 5 years from now, 3 years from now, 1 year from now even.

And that it is important for this nation to be among the leaders in a broad range of sciences, to take advantage of their interrelation and also of breakthroughs in any one of them. And that, in particular, in the high-energy physics, we are looking at these very deep questions of the ultimate fundamental constituents of matter and how the universe was put together.

The Super Collider, and now it will be the Large Hadron Collider will—and before that, the Tevatron at Fermilab, will address this question of what gives particles mass. And that still is before us. It still is one of the central scientific questions of high-energy physics. And we need to do a better job of educating people that this is, (a) exciting, and, (b) essential for the overall scientific and technological health of the country in the long term.

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Understanding Cell Growth and Regulation

Chairman **BARTLETT.** Thank you. Thank you for helping us make that point. Dr. Hodgson, you mentioned the Genomes to Life. And I have had a question ever since I first was a biology student more than 50 years ago. When you—if you remove half the liver, what remains re-grows. And when I first learned that, I asked myself the question, how do those dividing liver cells know that enough is enough and it is now time to quit? Are we close to finding out how they communicate so that they are able to make that judgment?

Dr. **HODGSON.** It is a magnificent question. And as you, sir, know, it is an extremely complex interrelated system where cells signal each other and there is a very complex cascade of interrelated mechanisms to tell cells what other cells know about and when to start and stop. Part of the goal of the Genomes to Life project is to build—begin to build the tools which would allow one to ask those questions.

Most people—and I speak for myself here—say that this question is so complex that it is unlikely that we will be able to experimentally completely understand it. You know, what we are going to have to do is we are going to have to combine experimental methodologies with computational modeling and approaches. And part of the excitement about the Genome to Life project and, as you know from looking at the information that has been prepared by my committee and by DOE, is that it is in close partnership with the computing area and Ed Oliver and his colleagues because it spans those two offices so intimately.

And so the combining of the computational power with experimental methodology and the tools of modern molecular biology, I would say that a better example is within 5 years we might understand how simple cells actually grow and function and communicate within those cells. It will take more than 5 years before we can answer your question. But for sure, the direction that we are moving is leading directly to being able to answer that question.

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Chairman **BARTLETT.** Thank you very much. Have you read Chromosome Six?

Dr. **HODGSON.** Yes. There are several wonderful books that—yes.

Dr. **WRIGHT.** May I just make a comment? There has been a mathematical model of the way the color in the black tetra—it is a little fish——

Chairman **BARTLETT.** Yes.

Dr. **WRIGHT** [continuing]. Spreads out and they have done experiments where they have taken cells from the black tetra and shown that the dye moves out to color it. And the mathematics and the computation give a first glimmer of understanding of why that happens and why it might happen in the larger system. It is a long way from the human liver, but it is a beginning.

Scientific Specialization and Multidisciplinary Research

Chairman **BARTLETT.** Yeah. The—Psalmist noted—and he didn't even know that there was a genome that we are fearfully and wonderfully made, and how often I have thought of that as I have studied these things. Just one last question and observation. We now are focusing more and more narrowly so that you are an expert not in nuclear physics, but in one narrow part of nuclear physics.

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And the question I have is, don't we run the risks of missing some opportunities to tie these things together because we no longer are educating generalists who are looking broadly at scientific advances and are then synthesizing solutions or questions from looking at several of these areas? And how do we expand the knowledge in these narrow areas while still, at the same time, educate people and have a focus on the big picture? We have 16 seconds remaining before I have to leave and so maybe you will need to respond for the record. Yes. Just one quick observation and then I have to run.

Mr. **GILMAN.** Yes. Let me just make a quick observation that I think that although we are very specialized, there are still among us people who are generalists, people who move from one field to another, who go from physics to biology, for example, is a prominent example. And more than that, we send our students who don't get jobs in high-energy physics into all the other fields of science and into industry. And that is maybe the most important transfer of intellectual power between fields.

Dr. **HODGSON.** And I might just end by saying I always tell my students they must take chemistry. As an example of a fundamental disciplinary science, mathematics, this grounding is extremely important.

Chairman **BARTLETT.** Thank you all very much for your testimony. We will excuse this panel and when we will return we will convene the final panel. Thank you.

Dr. **HODGSON.** Thank you.

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Dr. **WRIGHT.** Thank you very much.

[Recess]

Panel II

Chairman **BARTLETT.** Oh. I am sorry. I pressed it and it didn't go on. Let me reconvene this hearing and welcome our last panel. Dr. Richardson, who is Vice Provost for Research at Cornell University and a recipient of the 1996 Nobel Prize in Physics. We are honored. Thank you, sir, for coming. Dr. Shank, who is Director of DOE's Lawrence Berkeley National Laboratory, thank you for traveling all that distance to be with us. And Professor James Drake of the University of Maryland's Institute for Plasma Research. I especially want to welcome Dr. Drake not from my district, from my state, and I spent 5 very happy years at the University of Maryland getting my masters and my doctorate and teaching full time on the faculty there for 4 of those 5 years. That was about half a century ago now. Thank you for agreeing to be our witnesses today. We will begin with Dr. Richardson.

STATEMENT OF DR. ROBERT C. RICHARDSON, VICE PROVOST FOR RESEARCH, CORNELL UNIVERSITY

Dr. **RICHARDSON.** Mr. Chairman, Mr. Matheson, I am Bob Richardson and, as indicated Vice Provost for Research at Cornell University, and I am also Chairman of the Physics Policy Committee, the American Physical Society. It is a professional organization representing more than 40,000 physicists worldwide.

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I would like to thank you for the opportunity to testify today about the Department of Energy's Office of Science. And I also want to say how much gratitude I feel for the very elegant opening remarks Mr. Bartlett made at the beginning of today's hearings, and I intend to quote them in some of my numerous public science lectures. Because I think that one of the things we have to do is present to the general public why we want to do science so that they will care about it.

But that is not my testimony right now. My testimony concerns the administrative structure of the Department and the effect that the structure has had on the performance of the Office of Science. I am confident that this Subcommittee will use its collective wisdom, as it has so many times in past other issues, to craft solutions that will rebound to the benefit of American science in our nation.

I am here today speaking as a representative of a panel of 10 other distinguished scientists who have had extensive administrative and policy experience with DOE's scientific programs. The report from which my testimony is drawn, "DOE Science for the Future," was stimulated by discussions that took place at meetings of the American Physical Society's Physics Policy Committee last year. However, to be able to release its findings before the Bush Administration took office and the 107th Congress convened, the authors elected to work outside the framework of the American Physical Society in preparing their final report.

The report makes the following observations, which I trust we can agree on. The DOE Office of Science oversees outstanding national laboratories whose capabilities for solving complex interdisciplinary problems are not easily matched elsewhere. It also builds and operates large-scale user facilities of importance to all areas of science. It has been enormously successful in these efforts.

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For about a decade, however, DOE science budgets have been declining and have fared significantly less well than those of other agencies. These difficulties have been exacerbated by the perception of management and security problems throughout the Department. The situation has reached crisis proportions and the future U.S. leadership in many essential areas of science is in jeopardy.

The Director of the DOE Office of Science has responsibilities comparable to those of the director of the NSF and not very different from the directors of NIH and NASA, but he or she does not have the comparable authority or visibility.

Mr. Chairman, in framing its recommendations, the panel adopted the following guidelines, which I hope you and the Subcommittee will accept. First, the DOE missions in national security, environmental clean-up, science and energy are each important in their own ways. Any solution to present problems within DOE should tailor management, facilities, and budgets to optimize the performance of each of these missions.

Next, science and technology in the United States has prospered greatly from diversity of funding sources and modes of support. The diversity of funding sources should be maintained.

And, finally, the primary responsibility of DOE's science and energy programs should be to provide the new knowledge for the—for ensuring the scientific and technological base of our nation's economic prosperity in the 21st century. The mode in which these programs assume this responsibility should take advantage of the DOE's experience with large facilities and multidisciplinary research efforts.

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Mr. Chairman, based upon these guidelines, the report proposes two alternative solutions, without expressing a preference for one over the other. Alternative "A." Enhance the leadership and visibility of DOE science and energy by revising the management structure within the Department. One way to accomplish this goal would be to elevate the Director of the DOE Office of Science to the rank of Under Secretary for Science and Energy, with additional responsibilities as Science Advisor to the Secretary. This scheme would place the person in charge of science at a level above the large number of staff offices that are inevitable in such a complex agency. A primary objective would be to have a widely respected and influential scientist in a position where he or she can be an effective leader and spokesperson for DOE science and energy.

Alternative "B." Combine DOE science and energy programs with NIST, NOAA, and possibly USGS, to form the major part of a new 21st century Department of Commerce. The idea here is to create a—and we called it National Institutes of Science and Advanced Technology, NISAT, within a cabinet-level department in analogy to NIH within Heath and Human Services. An alternative would be to combine these same entities, that is, NISAT, into a independent sub-cabinet agency analogous to NASA in structure and government status. The new agency would be visible—a visible recognition by the U.S. Government that long-term research deserves—long-term drives economic progress.

Mr. Chairman, let me conclude by noting that the panel examined and rejected two other alternatives that have been suggested from time to time—either moving DOE science into NSF or creating a Department of Science that would include all Federal R&D programs. The report explains the rationale for rejecting these alternatives. I would be happy to answer questions about them later though.

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[The prepared statement of Dr. Richardson follows:]

PREPARED STATEMENT OF ROBERT C. RICHARDSON

Mr. Chairman, Ms. Woolsey and Members of the Subcommittee, I am Robert C. Richardson, Vice President for Research at Cornell University and Chairman of the Physics Policy Committee of the American Physical Society, a professional organization that represents more than 40,000 physicists nationwide. I would like to thank you for the opportunity to testify today about the Department of Energy's Office of Science.

My testimony concerns the administrative structure of the Department and the effect that the structure has had on the performance of the Office of Science. I am confident that this subcommittee will use its collective wisdom—as it has so many times in the past on other issues—to craft solutions that will redound to the benefit of American science and our nation.

I am here today, speaking as a representative of panel of ten other distinguished scientists who have had extensive administrative and policy experience with DOE's scientific programs. The report from which my testimony is drawn, *DOE Science for the Future*, was stimulated by discussions that took place at meetings of the American Physical Society's Physics Policy Committee last year. However, to be able release its findings before the Bush Administration took office and the 107th Congress convened, the authors elected to work outside the framework of the American Physical Society in preparing their final report.

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The report makes the following observations, upon which I trust we can all agree:

The DOE Office of Science oversees outstanding national laboratories whose capabilities for solving complex interdisciplinary problems are not easily matched elsewhere. It also builds and operates large-scale user facilities of importance to all areas of science. In large part, it has been enormously successful in these efforts. . .

For about a decade, however, DOE Science budgets have been declining. . .and have fared significantly less well than those of other agencies. These difficulties have been exacerbated. . .by the perception of management and security problems throughout the Department.. . . [The] situation has reached crisis proportions, and. . .future U.S. leadership in many essential areas of science is in jeopardy. . ..

The Director of the DOE Office of Science has responsibilities comparable to those of the director of the NSF and not very different from those of the directors of NIH and NASA; but he or she does not have comparable authority or visibility. . .

Mr. Chairman, in framing its recommendations, the panel adopted the following guidelines, which I hope you and the subcommittee will also accept:

The DOE missions in national security, environmental clean-up, science and energy are each important in their own ways. Any solution to present problems within DOE should tailor management, facilities, and budgets. . .to optimize the performance of each of these missions. . ..

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Science and technology in the United States has prospered greatly from diversity of funding sources and modes of support. . .. The diversity of funding sources should be maintained.

The primary responsibility of the DOE's science and energy programs should be to provide the new knowledge needed for ensuring the scientific and technological base of our nation's economic prosperity in the 21st Century. The mode in which those programs assume this responsibility should take advantage of the DOE's experience with large facilities and multidisciplinary research efforts. . ..

Mr. Chairman, based upon these guidelines, the report proposes two alternative solutions, without expressing a preference for one over the other.

Alternative A. Enhance the leadership and visibility of DOE science and energy by revising the management structure within the Department.

One way to accomplish this goal would be to elevate the Director of the DOE Office of Science to the rank of Under Secretary for Science and Energy, with additional responsibilities as Science Adviser to the Secretary. This scheme would ...place the person in charge of science at a level above the large number of staff offices that are inevitable in such a complex agency. A primary objective would be to have a widely respected and influential scientist in a position where he or she can be an effective leader and spokesperson for DOE science and energy.

Alternative B. Combine DOE science and energy programs with NIST, NOAA, and possibly USGS to form the major part of a new 21st Century Department of Commerce.

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The idea here is to create a "National Institutes of Science and Advanced Technology" (NISAT) within a cabinet-level department in analogy to the NIH within HHS. An alternative would be to combine these same entities; that is, "NISAT," into an independent sub-cabinet agency analogous to NASA in structure and governmental status. . .. The new agency would be a visible recognition by the US government that long-term research drives economic progress. . ..

Mr. Chairman, let me conclude by noting that the panel examined and rejected two other alternatives that have been suggested from time to time: either moving DOE Science into NSF or creating a Department of Science that would include all federal R&D programs. The report explains the rationale for rejecting these alternatives.

I would be happy to answer questions.

BIOGRAPHY FOR ROBERT C. RICHARDSON

Background and Family Matters:

Born, June 26, 1937 (Washington, DC); lived in Arlington, VA until graduation from Washington-Lee High School in 1954; parents from Virginia and North Carolina; one younger sister; Married to Betty McCarthy (Richardson) in 1962; Betty is currently a Senior Lecturer in the Cornell Physics Department; Children—Jennifer, born in 1965, BA Duke University 1989, MA Columbia University (Fine Arts in Writing) 1992; Pamela, born in 1966, BA Cornell University 1991, deceased 1994.

Present position:

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Vice Provost for Research and F.R. Newman Professor of Physics, Cornell University.

Education:

1958 B.S. degree in Physics from Virginia Polytechnic Institute
1960 M.S. degree in Physics from Virginia Polytechnic Institute
1966 Ph.D. degree in Physics from Duke University.

Employment History:

1959–60 Second Lieutenant, U.S. Army (served in U.S. Army Reserves until 1965)
1966–67 Research Associate, Cornell University
1968–71 Assistant Professor, Cornell University
1972–74 Associate Professor, Cornell University
1975–86 Professor, Cornell University
1984 Visiting Scientist, Bell Laboratories, Murray Hill, NJ
1987–present F.R. Newman Professor of Physics, Cornell University
1990–1997 Director of Laboratory of Atomic and Solid State Physics, Cornell University
1998–present Vice Provost for Research, Cornell University

Principal research interest:

Experimental low temperature physics, especially the properties of liquids and solids at sub-millikelvin temperatures.

Professional activities:

National Academy of Sciences, Chair of Physics Section 1989–1992
National Academy of Sciences, Committee on Human Rights 1987–1989
National Academy of Sciences, Nominating Committee 1993–1995, Chair 1995
International Union of Pure and Applied Physics, Commission C–5 (Very Low Temperatures) 1979–1984 (Chair 1981–84); Vice Chair, U.S. Liason Committee 1997–present
National Research Council, Panel on Condensed-Matter Physics 1983–1985
National Research Council, Board of Assessment for National Bureau of Standards 1983–89
Board of Editors, Journal of Low Temperature Physics 1984–present
Board of Editors, Institute of Physics (United Kingdom) 1989–1992
Visiting Committee, Division of Physics, Math, and Astronomy, Cal Tech 1986–89
National Science Foundation, Materials Division, Panel on Large Magnetic Fields (Co-Chair) 1986–88
National Research Council Panel CODATA 1987–89
National Research Council Fellowship Panel 1989–present (Chair of Physics Selection Committee)
National Research Council Associateship Programs Advisory Committee 1992–present
American Physical Society Panel, POPA (Panel on Public Affairs) 1989–1991
American Physical Society panel, CISA (Committee on International Scientific Affairs) 1990–92
American Physical Society, Chair, Division of Condensed Matter Physics 1995
Review Committee, Department of Physics, Penn State University, 1990
Advisory Committee, Department of Physics VPI&SU, 1989–92
Steering Committee, Federal Demonstration Partnership 1990–1996

Member of International Advisory Panel for Low Temperature Conferences in 1981, 1984, 1987, 1990 and 1993
National Research Council Board on Physics and Astronomy, 1994–1997; Vice Chair 1997–present
National Research Council Panel on Gravity Probe B, 1995
National Research Council, Panel on Condensed Matter and Materials Physics, 1996–present
Member, Brookhaven Science Associates Board of Directors 1998–present
Member, Board of Trustees, Duke University 1997–present
Member, National Science Board 1998–present
Member, NASA Life and Microgravity Science and Applications Advisory Panel, 1999–present
Member, Board of Directors, American Association for the Advancement of Science, 2000–present
Chair, American Physical Society PPC (Physics Planning Committee) 1999–present.

Honors:

Guggenheim Fellowship, 1975–76; 1982–83
Eighth Simon Memorial Prize [British Physical Society], 1976 (with D.D. Osheroff and D.M. Lee)
Buckley Prize [American Physical Society], 1981 (with D.D. Osheroff and D.M. Lee)

Fellow, American Association for the Advancement of Science, 1981
Fellow, American Physical Society, 1983
Member, National Academy of Sciences, 1986
Secretary of Class I (Mathematical and Physical Sciences) 2000–present
Foreign Member, Finnish Academy of Science and Letters (1993)
Fellow, American Academy of Arts and Sciences (1995)
Honorary Doctor of Science Degree, Ohio State University, June 2000

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Member, American Philosophical Society, 2001
Nobel Prize in Physics (1996) (shared with D.M. Lee and D.D. Osheroff)

Books written:

"Experimental Techniques in Condensed Matter Physics at Low Temperatures" (with Eric N. Smith and 21 Cornell graduate students) Addison-Wesley (1988).

Instructional Videos Produced:

"The World at Absolute Zero", a video tape of a public lecture at Cornell University
"Introductory Physics", a series of 20 video-taped lectures to accompany the introductory physics course taught at Cornell for students without a background in calculus.

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Chairman **BARTLETT.** Thank you very much. Dr. Shank.

STATEMENT OF DR. CHARLES V. SHANK, DIRECTOR, LAWRENCE BERKELEY NATIONAL LABORATORY

Dr. **SHANK.** Mr. Chairman, and, members of the Subcommittee, it is my pleasure to provide testimony on the Department of Energy's Office of Science. My perspective is that as Director of the Lawrence Berkeley National Laboratory, an Office of Science laboratory located in the hills above the University of California Berkeley campus. I want to talk to you this morning about the value of the Office of Science programs and their contributions to the Nation's scientific enterprise. I will then highlight the need for increased investment, both in research and in the infrastructure to perform that research. In addition, I will suggest options for increasing the effectiveness of the Office of Science.

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DOE's fundamental science underpins breakthrough discoveries. The Department or its predecessors have sponsored the research of more than 70 Nobel Prize winning scientists. Research at the Office of Science laboratories provides the foundation of our current knowledge of matter, energy, the properties of the elements, the basis for studying advances in nuclear medicine, and significant discoveries on the structures and processes of life.

Science Magazine's Breakthrough of the Year for the year 2000 was sequenced genomes, an outcome of the Human Genome Project, which was started by the DOE's Office of Science. The Office of Science has been instrumental in revising our views on the composition of matter and energy in the universe. The recent discovery of dark energy now points to an unforeseen type of energy that is accelerating the expansion of the universe.

Each year, 22,000 university, government, and industry-sponsored scientists conduct experiments at specialized user facilities operated by the Office of Science. DOE is unique among other scientific funding agencies in that it builds and operates major research facilities essential to experimental work in many fields.

Science on the cutting edge requires cutting-edge facilities. At Berkeley Lab, more than 70 percent of the current government-owned space was constructed before 1970. The average building is 35 years old. Berkeley Lab is not unique. In fact, 70 percent of the space in the entire DOE complex is more than 30 years old with many facilities exceeding their useful life expectancy. The aged facilities are a cloud on the future of world-class science at these facilities. A new level of sustained investment is required to ameliorate the situation.

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The Office of Science is bursting will well-formulated research opportunities that could merit significant budget increase. In the coming years, we see advances in nanoscience, the development of more powerful, computation models of combustion and climate change, the achievement of understanding molecular-level knowledge of genome functions, and controlling microbes for energy and environmental applications. And in addition, we are discovering the underlying properties of matter from high-temperature plasmas to solid state materials to quarks.

All of these issues compel us to address the imbalance in support for the physical sciences. In the last decade, we have seen biomedical research increase about 200 percent constant dollars, while the Office of Science has increased only 2 percent.

Harold Varmus has said the balance of the sciences is essential to progress in all spheres, including medicine. I propose a 15 percent per year real growth in the Office of Science budget over the next 5 years.

My colleague to my right discussed the DOE science for the future report, which eloquently describes the need for increasing the institutional visibility of the Office of Science if it is to continue to perform scientific research at the highest levels. I would characterize this need as giving the Office of Science a distinctive identity, one that would enable it to continue exercising its mission without endangerment from other peripheral activities.

Making the Office of Science a "NNSA-like entity," would give the Office control over those administrative areas that critically effect how it carries out its mission. The Office of Science has a need to have control over its own environment, health, safety, procurement, security, and other administrative activities so that these efforts are sized according to what the programs need to accomplish their mission. In essence, responsibility and accountability must be aligned.

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In summary, the Office of Science provides much for the Nation. It needs investment to remain world class. It also needs a distinctive identity to achieve its full potential. Thank you.

[The prepared statement of Dr. Shank follows:]

PREPARED STATEMENT OF CHARLES V. SHANK

Mr. Chairman and Members of the Subcommittee:

It is my pleasure to be here today to provide testimony on the Department of Energy's Office of Science. My perspective is as Director of the Lawrence Berkeley National Laboratory since 1989. We have a rich history of scientific discovery, and I am pleased to address the strengths derived from the Office of Science, the value of federal science investments, and the importance of the physical sciences to our national welfare.

I will begin by talking about the accomplishments of the Office of Science and its contributions to the Nation's science. I will then highlight the need for increased investment, both in research and in the infrastructure needed to perform that research. Finally, I will discuss ways of increasing the effectiveness of the Office of Science.

Office of Science Record of Accomplishment

The Office of Science deserves to be recognized for its leading role in several of the most advanced scientific breakthroughs of our time. The Office of Science initiated the Human Genome Project, and "Sequenced Genomes," was named as Science magazine's "Breakthrough of the Year" for 2000. At the heart of this success were multidisciplinary science, advanced instrumentation, and automation and computing capabilities that are the hallmark of Office of Science programs.

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A number of the "Runners-up Breakthroughs" for 2000 were supported by the DOE Office of Science National Laboratories, including x-ray crystallographic techniques that revealed the structure of the ribosome. The ribosome is the cell unit that constructs the proteins that form the genetic code of life. This discovery, which was announced last month, revealed the structure of the ribosome down to every single atom. This is amazing when you consider that it is made of hundreds of thousands of atoms. Also, the Office of Science has been instrumental in revising scientists' views on the composition of matter and energy in the Universe. These discoveries now point to an unforeseen type of dark energy that is accelerating the expansion of the Universe.

These discoveries took place because the Office of Science brings powerful physical, engineering and computing science capabilities to bear on many other fields of science, including the health sciences. Harold Varmus, president of Memorial Sloan-Kettering Cancer Center and former Director of the National

Institutes of Health, said in an October 2000 Washington Post article that the physical sciences sponsored by the Office of Science are of critical value. "Medical advances may seem like wizardry. But pull back the curtain, and sitting at the lever is a high-energy physicist, a combinatorial chemist, or an engineer." He also indicated the importance of increasing support to the fundamental science agencies. "This admirable effort should be vigorously supported. . .to include the Department of Energy's Office of Science, which funds half of all research in the physical sciences and maintains the national laboratories that are essential to biomedicine." The message is clear: the Office of Science is a distinctive and valued science agency that is an essential part of the fabric of American research.

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The challenge before the Congress is that the physical sciences threads in the fabric of American research are frayed. While our Nation's physical sciences research underpins other scientific fields, it has been neglected. For example, while biomedical research has increased about 200 percent in constant dollars since 1990, the Office of Science has only increased 2 percent. I join many other scientists who are greatly concerned about this imbalance. To quote Harold Varmus once again, "The balance of the sciences is essential to the progress in all spheres, including medicine." We should not forget that the vast majority of our economy, including energy, manufacturing, transportation, and the information technologies, are based on the advances of the physical sciences.

Investment in Research Infrastructure

Investments in Office of Science infrastructure and the facilities at the national laboratories must be sustained in order to help maintain our world leadership in science. Each year, more than 22,000 university, government, and industry-sponsored scientists conduct experiments at the facilities operated by the Office of Science. These scientists, including thousands of graduate students, cannot carry on their research without these unique and powerful tools, and the buildings, utilities and support systems essential for laboratories and instruments to function.

At Berkeley Lab, more than 70% of the current government-owned space was constructed before 1970, when the Laboratory was a single-purpose Atomic Energy Commission facility. The average building age is 35 years, and of the 1.7 million square feet of building space, approximately 331,000 square feet of space is in need of replacement.

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The Berkeley Lab conditions are not unique. All the civilian multiprogram laboratories comprise more than 16 million square feet of building space. Unfortunately, roughly one-third of the laboratories' facilities are trailers or other portable or temporary structures. Like Berkeley Lab, the majority of these facilities are old; many were built during or soon after World War II. For the entire DOE complex, approximately 70% of the space is more than 30 years old, and many building and facility infrastructure systems have exceeded their estimated useful life expectancy. The aged conditions of these facilities have adverse implications for the safety, security, cost, and continuity of DOE's science laboratories.

A new level of investment in Office of Science infrastructure is needed to: (1) accommodate 21st century research needs with the type and quality of space and equipment needed to meet physical sciences research needs; (2) provide a minimum satisfactory working environment for researchers that helps attract and retain high quality staff; (3) provide a safe, healthy, and secure working environment for laboratory employees and visitors, and to assure the protection of the environment of neighboring communities, and (4) enable efficient operations and maintenance, including conditions that promote high productivity and energy efficiency.

The Laboratories and support systems suited to accomplish 21st century research are highly instrumented, clean and controlled, and capable of supporting multidisciplinary research activities, including the interactive efforts of bench science, controlled systems for experiments, and computational modeling as examples. The majority of the current DOE building stock and support facilities is unsuited for current research, and a new level of infrastructure investment is essential to maintaining the outstanding science performed at the multiprogram Office of Science Laboratories.

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Increase the Office of Science Budget

The Office of Science provides key scientific and technological capabilities to address the Nation's large-scale challenges. These include providing the knowledge for clean, affordable, and secure energy, protecting and restoring the environment, ensuring a healthy, secure, and knowledgeable citizenry, and understanding and controlling energy and matter. The Office of Science is targeting priority areas in the coming years including advancing nanoscience; developing more powerful computational models of combustion, climate change, and the subsurface environment; achieving molecular-level understanding of genome functions; controlling microbes for energy and environmental applications; and discovering the underlying properties of matter from high-temperature plasmas to solid state materials to quarks.

Addressing the imbalance in support for the physical sciences, renewing the investments in infrastructure, and serving the larger scientific community will require a dramatic increase in the Office of Science budget over the next 5 years. A funding increase of 15 percent real growth each year would be a wise investment of Federal resources.

D. Allan Bromley, Science and Technology Advisor to former President Bush, stated in a March 9, 2001 New York Times editorial entitled "Science and Surpluses": "The 21st century economy will continue to depend on scientific innovation. Economists estimate that innovation and the application of new technology have generated at least half of the phenomenal growth in America's gross domestic product since World War II.. . . Technological innovation depends upon the steady flow of discoveries and trained workers generated by federal science investments in universities and national laboratories. These discoveries feed directly into the industries that drive the economy. It's a straightforward relationship: industry is attentive to immediate market pressures, and the federal government makes the investments that ensure long-term competitiveness."

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I am especially proud of the remarkable advances on several fronts that highlight the strong relationship between research and our economic future. The Office of Science has been making investments in x-ray optics for several decades, within the Office of Basic Energy Sciences program in developing advanced materials. As part of that effort, Berkeley Lab has developed the most advanced x-ray mirror and optical measuring expertise and instrumentation systems in the world. Our measurement systems, and our Advanced Light Source, have been crucial to the research partnership between the Virtual National Lab (Sandia, Lawrence Livermore, and Lawrence Berkeley) and industrial research partners (Intel, AMD, Motorola, Micron, Infineon, and IBM). This partnership has successfully developed a prototype tool to pattern microchips with extreme ultraviolet light, whose narrow wavelengths should enable ever-smaller feature sizes. Integrated circuit feature sizes should shrink to 1/1000th the width of a human hair, or less, with 30 to 100 nanometer features. As a result, smaller and more powerful electronic devices are envisioned with speeds more than 10 times faster than today's microprocessors and memory capacity up to 1,000 times those currently possible. This next-generation lithography approach now has the full support of the microchip industry for commercial microchip production starting in 2005–6 and continuing through 2020. Thus our x-ray research capabilities will take silicon microchips into the third decade of the new millennium, and the future of a key domestic industry is strengthened thanks to DOE's physical sciences research.

Increase the Effectiveness of the Office of Science

Before I conclude my remarks, I want to discuss one very important point about the Office of Science. One of today's witnesses participated in developing a paper entitled "DOE Science for the Future." That paper eloquently noted the importance of increasing the institutional visibility of the Office of Science if it is to continue to perform scientific research at the highest levels. I would characterize this need as giving the Office a distinctive identity, one that would enable it to continue its long-range research support without endangerment from other peripheral activities.

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Making the Office of Science a distinctive and effective entity within the Department of Energy would also require that it be given control over those administrative areas that often affect how it carries out its mission. The Congress last year recognized this need for DOE's Defense Programs in creating the National Nuclear Security Administration. The Office of Science has a similar need to have control over its own environment, health and safety, procurement, security and other administrative activities so that their efforts are sized according to what the programs need to accomplish their missions. In essence, responsibility and accountability must be aligned.

To summarize, DOE research in fundamental science is instrumental in the development of leading technologies that open new frontiers and bring great benefits to society. The Office of Science provides the most powerful and sensitive instrumentation and detector systems in the world, ranging from the highest resolution optical diagnostic systems for next-generation x-ray photolithography to the most powerful civilian supercomputing capability in the world. They developed the mathematical tools for studies of turbulence and combustion and area wellspring for energy supply, efficiency, and storage devices. In addition, they have developed some of the most advanced systems for determining the structure of biological molecules, for automating genome sequencing, and for noninvasive diagnosis of disease. We cannot, however, keep living off the research investment of the last fifty years made by our predecessors. We need to continue this investment for our generations and those beyond us. Maintaining these capabilities requires significantly increasing our investment in the programs of DOE's Office of Science, and providing the Office of Science with a distinct and effective identity, in order to help sustain the welfare of the nation in the 21st century and beyond.

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BIOGRAPHY FOR CHARLES V. SHANK

Charles Vernon Shank has been Director of Ernest Orlando Lawrence Berkeley National Laboratory in Berkeley, California, since September of 1989. A nationally recognized scientist and research leader, he oversees the oldest and most varied of the Department of Energy's multi-program research laboratories, with a budget of more than $400 million and a workforce of over 4,100.

In addition to his duties as Laboratory Director, Dr. Shank has a unique triple appointment as professor at the University of California, Berkeley, in the departments of physics, chemistry, and electrical engineering and computer sciences. He graduated from UC Berkeley in 1965 and went on to receive his M.S. and Ph.D. degrees there in 1969.

Following graduation, Dr. Shank joined the staff at AT&T Bell Laboratories. During his 20-year career at Bell Laboratories, he held numerous leadership positions and was Director of the Electronics Research Laboratory just before returning to Berkeley. At Bell Laboratories, he made pioneering contributions to the study of ultrafast events that occur in a millionth of a billionth of a second using short laser pulses. He contributed to fiber optic communications with the co-invention of the distributed feedback laser, a component in high data rate transmission systems.

Dr. Shank has served on numerous state and national committees and councils. They include the California Council on Science and Technology; the National Critical Technologies Panel of the U.S. Office of Science and Technology Policy; the Council on Competitiveness; the Center for Strategic and International Studies; the Solid State Sciences Committee of the National Research Council; the Environmental Technology Export Council; and the California Business-Higher Education Forum. He was the chair of the National Research Council's Committee on Optical Science and Engineering which published its report in 1998.

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Dr. Shank's scientific and service contributions have been recognized through honors that include the R. W. Wood Prize of the Optical Society of America; the David Sarnoff and Morris E. Leeds awards of the Institute of Electrical and Electronics Engineers; the Edgerton Award of the International Society for Optical Engineering; the John Scott Award; the Edward P. Longstreth Medal of the Franklin Society; and both the George E. Pake Prize and Arthur L. Schawlow Prize of the American Physical Society.

He has been elected to the National Academy of Sciences, the National Academy of Engineering, and the American Academy of Arts and Sciences. He is a Fellow of the American Association for the Advancement of Science, the American Physical Society, the Institute of Electrical and Electronics Engineers, and the Optical Society of America.

Dr. Shank maintains a vigorous research program and supervises a team of graduate students at Berkeley. He is author or co-author of more than 190 scientific publications.

Chairman **BARTLETT.** Thank you very much. Professor Drake.

STATEMENT OF PROFESSOR JAMES F. DRAKE, INSTITUTE FOR PLASMA RESEARCH, UNIVERSITY OF MARYLAND

Mr. **DRAKE.** Mr. Chairman, Mr. Matheson, I want to thank you for the invitation to come and speak to you. And I will be speaking specifically with regard to the Fusion Energy Sciences Program. The goals of the Fusion Energy Science Program are to establish the scientific knowledge base for the deployment—eventual deployment of fusion energy. This, of course, is one of the few environmentally benign sources of energy for the long term.

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Recent events, of course, reinforce the idea that simply—we simply must move in this direction. And I think the policy issue, which is really extremely important, is how does one sustain a very long-term program whose goals are many years in the future? So I first want to discuss this point a bit.

The Office of Fusion Energy Sciences supports first and fundamentally a field of science, this field of plasma science. Plasma being the fourth state of matter. Most of the universe is in the plasma state. And what this means, of course, is that much of the research that is going on in the Fusion Energy Sciences Program is science which is applicable to this very broad area and this fundamental area of science, plasma science.

And I want to illustrate this a bit, and my illustration is from this NRC report that just came out recently. And the reason for this cover here is if you look at the top, there is a picture of the trace data from the surface of the sun, magnetic loops—very beautiful picture as you have problem seen them many times. The second picture, however, is a picture from the TFTR Tokamak experiment, and that shows the high temperature plasma in the core. And it shows that plasma basically being expelled in a series of pictures.

And the bottom picture is a picture from a basic experiment which is going on at the Princeton Plasma Physics Laboratory. The crux of this is that all the processes that govern all three of these phenomenon are basically the same fundamental thing. It is the release of magnetic energy and how that controls the dynamics of a system. The crux is that science that is being studied within the Fusion Program is a broad science which has many applications to other allied fields, whether it is astrophysics or space science. So that is one of the near-term products of this program, and that is fundamental science.

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A second has to do with technological applications. And s I have—in particular, the program is a rich source of highly trained students who can go out then and work in industry, and this is, of course, extremely valuable. And I brought with me an example of one of the technological spin-offs that occurs not because you planned it. Because, as the Chairman very eloquently pointed out, because you're funding great science, and things happen, and you make discoveries. This is called a plasmatron. This device you hook up to your automobile engine. It takes gasoline and converts it into a hydrogen-rich fuel which is injected into your engine. It boosts fuel economy by 20 percent and reduces emissions by 90 percent. The implementation of a device like this is going to have enormous benefits and a near-term benefit of a program, something unexpected. And that is what science is all about.

I now want to talk a little bit about the role of science and the energy goal of the program. In the last several years, there had been a significant broadening of the range of experiments going on in this program. That range of experiments—what people may not realize is that the range of experiments are a consequence of scientific discovery and, again, unexpected scientific discovery.

And I am going to give you a simple example of this. It has been known for years that if you have a very hot plasma that it leaks out of the magnetic bottle. And it leaks out because there is very small scale flows and turbulence in that plasma. And the scientific discovery is the following. Imagine 100 million degree plasma. It is in a container. It is sitting there. You have got these small-scale flows. You can't stick probes into it. Yet, you would want to eliminate that turbulence so that plasma doesn't leak out anymore. How do you do that? This program has discovered how to do that. They have discovered how to eliminate that turbulence and seal the leaks in the bottle. It is a tremendous discovery. That discovery has led to the design of new experiments which are now being explored.

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The final thing I want to address—so scientific discovery is fundamentally linked to the progress toward fusion energy, and that is my point. There is no contradiction between science—good science, great science, and the progress toward the fusion goal.

In the last several years, there has been significant constraints on budgets. And I want to address specifically, there is a proposed bill by—sponsored by Representatives Lofgren and Nethercutt. The goal of that bill is to strengthen science bases as a program, and the bill addresses a number of the recommendations which were made in the NRC report. And I think I am out of time, so I don't want to go into details on that, but I think it is important for the Committee to look at that bill very seriously and see if they can use the funding increases discussed to try to address the issues raised in the NRC document. Thank you very much.

[The prepared statement of Mr. Drake follows:]

PREPARED STATEMENT OF PROFESSOR JAMES F. DRAKE

The Fusion Energy Sciences Program

Thank you for the opportunity to speak to the Fusion Energy Sciences Program. I will argue for the importance of this program as the primary funding source for a fundamental area of science with broad applications in allied scientific disciplines and with important and immediate technological applications. In spite of the constrained budgets of recent years the program has made steady progress toward the long range goal of achieving a practical fusion energy source. Much of this progress is a consequence of fundamental and unexpected scientific discovery, which is the hallmark of a true scientific endeavor. I will argue in favor of the proposed Fusion Energy Sciences Act of 2001, a bill sponsored by Reps. Lofgren and Nethercutt and a bipartisan group of members of the House. This bill would strengthen the science carried out in the program and initiate planning for a science-focused burning plasma experiment.

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Plasma Science as a Fundamental Discipline

The intrinsic importance of plasma science derives from its being the fourth state of matter and the fact that most of the known universe is in the plasma state. The field is rich in the variety of phenomena and their nonlinear and therefore complex behavior. The effort to achieve controlled fusion and the development of the field have proceeded together. The naive belief by scientists in the early years of the program about the ease of producing energy from fusion reflected the lack of appreciation of the complexity of the plasma state.

Fundamental ideas developed as a consequence of the fusion effort now permeate the vocabulary of allied fields. Plasma physicists invented "solitons" and proposed their use in communications and played a central role in the development of modern chaos theory. Processes which occur and are studied in fusion experiments are also important in, for example, space and astrophysics. An example is "magnetic reconnection", which is the mechanism for the release of magnetic energy in solar flares, storms in the earth's magnetosphere (space weather) and "disruptions" in laboratory fusion experiments. Thus, discovery in the Fusion Energy Sciences Program has and continues to impact other fields.

Technology Applications of Plasma Science

The technological applications of plasmas are many and are increasing with time. Billions of dollars are spent each year for the purchase of plasma processing equipment for the production of computer chips. It is the development of these processing techniques which has facilitated the reduction in the size of integrated circuits and the associated rapid increases in computer speed. Hardening of cutting tools for industrial applications, deposition of thin films and production of high power microwave sources for civilian and defense purposes are all technological applications of plasma based techniques. A promising near term energy application for plasma is the "plasmatron", a simple device developed by scientists at MIT which increases the fuel efficiency of gasoline automobile engines by 20% and reduces NO**X** emission by 90%. The plasmatron enhances the hydrogen content of the gasoline, allowing the engine to run much leaner than in a conventionally fueled engine.

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Scientific Discovery and the Progress Toward the Fusion Goal

The progress toward the fusion goal as measured by the growth in fusion power produced in experiments versus time is impressive. The power production increased from 0.1 watt in 1975 to 10 million watts in 1995. The highest rate of power production came from experiments on the TFTR and JET tokamaks which approached the long-sought, scientific-break-even condition, when the energy produced from fusion reactions equals the outside energy input required to maintain the plasma temperature.

What is perhaps less clear from a simple plot of the fusion power production is the role of scientific discovery in the program. In 1996 the program was changed from goal-driven energy development program to a program which focuses on developing the scientific basis for fusion energy. A reasonable question therefore is whether there is any conflict between the twin goals of the program: the long-range pursuit of a fusion energy source and the exploration of fusion related science issues. I would argue that there is no conflict here and that progress toward the fusion energy goal is in fact intrinsically linked to scientific discovery in the program.

A couple of examples serve to illustrate this point. The first concerns limits to the plasma pressure in a plasma held by a magnetic container. The early thinking was that above a critical pressure, the plasma containment would be lost as the plasma formed filaments and broke apart. A proposed theoretical idea was that under some conditions the plasma could actually become more "stable" and less subject to the formation of filaments as the pressure increased. This idea is called "second stability" and led to the design of a new class of experiments known as spherical tori, examples being the MAST and NSTX experiments in the U.K. and U.S., respectively. The success of the idea was demonstrated when MAST achieved the highest value of pressure ever obtained in a magnetic confinement experiment. Thus, a new class of magnetic containers was developed based on an unexpected scientific discovery.

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A second example concerns the suppression of turbulence. It has been known for many years that the leakage of plasma energy out of the magnetic containers in fusion experiments was caused by small scale plasma flows which cause the high temperature plasma to wander out of the container. In the early 1980's it was discovered that these flows were spontaneously suppressed in the edge of tokamaks and that the energy containment suddenly improved. This discovery marked a paradigm shift in the program since the observations demonstrated that turbulence was not intrinsic to magnetic containers. The exploration of the mechanism underlying the suppression of turbulence culminated in a set of experiments in the mid to late 1990's which demonstrated that turbulence could be suppressed throughout the plasma and that energy containment in magnetic bottles could therefore be manipulated. The development of techniques to remotely control small scale flows in a 100 million degree plasma ranks as one of the major scientific achievements of the fusion program, and reflects the rapidly increasing sophistication of the science being explored in the program. Experiments on the suppression of turbulence are being carried out in all of the major experiments and in several exploratory experiments.

The range of magnetic confinement experiments in operation and under construction in the program has increased dramatically since the program was restructured in 1996. The designs of these experiments are driven by scientific discoveries resulting from the tight coupling of theory, computation and experiment. The close interaction between these program elements reflects the new face of the fusion program.

Opportunities in the Fusion Energy Sciences Program

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The funding for the Fusion Energy Sciences Program has remained severely constrained over the past several years. As a result, there are significant areas where funding constraints are severely limiting scientific progress. The recently released NRC Assessment of the Department of Energy's Office of Fusion energy Sciences Program identified several of these areas. The Lofgren/Nethercutt Bill addresses directly several recommendations made in the NRC document. I will address three areas which are in particular need of increased support: the exploration of the burning plasma regime, theory and computation and benchmarking with observations and centers of excellence.

The Science of Burning Plasmas

The deuterium/tritium experiments on JET and TFTR and the associated production of significant amounts of fusion power in near break-even conditions were an important milestone in the fusion program. To advance fusion science further towards the ultimate goal of a practical fusion energy source, we must produce plasma conditions where the rate of release of fusion energy greatly exceeds the rate of energy input needed to sustain the plasma temperature so that fusion is the dominant energy source. The change from a plasma regime of energy break-even to a plasma regime of 'self-heating' is not a simple extension of our present understanding. Qualitatively new physical processes will occur in a self-heated or 'burning' plasma due to the large number of very energetic alpha particles that are produced. These include:

Turbulence driven by alpha particles and associated alpha particle loss and its impact on self-heating.

Stability and propagation of the fusion burn and fusion ignition transient phenomena.

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The impact of energetic alpha particles on pressure limits, transport barriers and associated turbulence suppression.

Since our theoretical models are not sufficiently complete to confidently predict these new phenomena and existing experiments are not capable of addressing these issues, a new experiment is required. Such a science-motivated burning experiment should not be considered a prototype for a fusion source. The selection of the optimum geometry for a fusion source must await the completion of the new generation of innovative plasma confinement experiments being presently being explored. Nevertheless, many of the important science issues in the burning plasma regime are of a generic nature—that is, they will be important in all magnetic confinement systems. Such a burning plasma experiment is therefore warranted. Recent high level reviews of the program by SEAB and the NRC have specifically recommended that planning for such an experiment commence.

Theory/Computation and Benchmarking with Observations

The role of theory and computation in the fusion program has fundamentally changed during the past decade. The utilization of high speed computers to complete direct numerical simulation of plasma dynamics in the realistic three-dimensional geometries of fusion plasmas is providing new insights and predictions for how and why plasmas evolve. These developments are particularly striking in the exploration of plasma turbulence and how the associated flows evolve and control energy leakage.

The increased capability of theory and computation to impact the design and interpretation of experiments has led to a significant increase in the interaction between theory and experiment. This positive development has enhanced the scientific productivity of the program as a whole. At the same time, however, the increased demand on the theory/computation program has stretched the resources in this area—there are not enough theorists to model the variety of new experiments in the program. In a less constrained budget environment the theory/computation program would have grown substantially to reflect the altered role of theory/computation. Budget constraints have prevented this natural growth.

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The development of advanced diagnostics to remotely diagnose plasma behavior has been a major success of the program. The increased theory and modeling capability has provided a wealth of computational data which could be compared with observations. The diagnostic development and implementation on even the major experiments has not been adequate for detailed theory/observational comparisons.

The Creation of Centers of Excellence in Plasma Science

Many of the major scientific topics in the fusion program are of sufficient complexity to require the close interaction of a team of scientists for their solution. The modeling of turbulence and associated leakage of plasma energy from magnetic containers is an example of such a complex problem. The solution of this problem requires the development of physical models which describe the extreme anisotropy of the turbulence along and across the magnetic field and the computational algorithms which can run on the most advance parallel computer platforms. Issues such as intermittency, avalanches, and chaotic behavior require a knowledge of modern dynamics. Visualization of the data from large data sets in three space dimensions is also a challenge. Comparison with observations to confront computational modeling is essential to validate the models. No one individual or small group of individuals has the knowledge to address all of these issues.

The fusion program has extensive experience in assembling critical mass groups to run large, multi-faceted experiments. The program has very little experience in promoting collaborations to attack specific scientific topics. The vision for such "Centers of Excellence" was outlined in some detail in the NRC report. The intent of these centers is to be multidisciplinary in nature in that they would bring together mathematicians, computer scientists as well as plasma scientists to attack a common problem. The participation of top scientists who are not normally funded as part of the fusion program will bring added expertise to the program and capitalize on the substantial investment made by other agencies in allied areas of science. At the same time the Centers would serve to extend the interest in important fusion science problems to a broader community.

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BIOGRAPHY FOR JAMES F. DRAKE, JR.

Born: Pasadena, CA, June 26, 1947; Married, 2 children

I. Education

Ph.D. UCLA (Physics), 1975
M.S. UCLA (Physics), 1972
B.S. UCLA, 1969

II. Work Experience

1994–1995 Humboldt Foundation Research Awardee, Max Planck Institut fur Plasmaphysik, Garching, Germany
1990–Present Professor, Department of Physics and Institute for Physical Science, University of Maryland, College Park, MD
1987–1990 Associate Professor, University of Maryland, College Park, MD
1985–1987 Senior Research Scientist, University of Maryland, College Park, MD
1979–1985 Senior Research Associate, University of Maryland, College Park, MD
1978–1979 Research Associate, University of Maryland, College Park, MD
1977–1978 Engineering, Member, Center for Plasma Physics and Fusion, UCLA
1975–1976 Adjunct Assistant Professor, UCLA
1975–1978 Assistant Research Physicist, UCLA
1972–1975 Research Assistant, UCLA

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1970–1972 Teaching Assistant, UCLA
1969–1973 Chancellor's Teaching Fellow, UCLA

III. Memberships

Phi Beta Kappa
Sigma Xi
American Physical Society

IV. Honors

E. Lee Kinsey Award, UCLA, 1969 (most outstanding graduating senior)
Chancellor's Teaching Fellowship, UCLA, 1969–1973
Fellow of the American Physical Society
Humboldt Foundation Research Award, 1994

V. Professional Services

Vice-Chairman of the Gordon Research Conference on Plasma Physics, (1980–1981).

Member, Sherwood Theory Executive Committee (1981–1983, 1986–1988).

Co-Chairman Local Arrangements Committee for Sherwood Theory Meeting (1983).

Chairman of the Gordon Research Conference on Plasma Physics (1981–1983).

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Member, Executive Committee of the Division of Plasma Physics of the American Physical Society (1985–1987, 1993–1996).

Divisional Associate Editor, *Physical Review Letters* (1986–1990).

Workshop on Sawteeth, Cincinnati, Ohio (Chair, 1990).

Executive Committee—University Fusion Association (1992–present).

Vice-President, University Fusion Association (1993–1995).

President, University Fusion Association (1995–1997).

TPX Advisory Committee (1993–1994).

TFTR Physics Advisory Committee (1995–1996).

NASA Review Panel on Space Physics Theory Program (Chair, 1995).

Sherwood Theory Program Committee (Chair, 1997).

DPP Centenary Committee (Chair, 1996–present).

FESAC Review Panel of ITER (Member, 1996–1997).

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GEM Tail/Substorm working group (Co-chair, 1997–present).

Vice-Chair, Division of Plasma Physics of the American Physical Society (1998).

DPP Fellowship Committee (Chair, 1998).

Forum for Major Next Step Fusion Experiments (Co-chair, 1998).

DIII–D Advisory Committee (1998–present).

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129. A. Zeiler, D. Biskamp, J.F. Drake and B.N. Rogers, Transition from resistive ballooning to h*i* driven turbulence in tokamaks, submitted to *Phys. Plasmas* (1998).

130. M.A. Shay, J.F. Drake, R.E. Demon, and D. Biskamp, Structure of the dissipation region during collisionless magnetic reconnection, *J. Geophys. Res.*, in press (1998).

VII. Invited Talks at National and International Meetings

1. J.F. Drake (with Y.C. Lee), Kinetic Theory of Tearing Instabilities, Sherwood Theory Meeting, San Diego, CA, 1977.

2. J.F. Drake, Kinetic Theory of Tearing and M = 1 Instabilities, *Bull. Am. Phys. Soc.* 22, 1105, 1977.

3. J.F. Drake (with P. Pritchett and Y.C. Lee), Nonlinear Evolution of Tearing Instabilities, Sherwood Theory Meeting, Gatlinburg, TN, 1978.

4. J.F. Drake, The Resistive Tearing Instability, American Astronomical Society—Solar Physics Division, Ann Arbor, MI, 1978.

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5. J.F. Drake, Tearing Modes and Magnetic Reconnection in the Reversed Field Theta Pinch, *Bull. Am. Phys. Soc.* 23, 782, 1978.

6. J.F. Drake (with C.S. Liu), Energy Cascade in Drift-Tearing Modes, Sherwood Theory Meeting, Mt. Pocono, PA, 1979.

7. J.F. Drake, Magnetic Fluctuations and Transport in Tokamaks, Cordon Research Conf. on Plasma Physics, Ventura, CA, 1980.

8. J.F. Drake, Stochasticity and Transport in the Lower Hybrid Drift Instability, General Meeting of the APS, Phoenix, AZ, March, 1981.

9. J.F. Drake (with T.M. Antonsen and Y.C. Lee), Tearing Modes in Toroidal Geometry, Sherwood Theory Meeting, Santa Fe, NM, 1982.

10. J.F. Drake, Stabilization of the M = 2 Tearing Mode in High Temperature Plasma, *Bull. Am. Phys. Soc.* 27, 1040, 1982.

11. J.F. Drake (with T.M. Antonsen, Jr.), Nonlinear Reduced Fluid Equations for Toroidal Plasmas, Sherwood Theory Meeting, Arlington, VA, 1983.

12. J.F. Drake, Reconnection in Sheared Magnetic Fields in Space and Solar Plasmas, International Astronomical Union Symposium No. 107, College Park, MD, 1983.

13. J.F. Drake, Tearing Mode and Anomalous Transport Processes, Chapman Conference on Magnetic Reconnection, Los Alamos, NM, 1983.

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14. J.F. Drake, Major Disruptions and Tearing and Ballooning Modes, Tenth International Conference on Plasma Physics and Controlled Nuclear Fusion Research, London, U.K., 1984.

15. J.F. Drake, Magnetic Energy Dissipation in Collisionless Plasma, Cordon Research Conf. on Space Plasma Physics, Andover, NH, 1985.

16. J.F. Drake, Sawteeth in Tokamaks, U.S.–USSR Fusion Theory Conference on Edge Physics and Transport in Tokamaks, Moscow, USSR, 1986.

17. J.F. Drake, Sawteeth in Tokamaks, Workshop on Sawtooth Oscillations in CIT, Princeton, NJ, 1986.

18. J.F. Drake, Sawteeth and Temperature Profiles in Tokamaks, Eleventh International Conference on Plasma Physics and Controlled Nuclear Fusion Research, Kyoto, Japan, 1986.

19. J.F. Drake (with P.N. Guzdar), Marfes and Condensation Instabilities in Tokamak Edge Plasma, Sherwood Theory Meeting, San Diego, CA, 1987.

20. J.F. Drake, Sawteeth in Tokamaks, Workshop on Tokamak Ignition Physics, Livermore, CA, 1987.

21. J.F. Drake, Turbulence and Transport by the h*e* Instability, U.S.–Japan Workshop and Plasma and Fluid Turbulence, Austin, TX, 1987.

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22. J.F. Drake (with R.E. Demon and R.G. Kleva), Disruptive Phenomena in Tokamak Plasma, Twelfth International Conference on Plasma Physics and Controlled Nuclear Fusion Research, Nice, France, 1988.

23. J.F. Drake (with A. Dimits, P.N. Guzdar, and A.B. Hassam), Temperature Gradient Modes, Streamers, and Anomalous Transport, International Conference on Plasma Theory, Lausanne, Switzerland, 1988.

24. J.F. Drake, Critical Comments on Models of Anomalous Transport in Tokamaks, Transport Task Force Meeting, Austin, Texas, 1989.

25. J.F. Drake, Status of the Nonlinear Behavior of the h*i* Instability, U.S. Dept. of Energy Review of Anomalous Transport in Tokamaks, Germantown, MD, 1989.

26. J.F. Drake, Basics of Reduced MHD and Tearing Modes, Summer School on Anomalous Transport in Tokamaks, San Diego, CA, 1989.

27. J.F. Drake, Drift-Tearing and Microtearing Modes in Tokamaks, Summer School in Anomalous Transport in Tokamaks, San Diego, CA, 1989.

28. J.F. Drake, Negative Compressibility h*e* and h*i* Instabilities in Tokamaks, Summer School on Anomalous Transport in Tokamaks, San Diego, CA, 1989.

29. J.F. Drake, Magnetic Reconnection in Collisionless Plasma, Second Huntsville Workshop on Magnetosphere/Ionosphere Plasma Models, Huntsville, AL, 1989.

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30. J.F. Drake, Review of Edge Turbulence Theory, Transport Task Force Workshop, San Diego, CA, 1989.

31. J.F. Drake, The Nonlinear Saturation and Transport by the Negative Compressibility h*i* Instability, 14th Annual Meeting of the Division of Plasma Physics of the American Physical Society, Anaheim, CA, 1989.

32. J.F. Drake, Density Limit Disruptions in tokamaks, U.S.–USSR Workshop on Tearing and Ballooning Modes, Moscow, USSR, 1989.

33. J.F. Drake (with P.N. Guzdar and A. Dimits), 3–D *)Ti* Driven Turbulence and Transport, Chaos and Turbulence in Fluids and Plasma, College Park, MD, 1990.

34. J.F. Drake (with R.G. Kleva), Collisionless Reconnection and the Sawtooth Crash, Workshop on Sawteeth in Tokamaks, Boston, MA, 1990.

35. J.F. Drake (with G. Burkhart and J. Chen), Structure of the Dissipation Region during Magnetic Reconnection in Collisionless Plasma, Research Trends in Nonlinear Space Plasma Physics, La Jolla, CA, 1991.

36. J.F. Drake, Convection Cell Peeling and the Generation of Sheared Flow, U.S.–Japan Workshop on Edge Turbulence and the Physics of the H–Mode, Madison, WI, 1991.

37. J.F. Drake, Turbulent Structure of the Magnetopause Current Layer, NSF GEM Workshop, Los Angeles, CA, 1991.

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38. J.F. Drake, Turbulence and Sheared Flow Generation in Tokamak Edge Plasma, Transport Task Force Workshop, Oak Ridge, TN, 1992.

39. J.F. Drake, Turbulence, Sheared Flow Generation and the L/H Transition, DOE Field Task Workshop, Germantown, MD, 1992.

40. J.F. Drake, The Formation and Levitation of Prominences in the Solar Corona, Spring AGU Meeting, Montreal, Canada, 1992.

41. J.F. Drake (with J.M. Finn, P. Guzdar, A.B. Hassam, D. McCarthy, T.M. Antonsen and C.S. Liu), Tokamak Edge Transport, Sheared Flow and the L–H Transition, Fourteenth Int. Conf. Plasma Phys. Controlled Nucl. Fusion Res., Wurzburg, Germany, 1992.

42. J.F. Drake, Transport in Magnetospheric Boundary Layers, Fall AGU Meeting, San Francisco, CA, 1992.

43. J.F. Drake, Short Scale Structure and Turbulence in the Magnetopause, NSF GEM Workshop on the Magnetopause, Snowmass, CO, 1993.

44. J.F. Drake, Subgrid Modeling in the Global Geomagnetic Circulation Model, NSF GEM Workshop on the Magnetopause, Snowmass, CO, 1993.

45. J.F. Drake, Collisionless Reconnection, NSF GEM Workshop on the Magnetotail/Substorm Campaign, Snowmass, CO, 1993.

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46. J.F. Drake, Tearing Modes and Magnetic Reconnection, Summer School on Plasma Fluctuations and Transport, Madison, WI, 1993.

47. J.F. Drake, Interchange, Ballooning and Resistive Ballooning Instabilities, Summer School on Plasma Fluctuations and Transport, Madison, WI, 1993.

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Chairman **BARTLETT.** Thank you very much. And there will be time, adequate time in the question and answer period, to expand on anything that you wanted to expand on. Let me turn now to our Ranking Member, Mr. Matheson.

From Fusion Research to Fusion Energy

Mr. **MATHESON.** Thank you, Mr. Chairman. And I appreciate the testimony of all of the witnesses. A second panel, very interesting and informative testimony. I really appreciate that. I would like to ask a couple of questions—first, for Professor Drake, if I could. Could you just say—the general question that I get asked sometimes is, what has to happen in terms of our Fusion Energy Sciences Program to take us from where we are to the point where we actually are realizing a meaningful energy source? How is that for a simple one to start?

Mr. **DRAKE.** That is a hard one I guess. I am waiting for the simple one later, I guess. The—there is a couple of things—of course, the—there is a range of experiments being explored right now. The goal of these experiments is to try to make the devices that contain hot plasma simpler, more compact, something which is going to be more readily usable as an economically viable energy source. I think Professor Hazeltine this morning talked about the fact that we have actually reached near break-even in experiments and I think the issue is no longer whether break-even is possible. The issue is whether we can make this whole thing an economically viable program.

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There is an area, however, where—there is a number of areas where new science is needed before we are really going to reach the point of producing energy. One is in the area of so-called burning plasmas. In a burning plasma experiment, you are producing more energy from fusion than you are—that you are inputting into the plasma to heat it up. We have not entered that regime yet. It is a regime in which fundamentally different processes occur and we really need to get at the science of that regime. And so that is one of the issues, for example, which is addressed in the Lofgren-Nethercutt bill.

So that is an area we need to work on. I think right now the program has been hurting for funding for several years and I think that has inhibited our ability to attract good students because I think, as the earlier panel pointed out, in a static funding situation, it is very hard to convince the best and the brightest that this is where they want to go.

Mr. **MATHESON.** It is my understanding that the Fusion Energy Sciences Program has been evolving and that there was a reorganization, I believe, in 1996. Is that correct? And before that, it was focused more on energy and less on science. And now the transition is made where folks see more in science and energy. Can you talk about the relationship between science and energy in the program?

Mr. **DRAKE.** Yeah. I am passionate about this issue and I have tried to say a little bit about that in my testimony. The progress in the program is fundamentally coupled to scientific discovery and one cannot separate the two. There is—if you look at the experiments that are ongoing now, most of them are designed to test new ideas, new ideas that we—you know, 20 years ago, we just had no clue as to what was going on in these systems.

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And as part of the science in the program you made a discovery—I will give you an example of one of these. And that is, it used to be believed that as you increase the pressure in the plasma, at some point, the plasma would sort of break up and go on and hit the wall. And there was a theoretical idea that as you increase the pressure, that the plasma would actually get more stable. And this phenomenon is called second stability, which was the name of it. And what was interesting was this seemed like a harebrained idea, but it actually turned out to work in the experiment.

And this has led to a couple of experiments—one is in the U.K., called MAST and another experiment, NSTX at Princeton. In which they took this idea and they built an experiment to test it, and lo and behold, they now have the world record for pressure in that experiment. It is, again, an example of exactly what the Chairman talked about at the beginning. It is a scientific discovery unexpected. It leads to a new idea and a better way of doing things. And I think that is why I feel very strongly that there is no contradiction at all between fundamental science, great science, and the energy goal. The two are coupled together.

Plasmatron Device for Gasoline Engines

Mr. **MATHESON.** Let me just ask—I got to ask about the plasmatron. You mentioned—when you are talk about the fuel efficiency——

Mr. **DRAKE.** And by the way, this is from MIT. I should have said that.

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Mr. **MATHESON.** I was going to ask—you mentioned the fuel efficiency and the emissions——

Mr. **DRAKE.** Yeah. Right.

Mr. **MATHESON** [continuing]. Issues. Where is that in terms of being in commercial application at this point?

Mr. **DRAKE.** So I have a two-page document which addresses that issue I can actually give you if you would like. And, in fact, my understanding is that the MIT scientists are supposed to come down here and talk to—I don't know whether it is Harlan or whoever else in a couple of weeks. I think they laid out a 10-year program of trying to complete development and implement this on gasoline engines. This is not my work, so I would have to defer to the scientists involved.

Chairman **BARTLETT.** Thank you. There will be another round, I think, of questioning. While we are on the gasoline to hydrogen, could you tell me very briefly how you do that?

Mr. **DRAKE.** Again, this is not my experiment, so I don't really know. There is a chamber which involves plasma physics which—and I am not that familiar with what they are doing—but the gas flows into the chamber and it is somehow enriched so that there is a much higher concentration of hydrogen in the gasoline than when it comes in. And that is then re-injected into the fuel with the rest of the gasoline from—that is coming into the engine. But I would have to defer to my colleagues from MIT to—with—for further discussion.

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Chairman **BARTLETT.** Okay.

Mr. **DRAKE.** And, again, I can provide you with the two-pager that I got from them.

Chairman **BARTLETT.** Well, we would be pleased to make that a part of the record without objection.

Chairman **BARTLETT.** Everyone, of course, is familiar with the advantages of hydrogen. And I am afraid that perhaps half of my colleagues think that this is a fuel source and, of course, it is not an energy source. You get hydrogen by using other energies and you—there will be less energy in the hydrogen than was in the energy that you used to produce the hydrogen or the first law of thermodynamics doesn't work, and it does, of course.

Mr. **DRAKE.** Could——

Chairman **BARTLETT.** But hydrogen has some amazing positives. Fuel cells——

Mr. **DRAKE.** Could I just interrupt you——

Chairman **BARTLETT** [continuing]. With high efficiencies? Yes, sir.

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Mr. **DRAKE.** Could I just interrupt and say in this case, the hydrogen, of course, is produced by the gasoline.

Chairman **BARTLETT.** Yes.

Mr. **DRAKE.** So it is not a separate injection process. So——

Chairman **BARTLETT.** Well, I understand that.

Mr. **DRAKE.** Yes. Very good. Thank you.

Chairman **BARTLETT.** Yeah. That in that little device, the concentration of hydrogen was increased by that device. But everyone is familiar with the advantages of hydrogen. It burns in a fuel cell. It may burn, what, 80 percent efficiently there, while the gasoline engine burns at about 25 percent efficiency. And if we are real lucky, we may push it to 30 or 33 or something. So there is some amazing capabilities of hydrogen. Also, when you burn it, of course, it is accepted—if you think water is a pollutant, it is totally non-polluting. You get only heat and water from it when you burn it. So all of the pollution is produced at the site where you are converting some other form of energy into hydrogen. And there you have the economy of scale and you can keep things cleaner because it is all in one place and it is bigger.

Environmental Remediation Options

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Dr. Richardson, you mentioned environmental cleanup. We have had in our society a commensalism relationship, I guess, between lawyers and society, and it is now—we are now threatened to have a parasitic relationship there as parameters become too numerous. And I mention that relative to environmental cleanup because on our Superfund cleanup sites, 70 percent of all the money has gone to lawyers. Maybe we need some cleanup there, but I don't know if that money is accomplishing that.

My question has to do with this cleanup. If these pollutants are not migrating—if they are not blowing into the air and not moving into an aquifer, why don't we just build a fence around them and go away? Because the longer we wait, the lesser the problem is. And we don't need to put an nursery school there and clean it up so the kids can eat the dirt. Why don't we just, you know, go away and let time take care of the problem?

Dr. **RICHARDSON.** Even though I have a Nobel Prize, I am not an expert in that field, so my opinion is just an—you know, just a lay opinion, because that is not my research field. But I suspect what you propose is how it is going to end up—some of it, not all of it—some of it is going to end up being solved in the places where it looks like it is going to be inert and it can be just blockaded. In an area that it is too expensive to get rid of it otherwise, it will just be considered a dump and put that way. But there are other places where it is obvious that we have to take positive action and you have mentioned them, where you have effected the aquifers and of a much broader area of the environment. I can't give any further on that.

Chairman **BARTLETT.** Dr. Shank.

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Dr. **SHANK.** I might point out that the approach that you describe is exactly one that was proposed and actually used by the Lawrence Berkeley National Lab and used to solve the problem of selenium pollution in the Kesterson Reservoir. There was a desire to dig it all up and move it—it was agricultural pollution of selenium, killing birds. And the desire was to move it away. And how that would be done at tens, maybe hundreds of millions of dollars. What was discovered with a good science program that, in fact, bacteria was fixing the selenium, changing it to a valance state, which was stable. And then if you capped off the top and waited 50 years, there would be no pollution problem. That, in fact, prevailed and it is the way in which the Kesterson Reservoir has been—has undergone environmental remediation at a fraction of the cost.

Consolidation of Government Science Programs

Chairman **BARTLETT.** Oh, thank you. And before my time for this round expires, let me ask very quickly, why did we reject the idea of a Department of Science?

Dr. **RICHARDSON.** Fundamentally, it is—the basic objection that we had, and we talked about it and argued about it for a long time, is that the country has benefited enormously from diversity of funding sources that comes from different missions that—I mean, different agencies that have different missions. Looking at a collection of scientific opportunities will seem quite different at the, say, NSF, where they are looking at the broad fundamental issues, from, say, the Department of Defense or the Department of Energy, where there—or NASA, where there are specific missions related to the agencies, but they still need fundamental science.

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And I think the communities benefited from having a diversity of opinions about what to back. You know, you can't—as you pointed out earlier, you can't say which thing is going to really be the winner. And so you like to have kind of marketplace of ideas where there are a bunch of, we hope, very clever people responsible for making the funding investments in the government, but they bet against each other, and so they pick different horses.

That even happened in Department of Energy. You could see people in the Air Force competing with ones in the Navy and the Army to see who could pick the best horse, you know, to win the race in a particular goal they wanted. So that is a fundamental concern we have about trying to put it all in one agency. Basically, diverse sources has worked and worked better than anywhere else in the world.

Chairman **BARTLETT.** Yeah. I thank you very much for your answer. Just on the surface, it would seem that if you focused it all in one place, it would get more attention and that would be good. But if they really screwed up——

Dr. **RICHARDSON.** But you can whittle it down easier too.

Chairman **BARTLETT.** Yes. That is true. It is more visible. But if they really screwed up in that one place——

Dr. **RICHARDSON.** Yeah.

Chairman **BARTLETT** [continuing]. Then we would have had it as a nation when it is diverse and spread across the government. My real concern is that too much of it is funded by government. I know that basic research largely needs to be funded there because industry has a hard time looking beyond the next financial statement. But when you get to R&D, we are funding for too much R&D out of government. More of that needs to be funded in industry and we need to help them do that by giving them tax credits. I don't think I or any bureaucrat in government will make as good as decisions where R&D money ought to be spent as the private sector out there. So I would hope that we can move of that funding to the private sector.

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Dr. **RICHARDSON.** I understand that point, but there is still another component—and now this is my own personal self-interest because I have been a college professor for so many years. And that is that there is an aspect of the fundamental science that is way off that—in the far distant future that industry is not going to have a want to develop. And it is those things that we have to really nurture and listen to off the wall ideas and make sure they get developed and that we draw the youth into it.

You know, one of the points I like to make is another important part of the governmental activity in the support of the long-range inspiring kind of stuff. You know, astronomy, cosmology, things in industry. And what it is going to do is, it draws in the best and the brightest from our youth. Trustees of my university are frequently asking for a better, long-term strategic plan. What are you going to be doing 10 years from now? That is—this is no way to run a business. And I have to answer, well, the people that are going to have the best ideas 10 years from now are still in high school. And I don't know how to find them to ask them the questions yet. And——

Chairman **BARTLETT.** Yeah. I think it is the right answer. In science, I don't have the foggiest idea what we are going to be doing in 10 years and we are going to have to have an——

Dr. **RICHARDSON.** So we have to have a lot of diversity and——

Chairman **BARTLETT.** Right.

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Dr. **RICHARDSON** [continuing]. And you just have people that stop and say, hey, that is a good idea and the time's right for developing. Let us put some money there and see where it goes and let it develop. And a lot of that just doesn't match the intellectual property interest and so forth, that industry has in its tradition. You know, the university produces research. It is open for the entire public to have. There are lots of very nice deals being worked now between industry and universities and that is important in some technologies, but there is a real difference in the cultures.

In my current day job, I spend a lot of time worrying about the conflicts on intellectual property and the differences in the underlying fundamental self-interest that the university culture has and industrial culture has. And they have to work hard to come together. And there are places where it works well and there are a lot of places where I don't think it is entirely promising that industry can cover it.

Chairman **BARTLETT.** Thank you very much for articulating the essential role that government plays in basic research. And because we are so essential there, because industry cannot afford the long-term investments that the taxpayers must make through their government, it is even more essential that we be responsible, and we have not been responsible. As a large nation, we spend a smaller percent of our GDP on basic research than any other competing nation in the world.

Dr. **RICHARDSON.** Absolutely.

Chairman **BARTLETT.** And that is silly in the short term. It is even sillier in the long term. And you can see from the empty chairs up here and the empty chairs behind you——

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Dr. **RICHARDSON.** Well——

Chairman **BARTLETT** [continuing]. The problem we have.

Dr. **RICHARDSON.** I mean, how can I help you fill the chairs?

Chairman **BARTLETT.** Well, yeah, that is what we are asking you. We need together to educate——

Dr. **RICHARDSON.** I agree.

Chairman **BARTLETT** [continuing]. The American people and the Congress.

Dr. **RICHARDSON.** But I also think the tying it to GDP, as a reinvestment, is really a critical idea.

Chairman **BARTLETT.** Oh. Yes. And we now are at a lower level than we have ever been in our history and lower than almost any power that we are competing against. In the short term, it is a threat to our economic superiority. And in the long term, it is a threat to our national security. We will not continue to have the world's best military unless we have the world's best scientists, mathematicians and engineer as a world's best basic research.

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Dr. **RICHARDSON.** Right.

Chairman **BARTLETT.** And, you know, we are at risk and we are glad you are here and we are glad that you are going us in trying to get this message out. Mr. Matheson.

Mr. **MATHESON.** Dr. Richardson, I just had a couple of questions on your testimony. You talked about an Alternative "B" that we would be combining the programs——

Dr. **RICHARDSON.** Yeah.

Mr. **MATHESON** [continuing]. With NIST and NOAA and USGS. Do you have any insight into how the folks in those agencies would react to that?

Dr. **RICHARDSON.** Yeah. We talked about this a long time. These are a lot of knowledgeable people with a lot of government experience. And we said, now, if we were cleaning away the boards and we are going to organize everything all over again, we would say NSF really does a pretty good job in covering science as a whole from a balanced perspective, covering all fields. It is way underfunded still, but I mean, apart from that. That is not the place to do this and what would we create. And this is the type of thing that we talked about doing and we would tie it strongly to the type—how it would drive the economy and it could fit into a new vision on Department of Commerce.

And then the old hand, you know, former science advisors and directors at Office of Science said, okay. But in order to do this, you are going to have to reorganize the whole government, including Congress and all of its committee structures. And so that our alternative "B" is a ambitious idea that would attack if you were starting from zero base, whereas Alternative "A" is one that is far less cumbrous, but I think could work. But it is really important that the—now that we have the NNSA, that the science——

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Mr. **MATHESON.** Uh-huh.

Dr. **RICHARDSON** [continuing]. Part of DOE be put on the same level so that there—it gets the attention and consideration and recognition that is needed.

Mr. **MATHESON.** In Alternative "B," we mentioned both science and energy programs. Does that mean that the energy efficiency and renewable energy programs at DOE would also be put into this——

Dr. **RICHARDSON.** In that Alternative "B,", yeah, we would be——

Mr. **MATHESON.** Okay.

Dr. **RICHARDSON.** And then we wanted to figure out somewhere else to put the cleanup stuff.

Mr. **MATHESON.** I was about to say, we would have here what is left for the Department of Energy.

Dr. **RICHARDSON.** That is up to the wise Congress to know. We could certainly it, but that—and, of course, that is one of the big burdens that Department——

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Mr. **MATHESON.** Yeah.

Dr. **RICHARDSON** [continuing]. Of Energy has. And then in—our view on—let me return a little bit to Alternative "A," because we have a better idea. You could also then have the third arm of Alternative "A," the people that we were dealing with the environmental cleanup and the legacy of the goal work, if you want to. Some agency is going to have to take that on. And there are also, in Department of Energy, a little bit of a hodgepodge, frankly, of things that got picked up Department of Interior and funny places. So when you look in the table for Department of Energy, there are these little anomalies that——

Mr. **MATHESON.** Yeah.

Dr. **RICHARDSON** [continuing]. Stick out all over the place. And I know it is a temptation in reorganizing bureaucracy to take all the stuff that looks too awkward to deal with and lump it together and put it someplace else and that can't be done. But one might look at logically reassigning those back to some of the source agencies from which they had come.

Mr. **MATHESON.** It seems to me that in the past there had been some management problems within the Department regarding planning or execution of large projects and allocation of resources and accountability. How do you think these two alternatives address those problems?

Dr. **RICHARDSON.** I mean, those are part of human nature or part of the nature of management of big things and big businesses. And I think you could have those problems under either of those alternatives. What is important, I think, is that despite the problems, there—they have been solved. And Department of Energy, in management of its major facilities, has a superb record. You know, it—that, in the end, they are there and they function and they do a terrific job of bringing new things online.

From my point of view, in looking at those facilities—by the way, the biggest problem is the funding to keep them going. I mean, we heard the testimony about RHIC today. And I take—it is not my field of science, but I take great delight in the completion of it. But then, now that this year's funding only has 10 weeks of running time on this brand new facility that everybody is champing at the bit to be able to use, you know, that is a fourth of the time that it could be running. It is—and that isn't going to—that problem can be with us under any kind of organization, because the facilities need the support, the will of the people, I guess, is the way I would put it.

Mr. **MATHESON.** I will yield back the rest of my time, Mr. Chairman.

Value and Role of DOE National Laboratories

Chairman **BARTLETT.** Thank you. Dr. Shank, you mentioned the fact that the facilities in DOE are old, that the newest buildings are like 30 years old.

Dr. **SHANK.** In some places.

Chairman **BARTLETT.** This, of course, reflects the history of our energy labs. They were largely built around our need to develop and understand nuclear weapons. And we aren't building those anymore. All we are doing now is maintaining the stockpile, and so there is not the pressure to fund this.

My question deals with how we solve a very fundamental problem we have relative to our energy labs. We have been talking of a basic research today and everybody is very enthusiastic about the basic research in our energy labs, but the labs do a whole lot more than basic research. And there is a feeling that a lot of the people in our labs are kind of looking for a mission, because we are no longer building nuclear weapons or exploring ways to build new nuclear weapons.

I am very supportive of a process that convenes a blue ribbon panel to look at this—the enormous resources we have in our energy labs to see where we go from here with the capabilities of those laboratories and the contribution that they might make to our society. And I wondered if you have thought about this and how we can politically do that.

See, one of the problems with doing this is that every one of these labs is in somebody's—some senator's state or some Congressman's district. And if you start looking at them, there is the risk that you make, including, gee, that lab needs to be downsized or changed or something and that now becomes a risk to your constituencies, so everybody says, not in my backyard. Which, of course, is why we have the Brack process for closing our defense bases, because we would never close any of them if we had to do it in Congress, because I am not going to vote to close your base if you don't close to—if you don't vote to close my base.

Have you had any thoughts about how we, as a country, look at this enormous resource that we have in our energy labs and decide where we go from here to use them most productively?

Dr. **SHANK.** Well, first, I want to make very clear that today I was talking about Office of Science and Office of Science laboratories. They are not involved, and have not been involved, in nuclear weapons. And so there is not——

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Chairman **BARTLETT.** I understand that.

Dr. **SHANK.** There is not an issue in which the nuclear weapon issue has left us without nothing to do. In actual fact, the laboratories are bursting with ideas. We are at the edge of breakthrough science, cutting edge science. I talked about in my testimony that these laboratories were picked as breakthroughs of the year in several scientific areas.

What we have are scientific laboratories which are producing, which are a very important part of the scientific program. And they are a very important part of the scientific fabric of the nation. And I think that before we talk about closing such laboratories, I think we really should look at the value that they bring, understand that value, and look at how we can enhance and make these entities as productive as they possibly can. They are a very important part of the fabric of what makes science. I pointed out that we had over 22,000 users—these—of the facilities at the laboratories, and the laboratories are delivering science.

I—and I want to make very clear that we should not be confused that our mission has changed because we have gone to the stockpile stewardship. We are not involved in stockpile stewardship and have not been involved in that. We are part of the scientific fabric of the country. So I think that is a very important premise upon which to talk about. You talked about the need to increase and to focus funding and do the most exciting science. Well, I think much of that exciting science, including the nanoscience, including the entire panel that you had here before, was describing the opportunities that we have available to use these facilities. I would really like to focus on how we can make an investment in these facilities, to bring them up to world-class capability, to deliver and really achieve the scientific objectives that we have laid out. So I really look at this as not downsizing our scientific activity, but really as an opportunity to make them fulfill their potential and really deliver and continue to deliver on the science that we are, in fact, actually doing.

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Underlying Role and Contributions of Basic Research in Physical Sciences

Chairman **BARTLETT.** Yeah. You will get no argument from this Subcommittee that we need to increase that funding. You mentioned that biomedical research and medicine has had a 200 percent increase in funding. I started my research life after the University of Maryland at two medical schools and then National Institutes of Health. And I noticed that when I was at the National Institutes of Health that all of the institutes were named for the diseases of old Congressman. That has now changed a little and we have—we are recognizing there are also women and children in our population.

But they get a lot of funding because each of us has a vested interest in what goes on there. And I regret that your research interests have not had a similar increase in funding. Because you can make a real case that if you aren't adequately funded, we are going to be limited in what we can do in medical research in the future——

Dr. **SHANK.** Absolutely.

Chairman **BARTLETT** [continuing]. Because that all begins where you leave off.

Dr. **RICHARDSON.** We are limited right now.

Chairman **BARTLETT.** Yeah.

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Dr. **RICHARDSON.** I mean, the name of the game in the genomics thing is imaging. And you want to see one of those proteins wiggling around doing its thing and figuring out how it works and you want to see them one at a time and watch them. And nobody has figured out how to do it. And you can't order it out of a catalog. Somebody has to invent it and there has to be a whole line of experimental scientists who are clever with their hands that will dream. And that is place where the 25 to 35-year-olds that stay up all night and try one thing after another and expand on the thing called atomic force microscope or whatever to be able to solve that. And that is not going to happen without support of the physical sciences and that generation of creative instrument inventors.

Dr. **SHANK.** I would like to lend myself to the remarks at the beginning where you talked about the physical sciences being the foundation for our economy. What I tell my friends is that what we do the work that allows us to create the economy to pay our medical bills.

Chairman **BARTLETT.** Ultimately, everything happens at a molecular level. Doesn't it?

Dr. **RICHARDSON.** Even medical bills?

Chairman **BARTLETT.** I am talking about physiology and medicine.

Dr. **RICHARDSON.** Yeah. Absolutely.

Chairman **BARTLETT.** Ultimately, it all gets down to a molecular level and then down to a sub-molecular level.

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Dr. **RICHARDSON.** Right.

Chairman **BARTLETT.** You are looking at the interaction of one——

Dr. **RICHARDSON.** You were saying it was called chemistry. Well, I was saying, no, it is all physics.

Chairman **BARTLETT.** That is right. That is right. Physics underlies the chemistry and—yeah. Yeah. Well, let me turn now to Mr. Matheson if he has additional comments or questions.

Mr. **MATHESON.** I am all done.

Chairman **BARTLETT.** Okay. Okay. Well, thank you very much. Let me take just a moment then. I have on my lapel here a little pin that says NEAR on it—the NEAR Satellite. I was at Johns Hopkins University, Applied Physics Laboratory, where I worked, by the way, in a former life, in the Space Development Division. I was there when we landed the NEAR Satellite on Eros. Now, two times as far away as we are from the sun, it took 35 minutes for a round-trip communications. You ask them a question—17b minutes to get the signal up there and 17b minutes to get it back. And I was fascinated. We landed that satellite and it didn't crash. It landed because it was only going 5 miles an hour. That Eros stone up there was so small that the gravitational pull——

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Dr. **RICHARDSON.** On Valentine's Day.

Chairman **BARTLETT** [continuing]. Was so low that you were in orbit traveling 5 miles an hour. And my question has to do with gravity. It would appear that gravity is an inherent property of all matter. I guess we need to be thankful for it because we would have a very chaotic universe if it were not for gravity. It would also be very nice if, on occasion, we could suspend gravity. It would make transportation a whole lot easier. Wouldn't it? How close are we to understanding gravity so that 1 day we might be able to do that?

Dr. **RICHARDSON.** Do you want——

Chairman **BARTLETT.** Yes, sir.

Dr. **RICHARDSON.** Well, I am not going to answer that directly, but I want to tell you what I think one of the most fantastic challenges in modern sciences and one that is comparable to the one that started general relativity and quantum mechanics a century ago—and that is the accelerating universe. And there is something we don't quite know how to fit in there. We try—the current framework of theoretical physics—they speculate on two things. One is called dark matter, that half stuff around as we—that is creating new gravity we can't detect or see. But then there is something that is helping push it away, which is a high-energy density, something called dark energy. I am not sure that I believe that because there is a principle, Occam's razor—when it gets too complicated, you say there has got to be a simpler principle.

But then what that means is, if I am right, is there is a fundamental piece of physics that we don't know yet. I won't be able to answer how far away we are, but I will tell you that some time in the next 10 or 15 years that we have the prospect of creating a whole new 21st century physics revolution that looks like the one that the 20th century had because, once again, revealed from astronomy, because that is where we got it in the 20th century.

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Dr. **SHANK.** I would like to certainly allow myself the excitement of dark energy and, of course, like to point out that a DOE lab, our laboratory was responsible for the Supernova search that, in fact, did discover dark energy. And it is part of DOE science being at the cutting-edge, breakthrough science. I think that that discovery of dark energy could profoundly change the way we think about gravity on the whole set of physics that is controlling our universe. And I agree with Professor Richardson—there is something very fundamental that we don't understand. This is one of the worst states of theory that we could imagine to be so many orders of magnitude off. And the scientists are embarrassed at this result.

Dr. **RICHARDSON.** That is the best time to be a scientist though——

Dr. **SHANK.** Absolutely.

Dr. **RICHARDSON** [continuing]. When you know it is all wrong and you——

Dr. **SHANK.** You have to do something new and that is—new discoveries just within the last few years and your national laboratories are involved.

Dr. **RICHARDSON.** In a big way.

Chairman **BARTLETT.** You know, when I think of these things I often think of the psalm or statement that we are counted as a small dust of the balance. He couldn't have appreciated that His sun was a mediocre star out to one edge of one of billions of galaxies out there, but still He had that insight.

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Professor Drake, you mentioned the problem of maintaining long-range programs. That is one of the problems of having government do it. The Congress is not only at times, enormously ignorant, we also can be very arbitrary and capricious. And putting the sustainability of these long-range programs at the mercy of a Congress puts them at enormous risk. How do we get around that?

Mr. **DRAKE.** Well, there is probably no easy answer, of course. I think, certainly in my field, the fluctuation and the price of energy has had—caused some serious problems because it was clear that a few years back when gasoline was that cheap, people weren't interested in energy. I think the only answer that I have is, and what I have tried to convey into my testimony, is that you need near-term products from your program.

And I—that is why I consider it so important too that, as part of the Fusion Program, you must look at what sorts of science discoveries are we making? Do these science discoveries have impact on other fields, whether it is an astrophysics or whether it is trying to understand space, weather, which is a big topic now. What happens when you have a coronal mass ejection and it comes and hits the earth and knocks out a few satellites? We know this is a problem and it is going to be a bigger problem in the future. So does the Fusion Program do research with—which links to those issues that are ongoing, and the answer is, yes. So you need that. And I think, as I was pointing out with this nice example here, technologies—implications—I think, you need series of results, otherwise the country and the Congress doesn't see that they are getting anything for their money. And so I think pointing out the importance of these, you know, ongoing results in science and in technology is what you really have to do to make the case.

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Energy Reserves and Consumption

Chairman **BARTLETT.** Let me suggest that perhaps the best way for you to get the support that you need for fusion energy is to help us articulate to the American people and this Administration the dimensions of the energy problem that we face as a Nation. As you may know, the best estimates of the world's experts—and we had a hearing not very many days ago, when we had them in—on the known reserves of oil in the world is about 1,000 gigabarrels. And there is a U.N. report to that effect, and all of our witnesses said that, yes, they agreed that that was the consensus of the world's expert.

If you are wildly optimistic about what you might find that you haven't found yet, at a very low level of confidence, like 5 percent level of confidence, there is maybe almost as much out there to be found as you have found now. That is a bit less than 2,000 gigabarrels of oil. That sounds like a lot. That is a big number. But when you look at what we use, it is bout 80 million barrels a day worldwide. We use a fourth of that, by the way, and at 2 percent of those known reserves, and probably less of it to be discovered than other places, because we have been drilling holes in our country for a long time looking for oil.

If you look at that use rate per day and do some very simple math and look at the increase in use, even ignoring the prevalent increase in use as a result of third-world nations trying to industrialize, we have about 30 years of oil left in the world. Now, that is not forever for sure. If you look at the other potential sources of energy, you have got wind, you have got sun, you have got geothermal, you have got biomass, you have got biodiesel. There are lots of other potential sources of energy. We have to be quite optimistic about all of them to have them add up to the enormous amounts of energy that we would now consume from fossil fuels.

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By the way, if we were to increase our light water reactors in this country, which is the only kind we have, the world reserves of fissionable uranium are about the same as the world reserves of oil and natural gas. They have a whole lot more coal, but we have it in this country and in China and your burn it, that is considerable expense to the environment and not all of it can you get out. You are not going to mine a 6-inch seam of coal. That is probably not economically feasible. So all of it out there is not usable.

But the only potential way we get home free in the future is fusion. And I think that your best argument for increased funding is to help us point out to the country the enormity of the challenge that we face. We have 2 percent of the known reserves. We use 25 percent of the world's oil. And I don't think it makes much sense to run out real quick and find that 2 percent and pump it, because if we did that tomorrow, what will we do the day after tomorrow? So if you will help us make that argument, I think we can help you get more funding because you are the only avenue where we get home free without a lot of stress and strain and big changes in our—in the way we live.

Mr. **DRAKE.** I totally agree and you clearly have the facts at your fingertips, which is very impressive. I think the frustrating part—point of view, from our point of view is, is that you see the—you imagine the consequences of 30 years down the road and simply not having the oil resources to run this country. And you ask yourself, what are you going to do? And the answer to that question is really staggering. The consequences are staggering. And that is why it is shocking to me that the country has not come to grips with this real issue. Because the end is there to be seen.

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And how you can look at the standard of living we have now and not have a long-term strategy to resolve that fundamental problem, that things are coming to an end at a particular point in time. It is astounding to me. And somehow we have to motivate both the public and the policy makers to come to grips with this. And it is again remarkable that people haven't picked up on this and demanded a solution.

Chairman **BARTLETT.** It is a matter of education, I think. There are a lot of people, and many of them in the Congress and in the Administration who believe that God, in his wisdom and foreknowledge, knew how profligate we would be in the use of energy, so he put a limitless amount of fossil fuels out there and it is just a matter of can we find them—kind of a hide and go seek kind of a thing. I think that that is not true. I think that the best advice of our experts, that their best judgment, that there is about 30 years remaining in the world, if you look at possible, yet-to-be-found reserves, and that the increase in use rate, you still come out around 30 years.

Too many people really believe that they will find a solution to it. And when they tell me that, oh, they will find a solution to it, I tell them you should have told that to those cliff dwellers out in the west. Their civilization is now gone. And I am sure they were telling each other that when things were going sour in their little world out there.

Global Climate Change

This relates to one other thing, and then we will close. And that is, this whole energy thing relates, of course, to global climate change and global warming. And when you reflect on the fact that our world that, at one time, has been very much colder with ice sheets coming down through southeastern Ohio, it has been very much warmer, because National Geographic just had this very interesting find of a Woolly Mammoth intact that they dug out of the tundra frozen for all these thousands of years with subtropical vegetation in its stomach. So the world, at one time, had been much warmer.

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Now, we were not here in any meaningful numbers in either one of those events for us to have affected the climate in the world. Now, the world may, in fact, be getting warmer. And, but the question I have is, it will be different, but will it be worse? If I live in Siberia, you might have a hard time convincing me that a warmer world would be a worser world. Huh?

Dr. **RICHARDSON.** That is what we say in upstate New York too.

Chairman **BARTLETT.** No. Clearly, clearly, where we grow grain would shift. Now, we are in the midst of a drought where I live. I live on a farm 50 miles from here. We are in a drought and maybe it is due because of global warming. So——

Dr. **RICHARDSON.** I am kind of concerned about doing the experiment though.

Chairman **BARTLETT.** Sir?

Dr. **RICHARDSON.** I am sort of concerned about doing the experiment to see how it works out.

Chairman **BARTLETT.** Yeah. That is probably the best advice you can get that, you know, let us leave well enough alone. It could be better. It could be worse. And—but maybe that is a risk you don't want to run. Now, but this is clearly a matter of education. The fact that it is changing may not be bad. Some change has been good. When will we have enough scientific evidence that we can know whether or not we need to be really serious about changing the rate at which we use fossil fuels and greenhouse gases and so forth? When we will know the end from the beginning. Yes, sir.

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Dr. **RICHARDSON.** You have described some of the natural cycles that are there, and they are really important and really fascinating. But I am pretty convinced that there is a major impact that man is putting on it that didn't exist there before. And that there is no known self-correction for the mankind addition that sits here on the background—maybe there is. But and that is why I am—I wasn't entirely facetious when I said I don't want to perform the experiment to drive it outside the bounds of the, you know, natural oscillations.

The—even the fascinating one, the terrific one you are talking about is a mastodon with the tropical food. But for the most part those changes came slowly enough so the people could decide they were going to move away from Greenland because there wasn't—it wasn't a healthy environment. That was, at the time, a small population and the world could adjust to it. Obviously, in that time, mankind wasn't changing it. It was changing all by itself too in the little ice age.

But I think we already have pretty good evidence that the changes we are making in the atmosphere are affecting the temperature. Now, how bad that is going to be and, even when that happens, as you put it, there are winners and losers. But the fraction of the land mass on the earth that is going to be a winner is not going to be real large, I think.

Chairman **BARTLETT.** I can understand the concern that you may not want to turn that corner because what you find there may not be very nice. Yeah. Well, I want to thank you all very much for your testimony. Mr. Matheson, do you have any——

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Mr. **MATHESON.** I want to thank you for taking the time to come here. It has been a fascinating hearing today and, Mr. Chairman, I appreciate your calling this hearing because it is very informative.

Chairman **BARTLETT.** Thank you very much and thank you for coming.

[Whereupon, at 1:37 p.m., the Subcommittee was adjourned.]

Appendix 1:

Answers to Post-Hearing Questions Submitted by Members of the Subcommittee on Energy

Next Hearing Segment(2)

(Footnote 1 return)
Details of the DOE's Office of Science FY 2002 budget request are included in the attachment.

(Footnote 2 return)
The B–Factory provides for collisions of 9 billion electron volts (GeV) electrons with 3-GeV positrons at high luminosity.

(Footnote 3 return)
The Tevatron is capable of accelerating protons and antiprotons for both fixed and colliding beam experiments at one trillion electron volts (TeV).

(Footnote 4 return)
The LHC is a 7 TeV on 7 TeV proton-proton colliding beam facility currently under construction at CERN, which is located near Geneva, Switzerland.

(Footnote 5 return)
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experiments at one trillion electron volts (TeV).

(Footnote 7 return)
The LHC is a 7 TeV on 7 TeV proton-proton colliding beam facility currently under construction at CERN, which is located near Geneva, Switzerland.

(Footnote 8 return)
A Budget Amendment transferring $5.0 million from HEP to Fusion Energy Sciences is expected to be transmitted shortly.

(Footnote 9 return)
A Budget Amendment transferring $2.7 million from ASCR to Fusion Energy Sciences is expected to be transmitted shortly.

(Footnote 10 return)
A Budget Amendment transferring $0.3 million from Energy Research Analysis to Fusion Energy Sciences is expected to be transmitted shortly.

(Footnote 11 return)
In addition, $10.0 million will be transferred to FES in a Budget Amendment that is expected to be submitted shortly. Details will be provided at that time.

(Footnote 12 return)
A Budget Amendment transferring $2.0 million from Program Direction to Fusion Energy Sciences is expected to be submitted shortly.

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