Nuclear Physics

Funding Profile by Subprogram

(dollars in thousands)

	FY 2008 Current Appropriation	FY 2009 Original Appropriation	FY 2009 Additional Appropriation[a]	FY 2010 Request
Nuclear Physics				
Medium Energy Nuclear Physics	107,206	121,752	+19,700	131,009
Heavy Ion Nuclear Physics	182,236	200,373	+16,235	219,556
Low Energy Nuclear Physics	82,279	94,618	+24,545	116,816
Nuclear Theory	34,411	39,376	+14,108	43,419
Isotope Development and Production for Research and Applications [b]	—	24,900	+15,212	19,200
Subtotal, Nuclear Physics	406,132	481,019	+89,800	530,000
Construction	17,539	31,061	+65,000	22,000
Total, Nuclear Physics	423,671[cd]	512,080	+154,800	552,000

Public Law Authorizations:
Public Law 95–91, "Department of Energy Organization Act", 1977
Public Law 101–101, "1989 Energy and Water Development Appropriations Act" (Established the Isotope Production and Distribution Program Fund)
Public Law 103–316, "1995 Energy and Water Development Appropriations Act" (Amendment to the Isotope Production and Distribution Program Fund to provide flexibility in pricing without regard to full-cost recovery)
Public Law 109–58, "Energy Policy Act of 2005"
Public Law 110–69, "America COMPETES Act of 2007"

Program Overview

Mission

The mission of the Nuclear Physics (NP) program is to discover, explore, and understand all forms of nuclear matter. The fundamental particles that compose nuclear matter—quarks and gluons—are relatively well understood, but exactly how they fit together and interact to create different types of matter in the universe is still largely not understood. To solve this mystery, NP supports experimental and theoretical research—along with the development and operation of particle accelerators and advanced technologies—to create, detect, and describe the different forms and complexities of nuclear matter that can exist in the universe, including those that are no longer found naturally.

[a] The Additional Appropriation column reflects the planned allocation of funding from the American Recovery and Reinvestment Act of 2009, P.L. 111–5. See the Department of Energy website at http://www.energy.gov/recovery for up-to-date information regarding Recovery Act funding
[b] The Isotope Development and Production for Research and Applications program is transferred to the Office of Science from the Office of Nuclear Energy in FY 2009.
[c] Includes $1,500,000 provided by the Supplemental Appropriations Act, 2008, P.L. 110–252.
[d] Total is reduced by $10,555,000: $9,425,000 of which was transferred to the Small Business Innovative Research (SBIR) program and $1,130,000 of which was transferred to the Small Business Technology Transfer (STTR) program.

Background

It is one of the enduring mysteries of the universe: What, really, is matter? What are the units that matter is made of, and how do they fit together to give matter the properties we observe? These are questions which philosophers have wrestled with for millennia. Twenty-four hundred years ago, the Greek philosopher Democritus suggested that if one were to divide matter into smaller and smaller pieces, one would eventually be left with indivisible entities called atoma. It was not until the 1800s, however, that scientists had solid evidence that such atoma—or atoms—actually existed, and it was not until the early 1900s that techniques were developed that made it possible to examine their composition.

In 1909 the physicist Ernest Rutherford fired a beam of helium ions at a thin sheet of gold foil and measured how the ions scattered, showing that each atom has at its center a small, dense, positively charged core, which Rutherford named the nucleus. Scientists later determined that the nucleus is surrounded by a cloud of tiny negatively charged electrons that account for less than 0.1% of the total mass of the atom. Upon closer inspection, researchers found that the nucleus was composed of even smaller particles: the positively charged proton and the electrically neutral neutron. Research showed that protons and neutrons are bound in the nucleus by a fundamental force named the strong force because it is far stronger than either gravity or electromagnetism, although it operates on smaller distance scales. As scientists delved further into the properties of the proton and neutron, they discovered that each proton and neutron is composed of three tiny particles called quarks. Quarks are bound together by yet other particles called gluons, which are believed to be the generators of the strong force. One of the major goals of nuclear physics is to understand precisely how quarks and gluons bind together to create protons, neutrons, and other hadrons (the generic name for particles composed of quarks) and, in turn, to determine how all hadrons fit together to create nuclei and other types of matter.

The quest to understand matter takes place through both theory and experiment, with both being necessary to develop a full understanding of the properties and behavior of matter. In the theoretical approach, scientists have developed a precise mathematical description of how the quarks and gluons in nuclear matter interact, referred to as Quantum Chromodynamics (QCD). On the experimental side, scientists accumulate a great deal of experimental data about the behavior of quarks and gluons as well as protons, neutrons, and nuclei in a variety of settings. Unlike Rutherford's table-top experiment, most of the experiments today require large facilities spanning acres. These particle accelerators slam bits of matter into each other, and scientists observe the results. The main differences from Rutherford's time are the ability to accelerate the bits of matter to much higher speeds, the variety of types of matter that can be used, and the sophistication of the instruments used in the observations. The careful integration and comparison of experimental measurements with theoretical calculations provides both insight into the behavior of matter and the information needed to test the validity of theoretical models.

Nuclear physics seeks to understand matter in all of its manifestations—not just the familiar forms of matter we see around us, but also such exotic forms as the matter that existed in the first moments after the creation of the universe and the matter that exists today inside neutron stars—and to understand why matter takes on the particular forms that it does. Nuclear physics has come to focus on three broad yet tightly interrelated areas of inquiry. These three areas are described in *The Frontiers of Nuclear Science*[a], a long range plan for nuclear science released in 2007 by the Nuclear Science Advisory Committee (NSAC). The plan represents a consensus within the nuclear science community about compelling scientific thrusts. The three frontiers the long range plan identified are:

[a] http://www.sc.doe.gov/np/nsac/nsac.html

- **Quantum Chromodynamics:** The focus of this frontier is to develop a complete understanding of how quarks and gluons assemble themselves into the various forms of matter and, as part of that process, to search for yet undiscovered forms of matter. While nuclear scientists want to know how quarks and gluons assemble to form matter, they also want to understand what happens when nucleons "melt." QCD predicts that nuclear matter can change its state in somewhat the same way that ordinary matter can change from solid to liquid to gas. This can happen when nucleons are compressed well beyond the density of atomic nuclei, as in the core of a neutron star, or when they are heated to the kind of extreme temperatures found in the early universe. One of the most startling recent discoveries is the creation of a new form of matter, thought to have existed in only moments after the birth of the universe under conditions of extreme temperature and density, and the fact that it behaves as an almost perfect liquid instead of a dilute gaseous plasma as originally hypothesized.
- **Nuclei and Nuclear Astrophysics:** Nuclear physicists seek to understand how protons and neutrons combine to form atomic nuclei and how these nuclei have arisen during the 13.7 billion years since the birth of the cosmos. The forces that bind protons and neutrons together into nuclei are immensely strong, with the result that nuclear processes such as nuclear fusion and fission can release huge amounts of energy. Looking inward, nuclear scientists seek a comprehensive description of the behavioral characteristics of multi-nucleon systems and marginally stable exotic nuclei not naturally found on earth. Looking outward, nuclear scientists seek to understand the nuclear processes that have shaped the cosmos, from the origin of the elements, the evolution of stars, and the detonation of supernovae, to the structure of neutron stars and the nature of matter at extreme densities. Nuclear scientists have taken great strides in nuclear astrophysics, for example by decreasing the limits of the age of the universe by about one billion years through studies of the reaction cross sections that control hydrogen burning in stars.
- **Fundamental Symmetries and Neutrinos:** Although the strong force plays the dominant role in the nucleus, it is not the only force that nuclear physicists must consider. Because protons (and quarks) are electrically charged, electromagnetism comes into play in such circumstances as proton-proton interactions, and the weak force is responsible for the transformation of protons into neutrons and vice versa. The three forces have been unified into a single theory, referred to as the Standard Model, which does an excellent job of explaining the interactions of the various fundamental particles. However, certain inadequacies of that theory have led physicists to begin developing a New Standard Model. In particular, nuclear physicists are interested in developing a better understanding of the fundamental properties of the neutron and of the neutrino, the nearly undetectable fundamental particle produced by the weak interaction that was first indirectly detected in nuclear beta decay. One of the most surprising results to come out of neutrino studies in the past many years was the discovery that electron neutrinos produced in the Sun are changing into a different type of neutrino, thus explaining the puzzling shortage of events seen in previous solar neutrino detectors and confirming models for solar energy production.

For over 50 years, this program and its predecessors have been at the forefront of the development and production of stable and radioactive isotope products that are now used worldwide. DOE applies its unique expertise and capabilities to address technology issues associated with the application, production, handling, and use of isotopes. Adequate supplies of medical and research isotopes are essential to maintain effective diagnosis, treatment, and research capabilities in the U.S. The program's products and services are sold to over 20 countries. The program produces isotopes only where there is no U.S. private sector capability or other production capacity is insufficient to meet U.S. needs.

Strategic and GPRA Unit Program Goals

The NP program has one Government Performance and Results Act (GPRA) Unit Program Goal which contributes to Strategic Goals 3.1 and 3.2 in the "goal cascade."

- GPRA Unit Program Goal 3.1/2.47.00—Explore Nuclear Matter—from Quarks to Stars—Understand the evolution and structure of nuclear matter, from the smallest building blocks, quarks and gluons, to the stable elements in the Universe created by stars; to unique isotopes created in the laboratory that exist at the limits of stability and possess radically different properties from known matter.

Contribution to GPRA Unit Program Goal 3.1/2.47.00, Explore Nuclear Matter - from Quarks to Stars

The NP subprograms (Medium Energy, Heavy Ion, Low Energy, Nuclear Theory, and Isotope Development and Production for Research and Applications) contribute to this goal by supporting innovative, peer-reviewed scientific research to advance knowledge and provide insights into the nature of energy and matter, and in particular, to investigate the fundamental forces that hold the nucleus of the atom together, and determine the detailed structure and behavior of atomic nuclei. NP contributes by building and supporting world-leading scientific facilities and state-of-the-art instruments necessary to carry out its basic research agenda. Scientific discoveries at the frontiers of nuclear physics further the Nation's energy-related research capacity, which in turn, provides for the Nation's security, economic growth and opportunities, and improved quality of life. The Isotope subprogram provides facilities and capabilities for the production of research and commercial stable and radioactive isotopes, scientific and technical staff associated with general isotope research and production, and a supply of critical isotopes to address the needs of the Nation.

The following indicators establish specific long-term goals in Scientific Discovery that NP is committed to, and progress can be measured against:

- Making precision measurements of fundamental properties of the proton, neutron, and simple nuclei for comparison with theoretical calculations to provide a quantitative understanding of their quark substructure;
- Searching for and characterizing the properties of the quark-gluon plasma by briefly recreating tiny samples of hot, dense nuclear matter;
- Investigating new regions of nuclear structure, studying interactions in nuclear matter like those occurring in neutron stars, and determining the reactions that created the nuclei of the chemical elements inside stars and supernovae; and
- Determining the fundamental properties of neutrinos and fundamental symmetries by using neutrinos from the sun and nuclear reactors and by using radioactive decay measurements.

Annual Performance Results and Targets

FY 2005 Results	FY 2006 Results	FY 2007 Results	FY 2008 Results	FY 2009 Targets	FY 2010 Targets
GPRA Unit Program Goal 3.1/2.47.00 – Explore Nuclear Matter, from Quarks to the Stars					
Maintained and operated Nuclear Physics scientific user facilities so the unscheduled operational downtime was 13%, on average, of total scheduled operating time. [Met Goal]	Maintained and operated Nuclear Physics scientific user facilities so the unscheduled operational downtime was 6%, on average, of total scheduled operating time. [Met Goal]	Maintained and operated Nuclear Physics scientific user facilities so the unscheduled operational downtime was 10.4%, on average, of total scheduled operating time. [Met Goal]	Achieve at least 80% average operation time of the scientific user facilities as a percentage of the total scheduled annual operating time. [Met Goal]	Achieve at least 80% average operation time of the scientific user facilities as a percentage of the total scheduled annual operating time.	Achieve at least 80% average operation time of the scientific user facilities as a percentage of the total scheduled annual operating time.
			Achieve within 10% for both the cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects. [Met Goal]	Achieve within 10% for both the cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects.	Achieve within 10% for both the cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects.
Medium Energy Nuclear Physics					
Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments in Hall A (2.83), Hall B (8.06), and Hall C (2.11), respectively, at the Continuous Electron Beam Accelerator Facility. [Met Goal]	Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments in Hall A (1.77), Hall B (9.9), and Hall C (1.9), respectively, at the Continuous Electron Beam Accelerator Facility. [Met Goal]	Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments in Hall A (2.49), Hall B (12.42), and Hall C (3.01) at the Continuous Electron Beam Accelerator Facility. [Met Goal]	Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments in Hall A, Hall B, and Hall C at the Continuous Electron Beam Accelerator Facility. FY 2008 Baseline: Hall A: 4.0; Hall B: 20.0; and Hall C: 5.0. [Met Goal]	Achieve at least 80% of the integrated delivered beam used effectively for experimental research in each of Halls A, B and C at the Continuous Electron Beam Accelerator Facility measured as a percentage of the scheduled delivered beam considered effective for each Hall.	Achieve at least 80% of the integrated delivered beam used effectively for experimental research in each of Halls A, B and C at the Continuous Electron Beam Accelerator Facility measured as a percentage of the scheduled delivered beam considered effective for each Hall.
				Achieve at least 80% of the projected integrated proton-proton collision luminosity sampled by each of the PHENIX and STAR experiments at the Relativistic Heavy Ion Collider, where the projected values take into account anticipated collider performance and detector data-taking efficiencies.	Achieve at least 80% of the projected integrated proton-proton collision luminosity sampled by each of the PHENIX and STAR experiments at the Relativistic Heavy Ion Collider, where the projected values take into account anticipated collider performance and detector data-taking efficiencies.

FY 2005 Results	FY 2006 Results	FY 2007 Results	FY 2008 Results	FY 2009 Targets	FY 2010 Targets
Heavy Ion Nuclear Physics					
Weighted average number (within 30% of baseline estimate) of millions of events sampled by the PHENIX (900) and recorded by the STAR (40) detectors, respectively, at the Relativistic Heavy Ion Collider. [Met Goal]	No Target. (The Relativistic Heavy Ion Collider did not operate in heavy ion mode during FY 2006)	Weighted average number (within 30% of baseline estimate) of millions of events sampled by PHENIX (5,100) and recorded by the STAR (86.6) detectors during the heavy ion run at the Relativistic Heavy Ion Collider. [Met Goal]	Weighted average number (within 30% of baseline estimate) of millions of heavy-ion collision events sampled by the PHENIX and recorded by the STAR detectors, respectively, at the Relativistic Heavy Ion Collider. FY 2008 Baseline: PHENIX sample=7,500; STAR recorded=60. [Met Goal]	No target. RHIC is not running heavy ion collisions in FY 2009.	Achieve at least 80% of the projected equivalent integrated proton-proton collision luminosity sampled by each of the PHENIX and STAR experiments at the Relativistic Heavy Ion Collider, where the projected values take into account anticipated collider performance and detector data-taking efficiencies.
Low Energy Nuclear Physics					
Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments at the Argonne Tandem Linac Accelerator System (28.1) and Holifield Radioactive Ion Beam (3.76) facilities, respectively. [Met Goal]	Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments at the Argonne Tandem Linac Accelerator System (24.6) and Holifield Radioactive Ion Beam (7.1) facilities. [Met Goal]	Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments at the Argonne Tandem Linac Accelerator System (27.6) and Holifield Radioactive Ion Beam (7.1) facilities. [Met Goal]	Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments at the Argonne Tandem Linac Accelerator System and Holifield Radioactive Ion Beam facilities, respectively. FY 2008 Baseline: ATLAS-22; HRIBF-2.4. [Met Goal]	Achieve at least 80% of the integrated delivered beam used effectively for all experiments run at each of the Argonne Tandem Linac Accelerator System and the Holifield Radioactive Ion Beam facilities measured as a percentage of the scheduled delivered beam considered effective for each facility.	Achieve at least 80% of the integrated delivered beam used effectively for all experiments run at each of the Argonne Tandem Linac Accelerator System and the Holifield Radioactive Ion Beam facilities measured as a percentage of the scheduled delivered beam considered effective for each facility.

Subprograms

To accomplish its mission and address the scientific challenges described above, the Nuclear Physics program is organized into five subprograms: Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, Nuclear Theory, and Isotope Development and Production for Research and Applications.

- The *Medium Energy* subprogram primarily explores the frontier of QCD with research conducted at two NP national user facilities and other facilities worldwide. The Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility (TJNAF or JLab) provides high quality beams of polarized electrons that allow scientists to extract information on the quark and gluon structure of protons and neutrons. CEBAF also uses polarized electrons to make precision measurements of parity violating processes that can provide information relevant to the development of the New Standard Model. The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) provides colliding beams of spin-polarized protons to probe the spin structure of the proton, another important aspect of the QCD frontier. This subprogram supports one university Center of Excellence with infrastructure capabilities to develop advanced instrumentation and accelerator equipment.
- The *Heavy Ion* subprogram also investigates the frontier of QCD, but with a different approach—by trying to recreate and characterize new and predicted forms of matter and other new phenomena that might occur in extremely hot, dense nuclear matter and which have not existed since the Big Bang. Measurements are carried out primarily using relativistic heavy ion collisions at RHIC. Participation in the heavy ion program at the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) provides U.S. researchers the opportunity to search for new states of matter under substantially different initial conditions than those provided by RHIC, yet still provide information regarding the matter that existed during the infant universe.
- The *Low Energy* subprogram studies the frontiers of Nuclear Structure and Astrophysics and Fundamental Symmetry and Neutrinos. Two NP national user facilities are pivotal in making progress in these frontiers. The Argonne Tandem Linac Accelerator System (ATLAS) at Argonne National Laboratory (ANL) is used to study questions of nuclear structure by providing high-quality beams of all the stable elements up to uranium and selected beams of short-lived nuclei for experimental studies of nuclear properties under extreme conditions and reactions of interest to nuclear astrophysics. The Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory (ORNL) provides beams of short-lived radioactive nuclei that scientists use to study exotic nuclei that do not normally exist in nature. HRIBF is also used to explore reactions of interest to nuclear astrophysics. The future Facility for Rare Isotope Beams (FRIB) is a next-generation machine that will advance the understanding of rare nuclear isotopes and the evolution of the cosmos. The subprogram supports four university Centers of Excellence, three with unique low energy accelerator facilities and one with infrastructure capabilities for developing advanced instrumentation. The program also partners with the National Reconnaissance Office and the United States Air Force to support limited operations of the 88-Inch Cyclotron at the Lawrence Berkeley National Laboratory (LBNL) for a small in-house research program and to meet national security needs.

  Also within the portfolio of this subprogram are experiments designed to develop a better understanding of the properties of neutrinos and, in particular, of their masses. This science is typically explored with large detectors buried underground to shield them so that they can detect rare particle signals. Measurements of symmetry properties, particularly the symmetry properties of the neutron, are carried out by nuclear physicists at the Spallation Neutron Source (SNS) at ORNL.

- The *Nuclear Theory* subprogram provides the theoretical underpinning needed to support the interpretation of a wide range of data obtained from all the other NP subprograms and to advance new ideas and hypotheses that stimulate experimental investigations. This subprogram supports the Institute for Nuclear Theory (INT) at the University of Washington, where leading nuclear theorists are assembled from across the Nation to focus on key frontier areas in nuclear physics. The subprogram also collects, evaluates, and disseminates nuclear physics data for basic nuclear research and for applied nuclear technologies with its support of the National Nuclear Data Center (NNDC). The extensive nuclear databases produced by this effort are an international resource consisting of carefully organized scientific information gathered from over 50 years of low-energy nuclear physics research worldwide.
- The *Isotope Development and Production for Research and Applications* subprogram supports the production and development of production techniques of radioactive and stable isotopes that are in short supply. Isotopes are high-priority commodities of strategic importance for the Nation and are essential for energy, medical, and national security applications and for basic research. A goal of the program is to make critical isotopes more readily available to meet domestic U.S. needs. This subprogram is steward of the Isotope Production Facility (IPF) at Los Alamos National Laboratory (LANL), the Brookhaven Linear Isotope Producer (BLIP) facility at BNL, and hot cell facilities for processing isotopes at ORNL, BNL, and LANL. The subprogram also coordinates and supports isotope production at a suite of university, national laboratory, and commercial accelerator and reactor facilities throughout the Nation to promote a reliable supply of domestic isotopes. The National Isotope Data Center (NIDC) at ORNL manages the coordination of isotope production across the many facilities and the business operations of the sale and distribution of isotopes.

Benefits

Nuclear science basic research is inherently relevant to a broad suite of applications that are important to the Nation. The advancement of knowledge of nuclear matter and its properties is intertwined with nuclear power, nuclear medicine, national security, the environmental and geological sciences, and isotope production. The NP program develops advanced instrumentation, accelerator technologies and techniques, and analytical and computational techniques that are needed for nuclear science research and which have broad societal and economic benefits.

History shows that research into the nucleus has led to a number of valuable applications with practical benefits to society. The realization that the nucleus contains a tremendous amount of energy led to the development of both nuclear power and the atomic bomb. Some of the cutting-edge instrumentation being developed for nuclear physics experiments, such as high-resolution gamma ray detectors, can provide improved imaging techniques with important applications in combating terrorism. The discovery and understanding of nuclear spin made possible the development of magnetic resonance imaging for medical use. Medical imaging, cancer therapy, and biochemical studies all rely on isotopes produced in accelerators that were first developed for nuclear research. Particle beams are used for cancer therapy and in a broad range of materials science studies.

Valuable applications have resulted from research into isotopes and nuclear radiation, which made possible the entire field of nuclear medicine used today in both the diagnosis and treatment of disease. Each day, over 40,000 medical patients receive nuclear medicine procedures. R&D investment has fueled the development of new isotopes and applications, including those for heart and lung imaging, cancer therapy, smoke detectors, neutron detectors, special nuclear material and explosive detection, oil exploration, industrial radiography, and tracers for climate change. The federal support of isotope development and production has reduced health care costs; for example, it has been demonstrated that the use of myocardial perfusion heart imaging in emergency department chest pain centers can reduce duration of stay on average from 1.9 days to 12 hours with a simultaneous reduction in charges. The applications resulting from isotope research have improved the ability of physicians to diagnose illnesses and improved the quality of life for innumerable patients, while at the same time strengthening national security.

Yet another societal benefit of the NP program is the boost to the Nation's R&D workforce through its support of undergraduate researchers, graduate students working toward an advanced degree, and postdoctoral associates developing their research and management expertise. These researchers provide new talent in research and help meet the demand for skilled personnel in a wide variety of technical, medical, security, and industrial fields that require the unique problem-solving abilities and the computational and technical skills developed through an education and experience in nuclear science. Approximately half of the scientists trained as nuclear physicists are found in such diverse areas as energy, nuclear medicine, commerce, medical physics, space exploration, finance, and national security.

Program Planning and Management

To ensure that funding is allocated as efficiently as possible, the NP program has developed a system of planning and priority setting that relies heavily on input from groups of outside experts. NP has also instituted a number of peer review and oversight measures designed to assess productivity and maintain effective communication and coordination among participants in NP activities. On an as-needed basis, the program has taken the initiative to establish working groups amongst federal agencies to tackle issues of common interest and enhance communication. The NP program takes all of this input into account in its budget requests, making decisions to maximize scientific impact, productivity, quality, and cost-effectiveness within the resources available.

The NP program works closely with NSF to jointly charter the Nuclear Science Advisory Committee (NSAC) for advice regarding compelling opportunities and productivity of the national nuclear science program. NP develops its strategic plan for the field with input from the scientific community via long range plans produced by NSAC every five to six years. These plans perform retrospective assessments of major accomplishments, assess and identify scientific opportunities, and set priorities for the next decade. NSAC provides NP with additional guidance in the form of reviews of subfields, special interest topics, and assessment of the management of the NP program itself. Over the past few years, NSAC has provided guidance regarding opportunities in neutrino science, performance measures to assess productivity of the field, and the effectiveness of the NP program management through a Committee of Visitors review. Ongoing NSAC activities currently include the prioritization of research opportunities with isotopes and the development of a long-term strategic plan for isotope production.

NP strategic plans are also influenced by National Academies reports and Office of Science and Technology Policy (OSTP) Interagency Working Group (IWG) efforts. The 2007 National Academies study *Advancing Nuclear Medicine through Innovation*[a] motivated NP to establish a federal working group with the National Institutes of Health (NIH), along with the Office of Science (SC) Office of Biological and Environmental Research, to better coordinate radioisotope production and to address other issues important to nuclear medicine. The National Academies is embarking on a new decadal study of nuclear science in 2009. In order to optimize interagency activities, NP is involved in two OSTP IWG's: *The Physics of the Universe* and *Large Scale Science.*

---

[a] http://dels.nas.edu/dels/rpt_briefs/advancing_nuclear_medicine.pdf

The NP program peer reviews all of its activities. Annual science and technology reviews of the national user facilities and isotope production facilities with panels of international peers assess operations, performance, and scientific productivity. These results influence budget decisions and the NP program's assessment of the laboratory performance documented in annual SC laboratory appraisals. Annual reviews of instrumentation projects, conducted by international experts, focus on scientific merit, technical status and feasibility, cost and schedule, and effectiveness of management organizations. The NP program conducted 17 reviews with panels of international experts in FY 2008. Performance of instrumentation projects are also assessed on a monthly and quarterly basis.

One of the most pressing priority-setting issues at the national user facilities is how to allocate available beam time, or time spent doing experiments on a facility's accelerator. Facility directors seek advice from Program Advisory Committees (PACs) to determine the allocation of this scarce scientific resource. The PACs review research proposals requesting resources and time at the facilities and then provide advice on the scientific merit, technical feasibility, and personnel requirements of the proposals.

The university grants program is proposal driven. The Nuclear Physics program funds the best and most promising of those ideas submitted in response to grant solicitation notices. Proposals are reviewed by external scientific peers and competitively awarded according to the guidelines published in 10 CFR 605. The quality and productivity of university grants are peer reviewed on a three-year basis. Laboratory groups performing research are peer reviewed on a four-year basis to examine the quality of research and to identify needed changes, corrective actions, or redirections of effort. Funding decisions in this budget request are influenced by the results of these periodic peer reviews of the national laboratory research efforts. The most recent review of laboratory research groups was in 2008, for the Heavy Ion subprogram.

Basic and Applied R&D Coordination

The knowledge, data, techniques, and methods of nuclear science are utilized in a broad portfolio of applications, including energy, waste disposal, nuclear medicine, commerce, medical physics, space exploration, finance, geology, environmental sciences, national security, and others. NP supports targeted initiatives in Applications of Nuclear Science and Technology. The primary goal of these initiatives is to pursue forefront nuclear science research and development important to the NP mission, but inherently relevant to applications. These initiatives are peer reviewed with participation from relevant federal agencies that directly support, and researchers that conduct, the applied sciences. The integration of the underpinning nuclear science advances resulting from innovative basic research to the applied sciences optimizes communication, cost effectiveness, performance, and technology transfer.

The Isotope Development and Production for Research and Applications subprogram is an excellent example of basic and applied R&D coordination. The subprogram produces commercial and now research isotopes that are important for basic research and applications. Since the program was transferred from the Office of Nuclear Energy to NP in FY 2009, NP has taken significant steps in aligning the industrial and research stakeholders of the isotope program with each other and with the nuclear science research community, all of whom can contribute collectively in advancing the technology of this field. NP sponsored a workshop in August 2008 to bring together all the stakeholder communities in the production and use of radioactive and stable isotopes. A report entitled *Workshop on the Nation's Needs for Isotopes: Present and Future*[a] documents the proceedings and outcomes of this workshop. Working with industry, NP has defined a path forward for ensuring the long-term availability of Californium-252, an isotope of strategic and economic importance to the Nation. NP is working with

[a] http://www.sc.doe.gov/np/program/isotope.html

NIH to develop strong communications and a mechanism for developing plans and priorities regarding medical isotope production. Research was initiated in FY 2009 to support the development of alternative production and extraction techniques of stable and radioactive isotopes and is continued in FY 2010. Also continued in FY 2010 is research that was initiated in FY 2009 to support the production of research isotopes identified by NSAC as needed for high priority research opportunities across a broad range of scientific disciplines.

Budget Overview

Today, NP is the largest federal steward for basic research in nuclear science, operating four national user facilities, as well as supporting isotope production and development for the Nation. The FY 2010 budget request of $552,000,000 is designed to optimize, within these resources and in the context of peer review, the scientific productivity of the program by ensuring a proper balance of research workforce, facility operations, and investments in advanced technology and capabilities.

The heart of the Nuclear Physics program is the group of highly trained scientists who conceive, plan, execute, and interpret the numerous experiments carried out at various nuclear physics facilities. The NP program supports scientists at both universities and national laboratories and is involved in a variety of international collaborations, and supports approximately two-thirds of the Nation's university researchers and graduate students who are doing fundamental nuclear physics research. More than 2,000 researchers and students at approximately 100 U.S. academic, federal, and private-sector institutions are supported. Research activities are conducted at approximately 85 academic institutions located in 34 states and the District of Columbia, as well as at 9 DOE laboratories in 8 states. Approximately 80 Ph.D. degrees are granted annually to students for research supported by the program. Six university Centers of Excellence provide unique hands-on training opportunities for junior scientists. The Outstanding Junior Investigator (OJI) program, initiated in FY 2000, makes approximately three new awards each year to early career tenure-track faculty and has been very successful in identifying, recognizing, and supporting promising junior university faculty and future leaders of the field.

NP supports research groups at nine national laboratories: Argonne, Brookhaven, Idaho, Thomas Jefferson, Los Alamos, Lawrence Berkeley, Lawrence Livermore, Oak Ridge and Pacific Northwest National Laboratories. National laboratory research is guided by the DOE mission and priorities and is the underpinning of strategic core competencies needed for the NP program. The national laboratory scientists work and collaborate with academic scientists, other national laboratory experimental researchers, and those carrying out theoretical investigations. The national laboratory scientists collect and analyze data as well as support and maintain the detectors and facilities used in these experiments. The national laboratories also provide state-of-the-art resources for the detector and accelerator R&D that paves the way for future upgrades and new facilities.

Investigating the frontiers of nuclear physics requires being able to accelerate various particles, such as protons, electrons, or a variety of ions, up to nearly the speed of light, smashing them into other particles, and then observing the results of the collisions. Exploring the various areas of nuclear physics demands having a variety of accelerators, each designed to examine the subatomic world in its own unique way and containing a variety of particle detectors and other equipment. Thus, NP supports a suite of facilities that complement one another and provide a variety of approaches to producing and collecting data about matter at the level of the nucleus, as well as the sub-nuclear level. The necessary equipment is large, complex, and expensive to build and operate, and thus it accounts for a significant portion of the program's budget. NP also supports collaborative work at foreign accelerator facilities, as well as joint development of instrumentation.

NP supports four national user facilities (RHIC, CEBAF, ATLAS, and HRIBF), each with capabilities found nowhere else in the world, that provide research time for scientists at universities and other federal laboratories. These major international facilities provide research beams for a user community of over 3,000 scientists from all over the world, with more than 2,000 of the users utilizing RHIC and CEBAF. Approximately 40% of the users are from institutions outside of the U.S., and often provide experimental equipment or instrumentation. A number of other SC programs, DOE offices (National Nuclear Security Administration and Nuclear Energy), federal agencies (NSF, NASA, and Department of Defense), and industries use the NP user facilities to carry out their own programs.

The FY 2010 budget request will support near optimal levels of operations at the national user facilities allowing progress towards achieving performance goals defined by the 2008 *Report to NSAC of the Subcommittee on Performance Measures*[a] for nuclear science. The facilities will provide an estimated 19,930 hours of beam time for research, an increase of ~2,285 hours compared with the anticipated beam hours in FY 2009. The major scientific user facilities will be maintained and operated so that the unscheduled operational downtime will be kept to less than 20%, on average, of total scheduled operating time. Investments will be made in programmatic infrastructure, facility equipment, and accelerator improvement projects that will increase reliability, cost-effectiveness, and productivity, and provide new capabilities to pursue high discovery science.

The only investment in construction is the continuation of the 12 GeV CEBAF Upgrade project, the highest priority in the NSAC Long Range Plan for Nuclear Science. Conceptual design and R&D also continue for the proposed Facility for Rare Isotope Beams (FRIB), a next generation nuclear structure and astrophysics machine that will map out the nuclear landscape. Approximately 4% of the total budget is invested in a handful of small-scale Major Items of Equipment (MIE) projects, all less than $20,000,000, in order to position the program strategically for the future to address compelling scientific opportunities identified by NSAC. The majority of these MIEs are collaborative in nature, with the DOE investment leveraged by contributions from other agencies and international partners. Two new MIEs are initiated in FY 2010: the STAR Heavy Flavor Tracker to study the new hot, dense matter created at RHIC, and the Rare Isotope Beam Science Initiatives to invest in forefront science opportunities at world-leading rare isotope beam facilities around the world.

Significant Program Shifts

The Isotope Production and Applications program was transferred from the Office of Nuclear Energy to NP in the FY 2009 Appropriation. The budget request for this program is presented in FY 2010 reflecting the approach of the rest of the Nuclear Physics subprograms that focus on research and operations, and the program is renamed “Isotope Development and Production for Research and Applications” to more accurately reflect its mission.

[a] http://www.sc.doe.gov/np/nsac/nsac.html

Medium Energy Nuclear Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Medium Energy Nuclear Physics			
Research			
University Research	17,712	19,009	20,443
National Laboratory Research	15,235	17,848	19,664
Other Research[a]	519	5,936	7,048
Total, Research	33,466	42,793	47,155
Operations			
TJNAF Operations	71,740	78,959	83,854
Bates Facility	2,000	—	—
Total, Operations	73,740	78,959	83,854
Total, Medium Energy Nuclear Physics	107,206	121,752	131,009

Description

The Medium Energy Nuclear Physics subprogram focuses primarily on questions having to do with Quantum Chromodynamics (QCD) and the behavior of quarks inside protons and neutrons, although it touches on all three scientific frontiers. Specific questions that are being addressed include: *What is the internal landscape of the nucleons? What does QCD predict for the properties of strongly interacting matter? What governs the transition of quarks and gluons into pions and nucleons? What is the role of gluons and gluon self-interactions in nucleons and nuclei?* One major goal, for example, is to achieve an experimental description of the substructure of the proton and the neutron. In pursuing that goal the Medium Energy subprogram supports different experimental approaches that seek to determine such things as: the distribution of up, down, and strange quarks in the nucleons; the roles of the gluons that bind the quarks; the role of the "sea" of virtual quarks and gluons, which makes a significant contribution to the properties of protons and neutrons; the effects of the quark and gluon spins within the nucleon; and the effect of the nuclear environment on the quarks and gluons. The subprogram also measures the excited states of hadrons (composite particles made of quarks, including nucleons) in order to identify which properties of QCD determine the dynamic behavior of the quarks.

The subprogram supports investigations into a few aspects of the second frontier, nuclei and nuclear astrophysics, such as the question: *What is the nature of the nuclear force that binds protons and neutrons into stable nuclei?* The subprogram also examines certain aspects of the third area, fundamental symmetries and nuclei, including the questions: *Why is there now more visible matter than antimatter in the universe? What are the unseen forces that were present at the dawn of the universe, but disappeared from view as it evolved?*

[a] In FY 2008, $3,691,000 was transferred to the SBIR program and $1,130,000 was transferred to the STTR program. This activity includes $3,663,000 for SBIR and $1,246,000 for STTR in FY 2009 and $4,259,000 for SBIR and $1,346,000 for STTR in FY 2010.

Funding supports both research and operations of the subprogram's primary research facility, CEBAF, while only research is supported at RHIC. Research support at both facilities includes the laboratory and university personnel needed to implement and run experiments and to conduct the data analysis necessary to publish results. Individual experiments are supported at the High Intensity Gamma Source (HIγS) at Triangle University Nuclear Laboratory, at Fermi National Accelerator Laboratory (Fermilab), and at several facilities in Europe. All these facilities produce beams of sufficient energy (that is, of small enough wavelength) to see details smaller than the size of a nucleon.

Selected FY 2008 Accomplishments

- A recent measurement from TJNAF may have a bearing on the property of neutron stars as well as advancing our knowledge about the interactions of neutrons and protons inside nuclei. This measurement found that high momentum protons inside a nucleus are 20 times more likely to pair with neutrons than other protons. A theoretical calculation that includes this pairing effect inside neutron stars indicates that it could have a significant effect on the star's structure.
- Significant progress has been made on one of NP's research milestones to determine the gluon contribution to the proton's spin. A new global analysis of the world's existing data that includes recent measurements made at RHIC and TJNAF indicates that while the magnitude of the gluon polarization inside the proton is small, less than 10%, the polarization may change sign. If true, this change in sign would be important in understanding how the gluons are polarized. Resolving this question will require the higher statistical data expected from RHIC in the next few years.
- TJNAF has developed a new mode of running CEBAF in which the two linear accelerators are operated at different energies. This new operating mode allows the facility greater flexibility in providing optimized beam energies and polarizations to the three halls increasing overall scientific productivity of the facility.

Detailed Justification

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Research	**33,466**	**42,793**	**47,155**
▪ **University Research**	**17,712**	**19,009**	**20,443**

These activities comprise a broad program of research, and include support of about 180 scientists and 150 graduate students at 38 universities in 22 states and the District of Columbia. Of this amount, $2,000,000 supports the MIT Research and Engineering (R&E) Center that has specialized infrastructure for fabrication of scientific instrumentation.

	FY 2008	FY 2009	FY 2010
▪ **National Laboratory Research**	**15,235**	**17,848**	**19,664**

This funding supports research groups at TJNAF, BNL, ANL, and LANL that carry out research at CEBAF and RHIC. It also supports two experiments at Fermilab and nuclear research using laser trapping technology at ANL.

	FY 2008	FY 2009	FY 2010
• **TJNAF Research**	**6,141**	**6,150**	**7,153**

This funding allows TJNAF staff to carry out their research efforts in the CEBAF experimental Halls A, B, and C. The remaining approximately 70% of the support for these staff is under Experimental Support discussed below. It also supports an active visiting scientist program at the

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010

laboratory and bridge positions with regional universities. The $1,003,000 increase in FY 2010 will add new staff for the new Hall D experimental hall to be built as part of the 12 GeV CEBAF Upgrade, and restore the visiting scientist and university programs that have been reduced the past several years.

• **Other National Laboratory Research**	**9,094**	**11,698**	**12,511**

Argonne National Laboratory scientists continue their primary research program at TJNAF, as well as one experiment at Fermilab, to search for a detailed understanding of the internal quark-gluon structure of the nucleon. ANL scientists are also using their unique laser atom-trapping technique to make a precision measurement of the atomic electric dipole moment that could shed light on the excess of matter over antimatter in the universe.

Support is provided to the RHIC spin physics research groups at BNL and LANL, which have important roles and responsibilities in the RHIC program.

At LANL, support is provided to allow scientists and collaborators to complete the Fermilab MiniBooNE anti-neutrino running and analysis, and to continue to develop a transition plan for future neutrino research.

▪ **Other Research**	**519**	**5,936**	**7,048**
• **SBIR/STTR and Other**	**519**	**5,686**	**6,418**

In FY 2008, $3,691,000 was transferred to the Small Business Innovation Research (SBIR) program and $1,130,000 was transferred to the Small Business Technology Transfer (STTR) program. This activity includes $3,663,000 for SBIR and $1,246,000 for STTR in FY 2009 and $4,259,000 for SBIR and $1,346,000 for STTR in FY 2010 as well as other established obligations that the Medium Energy Nuclear Physics subprogram must meet.

• **Accelerator R&D Research**	**—**	**250**	**630**

The Medium Energy Accelerator R&D Research at universities and laboratories will develop the knowledge, technologies, and trained scientists to design and build the accelerator facilities needed to carry out a forefront experimental program and to accomplish the DOE programmatic mission in nuclear physics.

Operations	**73,740**	**78,959**	**83,854**
▪ **TJNAF Operations**	**71,740**	**78,959**	**83,854**

Funding supports CEBAF operations and Experimental Support for 5,110 hours and 3-Hall operations schedule, a 3% increase from estimated running in FY 2009, increasing the utilization of the facility to 85%.

• **TJNAF Accelerator Operations**	**45,510**	**49,900**	**54,540**

Support is provided for operation ($49,000,000), capital investments ($840,000) and accelerator improvements ($3,200,000) to the CEBAF accelerator complex, and to maintain efforts in developing advances in superconducting radiofrequency technology ($1,500,000). A significant

		FY 2008	FY 2009	FY 2010

part of the increase in FY 2010 is due to power costs which are expected to be about $1,600,000 over FY 2009, which was up $2,900,000 over FY 2008.

	FY 2008	FY 2009	FY 2010
CEBAF Hours of Operation with Beam			
Achieved Operating Hours	3,914	N/A	N/A
Planned Operating Hours	3,500	4,965	5,110
Optimal Hours	5,600	5,980	5,980
Percent of Optimal Hours	70%	83%	86%
Unscheduled Downtime	8.0%	N/A	N/A
Number of Users	1,313	1,350	1,390

	FY 2008	FY 2009	FY 2010
• **TJNAF Experimental Support**	**26,230**	**29,059**	**29,314**

The FY 2010 request supports Experimental Support ($24,614,000) efforts at the level needed for 5,110 hours and a 3-Hall operations schedule. Support is provided for the scientific and technical staff, materials, and services for CEBAF, and to integrate assembly, modification, and disassembly of large and complex experiments. This includes the delivery or dismantling of cryogenic systems, electricity, water for cooling, radiation shielding, and special equipment for specific experiments.

FY 2010 funds for capital equipment ($4,700,000) are used for fabrication, assembly and installation of scientific instrumentation in the experimental halls, such as polarized targets, spectrometer systems, and new detectors. The Q_{weak} detector system being fabricated will perform a precision measurement of the weak charge of the proton. This support is necessary to implement high priority experiments in the current 6 GeV experimental program prior to the 12 GeV CEBAF Upgrade project installation.

	FY 2008	FY 2009	FY 2010
▪ **Bates Facility**	**2,000**	**—**	**—**

User facilities operations of the Bates Linear Accelerator Center at the Massachusetts Institute of Technology were terminated in FY 2005. The final funding increment for transfer of ownership of the facility was provided in FY 2008 as part of the agreement that turned ownership of the facility over to MIT in FY 2009 in exchange for MIT assuming responsibility for all future D&D activities and liability for the facility.

	FY 2008	FY 2009	FY 2010
Total, Medium Energy Nuclear Physics	**107,206**	**121,752**	**131,009**

Explanation of Funding Changes

	FY 2010 vs. FY 2009 ($000)
Research	
▪ **University Research**	
The increase in FY 2010 funding will provide additional university support (the equivalent of about nine new grants) for research at TJNAF, RHIC and Fermilab, and revitalization of university equipment and infrastructure.	+1,434
▪ **National Laboratory Research**	
The increase in FY 2010 funding supports the ANL and BNL Medium Energy research groups at levels needed to carryout their existing research programs and support a new experiment at Fermilab and a new experiment at TJNAF.	+1,816
▪ **Other Research**	
• SBIR/STTR and Other increases at levels required proportionate to research and development activities.	+732
• Increased Accelerator R&D research funding is provided for R&D efforts to develop the knowledge, technologies and trained scientists needed to design and build the accelerator facilities in order to accomplish the programmatic mission in nuclear physics, including feasibility efforts associated with a potential Electron-Ion Collider.	+380
Total, Other Research	**+1,112**
Total, Research	**+4,362**
Operations	
▪ **TJNAF Operations**	
• **TJNAF Accelerator Operations**	
FY 2010 funding operates CEBAF at levels needed to carry out the highest priority experiments within the current 6 GeV program. Increased funding covers cost of living plus $1,600,000 for increased power costs and a slight increase in operating hours.	+4,640
• **TJNAF Experimental Support**	
Increased funding primarily supports additional experimental capital equipment for the highest priority experiments within the current CEBAF 6 GeV program.	+255
Total, Operations	**+4,895**
Total Funding Change, Medium Energy Nuclear Physics	**+9,257**

Heavy Ion Nuclear Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Heavy Ion Nuclear Physics			
Research			
University Research	13,016	13,984	15,351
National Laboratory Research	22,896	27,174	30,494
Other Research[a]	—	5,612	6,817
Total, Research	35,912	46,770	52,662
Operations			
RHIC Operations	137,041	148,859	160,180
Other Operations	9,283	4,744	6,714
Total, Operations	146,324	153,603	166,894
Total, Heavy Ion Nuclear Physics	182,236	200,373	219,556

Description

The Heavy Ion Nuclear Physics subprogram focuses on studies of nuclear matter at extremely high densities and temperatures. A new program of research on hot nuclear matter began at the Relativistic Heavy Ion Collider (RHIC) at BNL in 2000 when the first collisions of counter-circulating gold nuclei were observed at beam energies ten times higher than those available at any other facility in the world. At RHIC, beams of gold nuclei are accelerated to close to the speed of light and then slammed head on into one another in order to create extremely high-energy collisions between pairs of gold nuclei. In the aftermath of these collisions researchers have seen signs of the same quark-gluon soup that is believed to have existed shortly after the Big Bang. With careful measurements, scientists accumulate data that offer insights into those brief moments immediately following the creation of the universe and begin to understand how the protons, neutrons, and other bits of normal matter developed from that soup.

The RHIC facility puts heavy ion research at the energy frontier of nuclear physics. RHIC serves two large-scale international experiments called PHENIX and STAR. In these experiments, scientists are now trying to determine the physical characteristics of the recently discovered perfect liquid of quarks and gluons. A 10-fold enhancement in the heavy ion beam collision rate and detector upgrades are expected to be completed within the next 5 years. Accelerator R&D is being conducted at RHIC in a number of advanced areas including cooling of high-energy hadron beams, high intensity polarized electron sources, and high-energy, high-current energy recovery linear (ERL) accelerators. The RHIC facility is used by about 1,200 DOE-, NSF-, and foreign agency-supported researchers.

The Large Hadron Collider (LHC) at CERN offers opportunities for making new discoveries in relativistic heavy ion physics. The LHC will provide a 30-fold increase in center-of-mass energy over what is available now. Scientists are preparing to conduct research using A Large Ion Collider Experiment (ALICE) and the Compact Muon Spectrometer (CMS). U.S. researchers are fabricating a

[a] In FY 2008, $4,390,000 was transferred to the SBIR program. This activity includes $5,296,000 for SBIR in FY 2009 and $5,481,000 for SBIR in FY 2010.

large Electromagnetic Calorimeter (EMCal) detector to be installed in phases in the ALICE experiment over the next few years. First heavy ion beam operations at the LHC are expected to start in 2010.

The RHIC and LHC research programs are directed primarily at answering the overarching questions that define the first frontier identified by the nuclear science community—Quantum Chromodynamics (QCD). The fundamental questions addressed include: *What are the phases of strongly interacting matter, and what roles do they play in the cosmos? What governs the transition of quarks and gluons into pions and nucleons? What determines the key features of QCD, and what is their relation to the nature of gravity and spacetime?*

Selected FY 2008 Accomplishments

- The wealth of heavy ion data from the years of operation of the RHIC collider has appeared in more than 200 scientific publications and these results are leading to a paradigm that the matter produced in highly energetic nucleus-nucleus collisions acts like a perfect liquid with minimum viscosity.

  Scientists are now trying to determine the physical characteristics of this perfect liquid. The temperature is one of the most important of these characteristics, for it is a measure of the average energy of the particles inside this liquid. Energetic photons (or light) emanating from this perfect liquid have been observed. These data suggest that the initial fluid temperature may correspond to an energy of about 600 MeV which is far greater than the critical temperature thought necessary for the formation of the quark-gluon plasma. This is approximately 500,000 times greater than the energy of particles in the core of the sun!
- In FY 2008, RHIC delivered high intensity beams of gold and deuterium ions. RHIC continued to exceed accelerator performance in each successive mode of operations. A new record of delivered luminosity (about 238 inverse nanobarns [nb^{-1}]) at a beam energy of 100 GeV per nucleon was achieved. This record is almost ten times the delivered luminosity of the previous run with the same colliding beam species of gold on gold in 2004. RHIC has also successfully demonstrated gold ion collisions at very low energy (about 1/2 normal injection energy of 9 GeV). Future low energy, heavy ion beam R&D could allow scientists to search for the postulated critical point in the QCD phase diagram of nuclear matter.
- Increased beam luminosity of heavy ion beams has been successfully demonstrated at RHIC using longitudinal stochastic cooling in one of the accelerator rings. Accelerator scientists expect the planned implementation of longitudinal and transverse stochastic cooling to both accelerator rings, together with a new 56 MHz storage radiofrequency system, will provide a 10-fold increase in gold beam luminosity by 2012 without the need for the previously envisioned RHIC II upgrade, saving the federal government an anticipated $100,000,000 investment.

Detailed Justification

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Research	**35,912**	**46,770**	**52,662**
▪ **University Research**	**13,016**	**13,984**	**15,351**

Research support is provided for about 120 scientists and 90 graduate students at 27 universities in 21 states. Funding supports research efforts at RHIC and the continuation of a modest program at the LHC. The university groups provide scientific personnel and graduate students needed for running

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010

the RHIC and LHC heavy ion experiments, data analysis and publishing RHIC results, and designing and fabricating the RHIC and LHC heavy ion detector upgrades.

	FY 2008	FY 2009	FY 2010
▪ **National Laboratory Research**	**22,896**	**27,174**	**30,494**

This funding supports research groups at BNL, LBNL, LANL, ORNL, and LLNL that carry out research primarily at RHIC and a modest program at the LHC. These scientists provide essential personnel for designing, fabricating, and operating the RHIC detectors; analyzing RHIC data and publishing scientific results; conducting R&D of innovative detector designs; project management and fabrication of MIEs and planning for future experiments. Also, BNL and LBNL provide substantial computing infrastructure for terabyte-scale data analysis and state-of-the-art facilities for detector and instrument development. During FY 2008, the five laboratory groups were reviewed and evaluated based on the significance of their accomplishments and the merit of future programs; the results of the review influence funding decisions of individual groups.

	FY 2008	FY 2009	FY 2010
• **BNL RHIC Research**	**9,187**	**9,737**	**8,982**

The FY 2010 budget request allows BNL scientists to continue to provide maintenance and infrastructure support of the RHIC experiments, to develop and implement new instrumentation, to effectively utilize the beam time for research, to train junior scientists, and to develop the computing infrastructure for use by the scientific community. The PHENIX Silicon Vertex Tracker (VTX) MIE, a joint project with the Japanese, received its final funding increment under the American Recovery and Reinvestment Act (Recovery Act) and is planned for completion in FY 2010. It is a barrel of silicon pixel and strip detectors that will provide precision measurement of heavy quark production to study the thermalization process in the heavy ion collisions. The PHENIX Forward Vertex Detector (FVTX) MIE also received its final funding under the Recovery Act and continues fabrication in FY 2010. Important for both the heavy ion and spin programs, this detector will provide vertex tracking capabilities to PHENIX by adding two silicon endcaps. The STAR Heavy Flavor Tracker (HFT) is a new MIE initiated in FY 2010. It is an ultra-thin, high-precision tracking detector that will provide direct reconstruction of short-lived particles containing heavy quarks. Support is also provided in FY 2010 for continued studies directed at developing the scientific case for a potential electron-heavy ion collider facility.

	FY 2008	FY 2009	FY 2010
• **Other National Laboratory Research**	**13,709**	**17,437**	**21,512**

Researchers at LANL, LBNL, LLNL, and ORNL provide unique expertise and facilities for RHIC and LHC detector upgrades and analyses of data. For example, at LBNL, the large scale computational system, Parallel Distributed Systems Facility (PDSF), is a major resource used for the analysis of RHIC and LHC data, in alliance with the National Energy Research Scientific Computing Center (NERSC). At LLNL, computing resources are made available for the PHENIX and LHC data analysis. LBNL staff led the fabrication of the LHC Heavy Ion MIE, a joint project with France and Italy that adds a large Electromagnetic Calorimeter (EMCal) to the CERN ALICE experiment to provide the capability to study energy loss in the quark gluon plasma. This support continues in FY 2010 according to the planned profile.

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
▪ **Other Research**	**—**	**5,612**	**6,817**
• **SBIR and Other**	**—**	**5,362**	**5,547**

In FY 2008, $4,390,000 was transferred to the Small Business Innovative Research (SBIR) program. This activity includes $5,296,000 for SBIR in FY 2009 and $5,481,000 for SBIR in FY 2010 as well as other established obligations that the Heavy Ion Nuclear Physics subprogram must meet.

• **Accelerator R&D Research**	**—**	**250**	**1,270**

The Heavy Ion Accelerator R&D research at universities and laboratories will develop the knowledge, technologies, and trained scientists to design and build the accelerator facilities needed to carry out a forefront experimental program and to accomplish its DOE programmatic mission in nuclear physics. This includes efforts associated with establishing technical feasibility of a possible future Electron-Ion Collider.

Operations	**146,324**	**153,603**	**166,894**
▪ **RHIC Operations**	**137,041**	**148,859**	**160,180**

RHIC operations are supported for an estimated 3,720 hour operating schedule (91% utilization) in FY 2010 that greatly expands the scientific opportunities. The Electron Beam Ion Source (EBIS) construction project is completed in FY 2010 and its implementation, along with detector upgrades, will allow the RHIC program to make incisive measurements leading to more definitive conclusions on the discovery of strongly interacting quark gluon matter and to establish whether other phenomena, such as a color glass condensate or chiral symmetry restoration exist in nature.

• **RHIC Accelerator Operations**	**106,158**	**115,460**	**124,430**

Support is provided for the operation ($119,130,000), capital investments ($1,500,000), and accelerator improvement projects ($3,800,000) of the RHIC accelerator complex. This includes the Tandem (that will be replaced by the Electron Beam Ion Source, which will be completed in FY 2010), Booster, and AGS accelerators that together serve as the injector for RHIC. Funding will support about 3,720 hours of operations, an increase of 1,240 hours compared to FY 2009. Measurements of rare particles will require higher integrated beam luminosity and support is provided for R&D of electron beam cooling and other luminosity enhancement technologies.

	FY 2008	FY 2009	FY 2010
RHIC Hours of Operation with Beam			
Achieved Operating Hours	2,566	N/A	N/A
Planned Operating Hours	3,192	2,480	3,720
Optimal Hours	4,100	4,100	4,100
Percent of Optimal Hours	80%	61%	91%
Unscheduled Downtime	16.7%	N/A	N/A
Number of Users	1,200	1,200	1,200

	FY 2008	FY 2009	FY 2010
	(dollars in thousands)		
• **RHIC Experimental Support**	**30,883**	**33,399**	**35,750**

Support is provided for the operation, maintenance, improvement, and enhancement of the RHIC experimental complex, including the STAR and PHENIX detectors, experimental halls, computing center, and support for users. The STAR and PHENIX detectors provide complementary measurements, with some overlap in order to cross-calibrate the measurements. Base capital equipment funding is increased relative to FY 2009 to provide the support for maintaining computing capabilities at the RHIC Computing Facility (RCF) and for instrumentation.

	FY 2008	FY 2009	FY 2010
▪ **Other Operations**	**9,283**	**4,744**	**6,714**

The Nuclear Physics program provides funding to BNL for minor new fabrications, needed laboratory equipment (including general purpose equipment), and other expenses. Funding of this type is essential for maintaining the productivity and usefulness of DOE-owned facilities and for meeting its requirement for safe and reliable facilities operation.

	FY 2008	FY 2009	FY 2010
Total, Heavy Ion Nuclear Physics	**182,236**	**200,373**	**219,556**

Explanation of Funding Changes

	FY 2010 vs. FY 2009 ($000)
Research	
▪ **University Research**	
The increase for University Research grants in FY 2010 is needed to support data collection with STAR and PHENIX, as well as a modest effort directed towards research at the LHC heavy ion program. Funds also support revitalization of university infrastructure and equipment.	+1,367
▪ **National Laboratory Research**	
• BNL RHIC Research is decreased relative to FY 2009 due to completion of funding for the PHENIX Silicon VTX and the PHENIX FVTX detector MIEs in FY 2009. Partially offsetting those decreases is an increase to initiate the STAR HFT MIE.	-755
• Other National Laboratory Research is increased in FY 2010 to ensure adequate support to the RHIC experiments and its upgrades, to effectively utilize the beam time for research, and to train students and junior scientists. Funding is provided for researchers to meet the U.S. commitments to the LHC heavy ion program. In addition, funding is increased by $1,000,000 for the continued fabrication of the LHC Heavy Ion MIE according to the planned profile.	+4,075
Total, National Laboratory Research	**+3,320**

	FY 2010 vs. FY 2009 ($000)
▪ **Other Research**	
• SBIR and Other increases at levels required proportionate to R&D activities.	+185
• Accelerator R&D Research is increased in FY 2010 to develop the knowledge, technologies, and trained scientists needed to design and build accelerator facilities to accomplish DOE's programmatic mission in nuclear physics, including efforts aimed at establishing technical feasibility of a possible future Electron Ion Collider.	+1,020
Total, Other Research	**+1,205**
Total, Research	**+5,892**
Operations	
▪ **RHIC Operations**	
• RHIC Accelerator Operations: The FY 2010 request supports an approximate 50% increase in operating hours to meet the program's scientific goals and performance measures, allowing the RHIC facility to operate at 91% utilization. An increase of $800,000 is provided for accelerator improvement projects (AIP) to impact operational efficiencies and provide new capabilities. Capital Equipment is increased by $430,000 to replace or upgrade aging equipment.	+8,970
• RHIC Experimental Support is increased commensurate with the increase in operating hours to provide for experimental scientific/technical staff, materials and supplies, and capital equipment to effectively support the maintenance and operation of the PHENIX and STAR detectors at RHIC during this run.	+2,351
Total, RHIC Operations	**+11,321**
▪ **Other Operations**	
Increased funding is provided for general purpose equipment at BNL for upgrading and replacing aging laboratory equipment and for other small infrastructure and equipment revitalization within the national laboratory heavy ion complex.	+1,970
Total, Operations	**+13,291**
Total Funding Change, Heavy Ion Nuclear Physics	**+19,183**

Low Energy Nuclear Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Low Energy Nuclear Physics			
Research			
University Research	18,836	21,100	26,266
National Laboratory Research	30,808	29,470	42,213
Other Research[a]	3,800	2,386	1,886
Total, Research	53,444	52,956	70,365
Operations	28,835	41,662	46,451
Total, Low Energy Nuclear Physics	82,279	94,618	116,816

Description

The research effort supported by the Low Energy Nuclear Physics subprogram aims primarily at answering the overarching questions associated with the second frontier identified by NSAC—nuclei and nuclear astrophysics. These questions include: *What is the nature of the nuclear force that binds protons and neutrons into stable nuclei and rare isotopes? What is the origin of simple patterns in complex nuclei? What is the nature of neutron stars and dense nuclear matter? What is the origin of the elements in the cosmos? What are the nuclear reactions that drive stars and stellar explosions?* One goal of Low Energy Nuclear Physics is to develop a comprehensive description of nuclei across the entire nuclear chart. The coming decade of nuclear physics studies with rare isotope beams may reveal new nuclear phenomena and structures unlike those that are known from studies using stable nuclei. Experiments measure the cross sections of nuclear reactions that power stars and spectacular stellar explosions and are responsible for the synthesis of the elements. The subprogram also investigates aspects of the third frontier of fundamental symmetries and neutrinos. Questions addressed in this frontier include: *What is the nature of the neutrinos, what are their masses, and how have they shaped the evolution of the universe? Why is there now more visible matter than antimatter in the universe? What are the unseen forces that were present at the dawn of the universe but disappeared from view as the universe evolved?* Neutrinos are now known to have small but none-zero masses. The subprogram seeks to measure, or set a limit on, the neutrino mass and to determine if the neutrino is its own antiparticle. These neutrino properties are believed to play a role in the evolution of the cosmos. Experiments with cold neutrons also investigate the dominance of matter over antimatter in the universe, as well as other aspects of fundamental symmetries and interactions.

Funding supports both research and operations of the subprogram's two major national user facilities, HRIBF and ATLAS. HRIBF and ATLAS serve a research community of close to 700 researchers, including international researchers and those supported by DOE and NSF.

The NP program also supports the LBNL 88-Inch Cyclotron for a small in-house nuclear physics and chemistry research program, while the National Reconnaissance Office (NRO) and U.S. Air Force

[a] In FY 2008, $1,344,000 was transferred to the SBIR program. This activity includes $1,426,000 for SBIR in FY 2009 and $1,476,000 for SBIR in FY 2010.

(USAF) provide support towards improvements in radiation hardness of electronic circuit components against damage caused due to cosmic rays. A Memorandum of Agreement between NP, NRO, and the USAF provides for joint support of the 88-Inch Cyclotron through 2011. In FY 2010, fabrication continues at LBNL for the Gamma Ray Energy Tracking In-Beam Nuclear Array (GRETINA) MIE, a segmented germanium detector array with unparalleled position and energy resolution for nuclear structure studies with fast nuclear beams.

The subprogram also supports accelerator operations at Texas A&M University (TAMU), at the Triangle Universities Nuclear Laboratory (TUNL) at Duke University, and at Yale University for studies in nuclear structure and nuclear astrophysics that are especially suited to university facilities. At the University of Washington, the subprogram supports infrastructure in order to enable scientific instrumentation projects. Each of these university Centers of Excellence has a critical mass of nuclear physics faculty involved in research that is conducted both on and off campus plus about 15-25 graduate students at different stages of their education.

Progress in both nuclear structure and nuclear astrophysics studies depends increasingly upon the availability of rare isotope beams. While the U.S. today has first-generation facilities with capabilities for these studies, a facility with next-generation capabilities for short-lived radioactive beams is needed to maintain a leadership role. A study by the National Academies concluded that such a facility was a priority for the U.S., and the NSAC Long Range Plan recommended its construction. In FY 2008, a Funding Opportunity Announcement invited proposals for a Facility for Rare Isotope Beams (FRIB). Following peer review of the submitted proposals, the DOE selected Michigan State University as the host institution to establish FRIB and site the facility on its campus. In FY 2010 facility-specific R&D and Conceptual Design activities for this facility continue.

In the area of neutrino physics, U.S. researchers at the Kamioka Large Anti-Neutrino Detector (KamLAND) experiment in Japan are continuing to study the properties of anti-neutrinos produced by nuclear power reactors. The experiment is entering a new phase to measure lower-energy solar neutrinos following an upgrade of the detector. In FY 2008, U.S. researchers joined the Italian-lead Cryogenic Underground Observatory for Rare Events (CUORE) experiment at the Gran Sasso Laboratory, to search for evidence that the neutrino is its own antiparticle (a Majorana particle) and determine or set a limit on the effective Majorana mass of the neutrino. In FY 2007, U.S. university scientists began participation in the German-lead Karlsruhe Tritium Neutrino (KATRIN) experiment to determine the mass of the electron neutrino by measuring the beta decay spectrum of tritium.

Finally, the Low Energy subprogram supports studies of fundamental interactions and symmetries using neutrons or nuclei. Sensitive experiments are being prepared to be mounted at the Fundamental Neutron Physics Beamline (FNPB), which will be completed in FY 2010 at the Spallation Neutron Source (SNS).

Selected FY 2008 Accomplishments

- An important question for Earth science is to understand the source of heat at the Earth's core and whether nuclear reactions play a role. With data from the KamLAND experiment, researchers recently set an upper limit of 6.2 TW for a possible antineutrino-emitting nuclear reactor at the Earth's center.

- Using novel techniques, researchers have produced and measured radii of two rare isotopes of helium, namely ^{6}He and ^{8}He, which led to the counter intuitive result that the charge radius of the heavier ^{8}He is smaller than that of ^{6}He. This important result is in good agreement with recent *ab initio* theoretical calculations and provides a critical test of present understanding of the fundamental forces that bind together protons and neutrons in atomic nuclei.

- The purity of rare isotope beams is of crucial importance for research programs in nuclear physics and astrophysics. Scientists at HRIBF at ORNL recently patented a novel beam purification technique that uses lasers to neutralize unwanted negative ions. The technique will be applied to produce almost pure beams of rare isotopes of fluorine, chlorine, and nickel, which are important to nuclear structure physics to better understand the reaction rates for rapid proton capture in nuclei and synthesis of rare proton-rich nuclei.
- The High Intensity Gamma Source (HIγS) facility at the Duke Free Electron Laser Laboratory was upgraded successfully to provide tunable, polarized, nearly mono-energetic gamma-ray beams in the energy range of 2 to 60 MeV. The intensities of these beams are several orders of magnitude larger than those available at other sources. The unique qualities of HIγS beams will allow scientists to study stellar production of carbon and oxygen.

Detailed Justification

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Research	**53,444**	**52,956**	**70,365**
▪ **University Research**	**18,836**	**21,100**	**26,266**

Support is provided for the research of about 123 scientists and 97 graduate students at 35 universities to perform research at in-house or national laboratory facilities. FY 2010 funding augments experimental capabilities at research universities and supports the NP workforce at levels needed to reach NSAC performance measures.

University researchers conduct programs using the low energy heavy ion beams and specialized instrumentation at the ATLAS and HRIBF national user facilities. These efforts at the user facilities involve about two-thirds of the university scientists supported by this subprogram.

Accelerator operations are supported for in-house research programs at the facilities at Duke University, TAMU, and Yale University. These small university facilities have well-defined and unique physics programs, providing photons, neutrons, light ion beams, or heavy ion beams; specialized instrumentation; and opportunities for long-term measurements that complement the capabilities of the national laboratory user facilities.

Accelerator and non-accelerator experiments directed at fundamental measurements are supported, such as KamLAND, KATRIN, and studies with cold neutrons at the SNS with the FNPB.

▪ **National Laboratory Research**	**30,808**	**29,470**	**42,213**

Support is provided for the research programs of scientists at six national laboratories (ANL, BNL, LBNL, LANL, LLNL, and ORNL). Funding decisions are influenced by the results of periodic peer reviews of the national laboratory research groups. Results of these evaluations and the relative ranking of the groups have been factored into the groups' funding in subsequent years.

• **National Laboratory User Facility Research**	**11,002**	**9,027**	**8,986**

ANL researchers use stable and selected radioactive beams from ATLAS coupled to ion traps, Gammasphere, and the Fragment Mass Analyzer for nuclear structure studies. The Advanced Penning Trap measures atomic masses with high precision. ORNL researchers use radioactive beams from the HRIBF and specialized spectrometers to study the nuclear structure of nuclei far

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010

from stability. Specialized equipment is employed, such as a system that integrates gamma-ray and charged-particle detectors with a recoil mass separator. The high-pressure gas target is being utilized in an experimental program in nuclear astrophysics. Additional support for these staff is provided as experimental support discussed under User Facility Operations below.

• **Other National Laboratory Research**	**19,806**	**20,443**	**33,227**

Scientists at BNL, LBNL, LLNL, LANL, and ORNL play important roles in several high-priority accelerator- and non-accelerator-based experiments (KamLAND, nEDM and CUORE). R&D activities are also supported for another neutrino-less double beta decay (DBD) experiment based on a different technology. Capital equipment funding is increased in FY 2010 to support the ongoing instrumentation projects according to planned profiles and to initiate a new MIE.

Research efforts relevant to Applications of Nuclear Science and Technology (+$1,527,000) are increased and will be competed among university and laboratory researchers. These initiatives support nuclear science research that is inherently relevant to a broad suite of applications; additional funding is provided for this effort in the Nuclear Theory subprogram for Nuclear Data activities.

The GRETINA MIE is especially important for the study of the nuclear structure of rare isotopes produced in reactions with fast fragmentation beams. FY 2010 is the final year of funding ($430,000) for GRETINA which is scheduled for completion in FY 2011.

Support is provided for groups at BNL, LANL, and LBNL to conclude the analysis of data and publication of results from completed and ongoing neutrino experiments, and develop next generation neutrino experiments.

Support is provided to ORNL to continue to coordinate and play a leadership role in the development of the scientific and experimental program at the FNPB. The FNPB project is a beamline at the SNS that will deliver record peak currents of cold and ultra-cold neutrons for studying the fundamental properties of the neutron, leading to a refined characterization of the weak force. Fabrication of the FNPB began in FY 2004 and will be complete in FY 2010. FNPB received $600,000 under the Recovery Act to complete funding of the project.

In FY 2010, $4,500,000 is provided to pursue the measurement of the electric dipole moment of the neutron (nEDM), a high discovery potential experiment at the FNPB. The nEDM experiment is a joint DOE/NSF experiment. The measurement of a non-zero electric dipole moment of the neutron will significantly constrain extensions of the Standard Model.

In FY 2010, $4,500,000 is provided to continue fabrication of the CUORE experiment to search for neutrino-less double beta decay (DBD). This is a joint DOE/NSF project. R&D also continues on additional technical approaches to DBD.

In FY 2010, $4,200,000 is provided to initiate new Rare Isotope Beam Science Initiatives to support forefront scientific instrumentation opportunities at rare isotope beam facilities around the world.

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
▪ **Other Research**	**3,800**	**2,386**	**1,886**
• **Generic Rare Isotope Beam R&D**	**3,800**	**—**	**—**

In FY 2008, funds were provided for R&D activities aimed at development of generic rare isotope beam capabilities. In FY 2009, these R&D activities became facility-specific and part of the Total Project Cost of the proposed Facility for Rare Isotope Beams, as reflected in Operations below.

• **SBIR and Other**	**—**	**2,386**	**1,886**

In FY 2008, $1,344,000 was transferred to the SBIR program. This activity includes $1,426,000 for SBIR in FY 2009, and $1,476,000 for SBIR in FY 2010. Funding is also provided for other established obligations including the Lawrence and Fermi Awards, which provide annual monetary awards to honorees selected by DOE for outstanding contributions to science.

Operations	**28,835**	**41,662**	**46,451**
▪ **User Facility Operations**	**25,485**	**30,830**	**33,198**

In FY 2010, funding supports accelerator operations and experimental support at ATLAS ($16,553,000) providing increased beam hours compared to FY 2009 levels, and the more cost effective 7 day-a-week operations mode. The Californium Rare Ion Breeder Upgrade (CARIBU) AIP project is completed in FY 2010 to enhance the radioactive beam capabilities of ATLAS.

In FY 2010, funding supports accelerator operations and experimental support at HRIBF ($16,645,000) at increased levels in comparison to FY 2009, and with a transition from 5 to 7 day-a-week operations. The facility begins to commission a second source and transport beamline (IRIS2) for radioactive ions, which will increase operations efficiency and reliability.

	FY 2008	FY 2009	FY 2010
ATLAS Hours of Operation with Beam			
Achieved Operating Hours	5,672	N/A	N/A
Planned Operating Hours	5,200	5,200	5,900
Optimal Hours	6,600	6,600	6,600
Percent of Optimal Hours	86%	79%	89%
Unscheduled Downtime	5.5%	N/A	N/A
Number of Users	387	360	410

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010

	FY 2008	FY 2009	FY 2010
HRIBF Hours of Operation with Beam			
Achieved Operating Hours	4,431	N/A	N/A
Planned Operating Hours	3,800	5,000	5,200
Optimal Hours	6,100	6,100	6,100
Percent of Optimal Hours	73%	82%	85%
Unscheduled Downtime	17.6%	N/A	N/A
Number of Users	257	260	260

	FY 2008	FY 2009	FY 2010
▪ **Other Operations**	**3,350**	**3,832**	**4,253**

The NRO and USAF will jointly provide $2,200,000 to utilize the 88-Inch Cyclotron for approximately 2,000 hours for their testing program. NP will provide $4,089,000 to utilize it for approximately 3,000 hours for the in-house nuclear physics research program. Funding is also provided for maintenance of the Oak Ridge Electron Accelerator (ORELA) for criticality measurements supported by DOE/NNSA.

	FY 2008	FY 2009	FY 2010
▪ **Facility for Rare Isotope Beams**	**—**	**7,000**	**9,000**

Funds are requested to continue R&D and conceptual design activities aimed at developing FRIB. This facility will enable world-leading research opportunities in nuclear structure, nuclear astrophysics, and fundamental studies, and complement other rare isotope beam research programs at facilities elsewhere in the world.

	FY 2008	FY 2009	FY 2010
Total, Low Energy Nuclear Physics	**82,279**	**94,618**	**116,816**

Explanation of Funding Changes

	FY 2010 vs. FY 2009 ($000)
Research	
▪ **University Research**	
FY 2010 funding is increased to augment experimental capabilities at research universities and levels of personnel needed to support the experimental programs and achieve NSAC performance goals, operate university accelerators, and support non-accelerator initiatives. Funding supports revitalization of university infrastructure and equipment.	+5,166
▪ **National Laboratory Research**	
• National Laboratory User Facility Research funding maintains personnel at levels needed to support the highest priority research efforts and activities at the ATLAS and HRIBF and includes maintaining and implementing scientific instrumentation at the user facilities.	-41

	FY 2010 vs. FY 2009 ($000)
Other National Laboratory Research funding supports a suite of MIEs according to their planned project profile, maintaining cost and schedule baselines and meeting international commitments. These include GRETINA (-$1,570,000), CUORE (+$2,500,000), nEDM (+$3,400,000), Rare Isotope Beam Science Initiatives (+$4,200,000), and FNPB (-$1,500,000) for which funding is complete in FY 2009. In addition, increased support is provided for laboratory computing, instrumentation, and workforce for enhanced research efforts (+$4,227,000); and Applications of Nuclear Science and Technology is increased (+$1,527,000) to support nuclear science research that is inherent to a broad suite of applications.	+12,784
Total, National Laboratory Research	**+12,743**
▪ **Other Research**	
SBIR and other funded at levels required proportionate to R&D activities.	-500
Total, Research	**+17,409**
Operations	
▪ User Facility Operations increases for HRIBF (+$1,198,000) and ATLAS (+$839,000) to maintain staff and more effectively operate these two national user facilities, and capital investments increase (+$331,000) to address a backlog of small instrumentation and infrastructure needs.	+2,368
▪ Other Operations increases to provide needed funding for maintenance of the 88-Inch Cyclotron.	+421
▪ The increase for the Facility for Rare Isotope Beams reflects additional funds to continue R&D and conceptual design activities.	+2,000
Total, Operations	**+4,789**
Total Funding Change, Low Energy Nuclear Physics	**+22,198**

Nuclear Theory

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Nuclear Theory			
Theory Research			
University Research	13,606	14,999	15,968
National Laboratory Research	12,404	14,189	16,354
Scientific Discovery through Advanced Computing (SciDAC)	2,304	2,777	2,773
Total, Theory Research	28,314	31,965	35,095
Nuclear Data Activities	6,097	7,411	8,324
Total, Nuclear Theory	34,411	39,376	43,419

Description

The Nuclear Theory subprogram supports theoretical research at universities and DOE national laboratories with the goal of improving our fundamental understanding of nuclear physics, interpreting the results of experiments carried out under the auspices of the experimental nuclear physics program, and identifying and exploring important new areas of research.

This subprogram addresses all three of nuclear physics' scientific frontiers. A major theme of this subprogram is an understanding of the mechanisms and effects of quark confinement and de-confinement. A quantitative description of these phenomena starting from the fundamental theory of QCD remains one of this subprogram's great intellectual challenges. New theoretical and computational tools are being developed to describe nuclear many-body phenomena, which will likely have important applications in condensed matter physics and in other areas of the physical sciences. Another major research area is nuclear astrophysics, which includes efforts to understand the origins of the elements (as in supernovae) and the consequences that neutrino masses have for nuclear astrophysics and for the current theory of elementary particles and forces.

One area of nuclear theory that has a particularly pressing demand for large dedicated computational resources is that of lattice quantum chromodynamics (LQCD). LCQD calculations are critical for understanding many of the experimental results from RHIC and CEBAF that involve the strong interaction between quarks and gluons. This subprogram provides researchers with adequate access to powerful supercomputers for these studies, such as the high-performance computational facility at the National Energy Research Scientific Computing Center (NERSC) at LBNL, as well as specialized computers at other institutions. In a joint effort started in FY 2006, the Nuclear Theory subprogram and the High Energy Physics (HEP) Theory subprogram initiated the development of large-scale facilities to provide computing capabilities based on community cluster systems. By the end of FY 2009, it is anticipated that this joint HEP/NP initiative will be operating facilities with an aggregate capacity of 18 teraflops; this initiative continues in FY 2010.

The Nuclear Theory subprogram also sponsors the Institute for Nuclear Theory (INT) at the University of Washington, which carries out a range of activities in support of the work of the nuclear physics community. INT includes visiting scientists, research fellows, postdoctoral fellows, graduate students, and several leading nuclear theorists as permanent staff. INT also hosts a series of specialized research programs on specific topics in nuclear theory and related fields that are identified by the research community as being of high priority.

The National Nuclear Data program compiles, evaluates, and disseminates nuclear data for basic research and applications in an on-line data base that is readily accessible and user oriented.

The Nuclear Theory subprogram is strengthened by its interactions with complementary programs overseas, NSF-supported theory efforts, programs supported by the DOE HEP program, Japanese-supported theoretical efforts related to RHIC at the RIKEN Center at Brookhaven National Laboratory, and the Japan-U.S. Theory Institute for Physics with Rare Isotope Nuclei (JUSTIPEN) at RIKEN in Wako, Japan.

Selected FY 2008 Accomplishments

- The quark-gluon plasma (QGP), which is studied in experiments at RHIC, appears to behave as an exotic perfect fluid. Recently, string theory methods have been used to calculate some of the fluid parameters of the QGP, such as viscosity and entropy density. This provides a novel application of the work of string theorists to current experimental studies; string theory usually addresses extremely high energies and tiny length scales that are far removed from experiments.
- The prediction of properties of large nuclei starting from the basic interactions between two and three neutrons and protons has long been a goal of nuclear theory. Recent advancement in this effort have been reported by the SciDAC Collaboration Universal Nuclear Energy Density Functional (UNEDF), which is supported by NP, the National Nuclear Security Administration, and the Advanced Scientific Computing Research program; their results include coupled-cluster calculations of the properties of medium-sized nuclei containing up to 40 and 48 neutrons and protons.
- Important progress has been made in the determination of the nuclear forces between neutrons and protons in the nucleus using a lattice formulation of QCD implemented on a supercomputer. In this work, direct QCD predictions for the nuclear forces between strongly interacting particles known as mesons (quark-antiquark bound states) were studied. This preliminary study of mesons will be followed by supercomputer-based studies of the true nuclear force between neutrons and protons, as is observed within nuclei.

Detailed Justification

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Theory Research	**28,314**	**31,965**	**35,095**
▪ **University Research**	**13,606**	**14,999**	**15,968**

The Nuclear Theory program supports the research of approximately 150 academic scientists and 110 graduate students through 65 research grants at 43 universities in 28 states and the District of Columbia. The funding will support the necessary level of theoretical effort needed for interpretation of experimental results obtained at the NP facilities, the training of next-generation nuclear theorists, and will allow the start of several new research grants in specific growth areas of nuclear theory. The overall nuclear theory effort is aligned with the experimental program through the program performance milestones established by NSAC.

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
▪ **National Laboratory Research**	**12,404**	**14,189**	**16,354**

Research programs are supported at seven national laboratories (ANL, BNL, LANL, LBNL, LLNL, ORNL, and TJNAF) to achieve NSAC performance goals and interpret experimental results. The nuclear theory research at a given laboratory provides support to the experimental programs at that laboratory, or takes advantage of some unique facilities or programs at that laboratory. The larger size and diversity of the national laboratory groups make them particularly good sites for the training of nuclear theory postdoctoral associates. In FY 2009, the laboratory groups will be evaluated based on the significance of their accomplishments and future program, scientific leadership, creativity and productivity of the personnel, and the overall cost-effectiveness of the group. Results of the review will influence future budget decisions.

Support continues for the Excited Baryon Analysis Center (EBAC) at TJNAF. In FY 2010 continued investments in LQCD computer capabilities will be supported in a joint effort with High Energy Physics.

▪ **Scientific Discovery through Advanced Computing (SciDAC)**	**2,304**	**2,777**	**2,773**

SciDAC is a collaborative program that partners scientists and computer experts in research teams to address major scientific challenges that require supercomputer facilities at the current technological limits. Supported SciDAC efforts include nuclear astrophysics, grid computing, QCD, low energy nuclear structure and nuclear reaction theory and advanced accelerator design. In FY 2010, NP partners with ASCR, HEP, and NNSA to fund these efforts.

Nuclear Data Activities	**6,097**	**7,411**	**8,324**

This effort involves the work of several national laboratories and universities and is guided by the DOE-managed National Nuclear Data Center (NNDC) at BNL. Funding provides support for a viable effort and addresses long-standing issues in staffing shortages. The NNDC relies on the U.S. Nuclear Data Network (USNDN), a network of DOE-supported individual nuclear data professionals located in universities and national laboratories that perform assessment as well as developing modern network dissemination capabilities. The NNDC participates in the International Data Committee of the International Atomic Energy Agency.

Funding is also provided to support initiatives in Applications of Nuclear Science and Technology, including efforts relevant to nuclear fuel cycle.

Total, Nuclear Theory	**34,411**	**39,376**	**43,419**

Explanation of Funding Changes

	FY 2010 vs. FY 2009 ($000)
Theory Research	
▪ **University Research**	
FY 2010 provides increased support for personnel to focus on the theoretical understanding of the research that was identified in the NSAC report on performance measures and milestones and to implement recommendations from the NSAC Subcommittee on Nuclear Theory.	+969
▪ **National Laboratory Research**	
FY 2010 funding provides increased support for theoretical efforts needed to achieve the scientific goals of the Nuclear Physics program, including the continuation of the LQCD initiative with HEP.	+2,165
▪ **Scientific Discovery through Advanced Computing (SciDAC)**	
FY 2010 funding allows for continued support in the most promising areas for progress in nuclear physics with terascale computing capabilities.	-4
Total, Theory Research	+3,130
Nuclear Data Activities	
FY 2010 funding increases are needed to support a viable effort in Nuclear Data related activities (+$246,000), and to expand Applications of Nuclear Science and Technology (+$667,000).	+913
Total Funding Change, Nuclear Theory	**+4,043**

Isotope Development and Production for Research and Applications

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Isotope Development and Production for Research and Applications			
Research			
National Laboratory Research	—	4,860	3,000
Other Research[a]	—	200	90
Total, Research	—	5,060	3,090
Operations			
University Operations	—	200	250
Isotope Production Facility Operations	—	2,790	1,068
Brookhaven Linear Isotope Producer Operations	—	770	600
National Isotope Data Center (NIDC)	—	1,024	1,440
Other National Laboratory Operations	—	15,056	12,752
Total, Operations	—	19,840	16,110
Total, Isotope Development and Production for Research and Applications	—[b]	24,900	19,200

Description

In FY 2009, this new subprogram was transferred to the Office of Science from the Office of Nuclear Energy. The FY 2010 budget request for Isotope Development and Production for Research and Applications is reflective of the rest of the Nuclear Physics budget with a focus on Research and Operations. This subprogram continues to re-establish the goal of supporting research and development and production of research isotopes. To achieve this goal, the Isotope Development and Production for Research and Applications subprogram provides facilities and capabilities for the production of research and commercial stable and radioactive isotopes, scientific and technical staff associated with general isotope research and production, and a supply of critical isotopes to address the needs of the Nation. The immediate benefits of a viable research and development component of the Isotope Development and Production for Research and Applications subprogram include the reduced dependence on foreign supplies, new scientific applications for isotopes not currently supplied, and the ability to meet both present and future research needs for isotopes.

Stable and radioactive isotopes are vital to the mission of many Federal agencies and play a crucial role in basic research, medicine, industry, and homeland defense. Isotopes are produced for the National Institutes of Health and their grantees, National Institute of Standards and Technology, Environmental Protection Agency, Department of Agriculture, National Nuclear Security Administration, Department of

[a] This activity includes $125,000 for SBIR and $15,000 for STTR in FY 2009 and $80,000 for SBIR and $10,000 for STTR in FY 2010.
[b] Funding prior to FY 2009 is provided under the Nuclear Energy, Radiological Facilities Management program.

Homeland Security, other DOE Office of Science programs, and other Federal agencies. The subprogram also supports research related to the development of advanced isotope production techniques.

Isotopes are used to improve the accuracy and effectiveness of medical diagnoses and therapy, enhance national security, improve the efficiency of industrial processes, and provide precise measurement and investigative tools for materials, biomedical, environmental, archeological, and other research. Some examples are: strontium-82 used for heart imaging; germanium-68 used for calibrating the growing numbers of imaging scanners; arsenic-73 used as a tracer for environmental research, and nickel-63 used as a component in gas sensing devices or helium-3 as a component in neutron-detectors both used for applications in homeland defense. Some isotopes are critical resources to very diverse operations in industry and science and have a profound impact on the Nation's economy and national security. Californium-252, for example, is used in a wide array of applications for medicine, homeland defense, and energy security.

The consequences of shortages of radioactive and stable isotopes needed for research, medicine, homeland security, and industrial applications can be extremely serious ranging from the inability to treat cancer to the failure of detecting terrorist threats. NP sponsored a workshop in August 2008 with stakeholders from the research community, industry and Federal agencies to identify those isotopes critical to meeting the Nation's present and future needs and the role of the Isotope Development and Production for Research and Applications subprogram in fulfilling these needs. NSAC was charged in August 2008 to develop a prioritized list of research topics using isotopes and to develop a long-range strategic plan for stable and radioactive isotope production. A final report will be issued in summer of 2009. NP has also established a working group with the National Institutes of Health to address the recommendations of the recent National Academies report, *Advancing Nuclear Medicine through Innovation*[a], which identified several areas in isotope production warranting attention. Finally, NP has facilitated the formation of a federal working group on He-3 supply, involving staff from NP, NNSA, the Department of Homeland Security, and the Department of Defense.

Isotopes are made available by using the Department's unique facilities, the Brookhaven Linear Isotope Producer (BLIP) at BNL and the Isotope Production Facility (IPF) at LANL, of which the subprogram has stewardship responsibilities. The subprogram also produces isotopes at the reactors at Oak Ridge and Idaho National Laboratories. In FY 2009, the subprogram will explore production capabilities at university and other laboratory facilities in order to make high priority isotopes more available. Hot cell facilities at Brookhaven, Oak Ridge, and Los Alamos National Laboratories are used and maintained by the program for processing and handling irradiated materials and purified products. Facilities at other national laboratories are used as needed, such as for processing and packaging strontium-90 from the Pacific Northwest National Laboratory. Over 50 researchers and staff at the national laboratories are supported to provide the technical expertise in research, development, and transportation of isotopes. Research and development includes target fabrication, enhanced processing techniques, radiochemistry, material conversions, and other related services.

The Isotope Development and Production for Research and Applications subprogram, which operates under a revolving fund as established by the FY 1990 Energy and Water Development Appropriations Act (Public Law 101–101) as modified by Public Law 103–316, maintains its financial viability by utilizing a combination of Congressional appropriations and revenues from the sale of isotopes and services. These resources are used to maintain the staff, facilities, and capabilities at user-ready levels

---

[a] http://dels.nas.edu/dels/rpt_briefs/advancing_nuclear_medicine.pdf

and to support peer-reviewed research and development activities related to the production of isotopes. Commercial isotopes are priced at full cost. Research isotopes are priced to provide reasonable compensation to the government while encouraging research. Investments in new capabilities are made to meet the growing demands of the Nation and foster research in the applications that will support the health and welfare of the public.

The subprogram is benefitting substantially from Recovery Act funding, which complements the FY 2010 Budget Request. Support under the Recovery Act was provided for an initiative to support R&D on the development of alternative and innovative approaches for the development and production of critical isotopes. Recovery Act support was also provided for the utilization of isotope production facilities, which included additional operations for the production of isotopes, one-time investments to improve the efficiency or provide new capabilities for the production of isotopes, and opportunities to establish production capabilities at new production sites.

FY 2008 Selected Accomplishments

- Researchers at ORNL successfully developed the production of high specific activity lutetium-177 used in peptide radio-labeling. Lutetium-177 emits a low beta energy, which reduces radiation side effects and produces a tissue-penetration range appropriate for smaller tumors and colon, bone, liver, and lung cancer. Samples of high specific activity lutetium-177 have been distributed to research institutions worldwide for testing.
- In a collaborative effort, barium-131 and barium-140 were produced at the High Flux Isotope Reactor (HFIR) and at the BR2 reactor at Mol, Belgium, respectively. Both irradiations enabled researchers to assess yields, burn up, and other reactor production parameters. Cesium-131, the daughter isotope of barium-131, is an alternative for the manufacture of seed implants for prostate cancer therapy. The daughter of barium-140, lanthanum-140, is a high-energy gamma emitter that is of interest for a potentially new imaging technology.
- Researchers developed the production of yttrium-86 at BNL which resulted in high yields, but less purity than desired. Yttrrium-86 is a short-lived isotope emitting positrons, which can be used for positron emission tomography (PET) imaging prior to cancer immunotherapy with yttrium-90. Yttrium-86 labeled tumor-seeking monoclonal antibodies can be used for evaluating effective tumor uptake and radiation dose. Experiments to improve the product purity will be conducted in FY 2009 using low-energy protons.
- NP negotiated a partnership with industry to support continued production of californium-252, critical to many applications in industry, homeland defense, and research.

Detailed Justification

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Research	**—**	**5,060**	**3,090**

Research is supported to identify, design, and optimize production targets and separation methods. Examples for planned research includes: the need for positron-emitting radionuclides to support the rapidly growing area of medical imaging using PET; the development of isotopes that support medical research to be used to diagnose diseases spread through acts of bioterrorism as well as their treatment; the development of production methods for alpha-emitting radionuclides that exhibit great potentials in

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010

disease treatment; the development and use of research isotopes for various biomedical applications; and the need for alternative isotope supplies for national security applications and advanced power sources. Priorities in research isotope production are informed by guidance from NSAC. All R&D activities are peer reviewed. In addition, Recovery Act funding continues to support R&D in alternative isotope production techniques, which complements these research efforts in FY 2010.

	FY 2008	FY 2009	FY 2010
▪ **National Laboratory Research**	**—**	**4,860**	**3,000**

Support is provided for scientists at the national laboratories (BNL, LANL, ORNL, INL, PNNL) to perform peer-reviewed experimental research on targets, separation technology maturation and development of isotope production techniques, and for the production of research isotopes at affordable rates. R&D activities utilize the reactors at INL and ORNL and the accelerators at LANL and BNL. Researchers provide unique expertise and facilities for data analysis.

	FY 2008	FY 2009	FY 2010
▪ **Other Research**	**—**	**200**	**90**

This activity includes $125,000 for SBIR and $15,000 for STTR in FY 2009 and $80,000 for SBIR and $10,000 for STTR in FY 2010.

	FY 2008	FY 2009	FY 2010
Operations	**—**	**19,840**	**16,110**

Operations funding is provided to support the core facility scientists and engineers and to effectively operate the Isotope Development and Production for Research and Applications facilities, including facility maintenance and investments in new capabilities. In addition, Recovery Act funding continues to support enhanced utilization of isotope facilities, including additional isotope production and one-time investments in infrastructure and new capabilities.

	FY 2008	FY 2009	FY 2010
▪ **University Operations**	**—**	**200**	**250**

Funding is provided to academic institutions with reactors and cyclotrons for the production and development of isotopes to enhance the subprogram's isotope portfolio.

	FY 2008	FY 2009	FY 2010
▪ **Isotope Production Facility (IPF) Operations**	**—**	**2,790**	**1,068**

The IPF operates in a parallel-mode in accordance with the Los Alamos Neutron Science Center (LANSCE) of about 22 weeks in FY 2010. The IPF produces isotopes such as germanium-68, strontium-82, and arsenic-73. Support is provided in FY 2010 for the operation, maintenance, and improvement of the IPF, including radiological monitoring, facility inspections, and records management. Upgrades at IPF, including one-time costs for replacement of the control and target loading systems, were funded in FY 2009.

	FY 2008	FY 2009	FY 2010
▪ **Brookhaven Linear Isotope Producer (BLIP) Operations**	**—**	**770**	**600**

BLIP operates in parallel mode in accordance with the RHIC operating schedule and additionally in dedicated mode to meet customer needs. BLIP produces isotopes such as copper-67, germanium-68 and strontium-82. Support is provided in FY 2010 for the operation, maintenance, and improvement of BLIP, including radiological monitoring, facility inspections, and records management. Several one-time equipment upgrades were funded in FY 2009.

(dollars in thousands)

	FY 2008	FY 2009	FY 2010
▪ **National Isotope Data Center (NIDC)**	**—**	**1,024**	**1,440**

The National Isotope Data Center (NIDC) is a management information center for all national laboratories and universities in the subprogram's portfolio producing and distributing isotopes. The NIDC coordinates and integrates multi-laboratory isotope production schedules, maintains isotope inventory balances and transportation container inventory and certifications, and conducts various outreach and societal activities. The business office within the NIDC is located at ORNL and coordinates all customer data such as official quotations, account balances, shipping schedules and delivery tracking, and other pertinent information. Funding is provided to support the staff located throughout the national laboratory complex that are needed to oversee these activities.

	FY 2008	FY 2009	FY 2010
▪ **Other National Laboratory Operations**	**—**	**15,056**	**12,752**

The Isotope program makes intensive use of hot cell facilities at the three main isotope production sites: BNL, LANL, and ORNL. Funding is provided to each of these facilities for the technical expertise and hot cell facilities in order to support the handling and processing of radioactive materials. Support is provided in FY 2010 for the Chemical and Material Laboratories at ORNL that is used for processing stable isotopes, as well as activities including radiological monitoring, facility inspections, records management, the certification of isotope shipping casks, and other related expenses. The one-time costs for modernization of the train control system to meet current facility requirements at LANL and relocation of sub-category-3 level quantities of radioisotope materials at ORNL were funded in FY 2009.

	FY 2008	FY 2009	FY 2010
Total, Isotope Development and Production for Research and Applications	**—**	**24,900**	**19,200**

Explanation of Funding Changes

	FY 2010 vs. FY 2009 ($000)
Research	
Reduced funding for research and development reflects the increased congressional funding for this activity in FY 2009. These activities are guided by priorities in research isotope production developed by NSAC and are complemented by Recovery Act funding for R&D on alternative isotope production techniques.	-1,970
Operations	
▪ **University Operations**	
Increased funding enhances capability, staff, and expertise for cost-efficient operations to develop and produce isotopes.	+50

	FY 2010 vs. FY 2009 ($000)
▪ **Isotope Production Facility (IPF) Operations**	
The reduced funding in FY 2010 reflects completion in FY 2009 of upgrades, including a one-time investment to address infrastructure needs at the IPF in the control system and target loading system.	-1,722
▪ **Brookhaven Linear Isotope Producer (BLIP) Operations**	
The reduced funding in FY 2010 reflects completion in FY 2009 of one-time investments for the replacement of the acid fume scrubber system, upgrades to the BLIP beam, and the installation of a crane/rail system for manipulator repairs.	-170
▪ **National Isotope Data Center (NIDC)**	
An increase is provided for the NIDC to meet its mission to coordinate isotope activities and customer data.	+ 416
▪ **Other National Laboratory Operations**	
The reduced funding in FY 2010 reflects completion of upgrades in FY 2009, including one-time investments for modernization of the train control system at LANL and relocation of sub-category-3 level quantities of radioisotope materials at ORNL.	-2,304
Total, Operations	**-3,730**
Total Funding Change, Isotope Development and Production for Research and Applications	**-5,700**

Construction

Funding Schedule by Activity

	FY 2008	FY 2009	FY 2010
	(dollars in thousands)		
Construction			
07-SC-02, Electron Beam Ion Source, BNL	4,162	2,438	—
06-SC-01, 12 GeV CEBAF Upgrade (PED/Construction), TJNAF	13,377	28,623	22,000
Total, Construction	17,539	31,061	22,000

Description

This subprogram provides for Construction and Project Engineering and Design (PED) that is needed to meet overall objectives of the Nuclear Physics program.

Detailed Justification

	FY 2008	FY 2009	FY 2010
	(dollars in thousands)		
07-SC-02, Electron Beam Ion Source, BNL	**4,162**	**2,438**	—

The Electron Beam Ion Source (EBIS) project to replace the high maintenance tandems as the RHIC pre-injector, leading to more cost effective operations and new research capabilities, will be completed in FY 2010 with funding appropriated in previous years. This project is jointly supported between NP and NASA.

06-SC-01, 12 GeV CEBAF Upgrade (PED/Construction), TJNAF	**13,377**	**28,623**	**22,000**

In FY 2010, funding is requested to continue construction of the 12 GeV CEBAF Upgrade. The upgrade was identified in the 2007 NSAC Long-Range Plan as the highest priority for the U.S. Nuclear Physics program and is a near-term priority in the SC 20-Year Facilities Outlook. The upgrade will enable scientists to address one of the mysteries of modern physics—the mechanism of quark confinement. In FY 2009, funding for PED activities is completed. In addition to the funding reflected above, the project also received Recovery Act funding of $65,000,000 in FY 2009 which advances a portion of the original FY 2010 and FY 2011 planned funding.

Total, Construction	**17,539**	**31,061**	**22,000**

Explanation of Funding Changes

	FY 2010 vs. FY 2009 ($000)
07-SC-02, Electron Beam Ion Source, BNL	
The last year of funding for this project was FY 2009.	-2,438

	FY 2010 vs. FY 2009 ($000)
06-SC-01, 12 GeV CEBAF Upgrade (PED/Construction), TJNAF	
Support is provided to continue construction of the 12 GeV CEBAF Upgrade according to the planned profile and taking into account advanced funding provided under the Recovery Act.	-6,623
Total Funding Change, Construction	**-9,061**

Supporting Information

Operating Expenses, Capital Equipment and Construction Summary

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Operating Expenses	366,991	435,738	467,849
Capital Equipment	26,574	38,126	53,523
General Plant Projects	7,736	1,000	2,000
Accelerator Improvement Projects	4,831	6,155	6,628
Construction	17,539	31,061	22,000
Total, Nuclear Physics	423,671	512,080	552,000

Funding Summary

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Research			
National Laboratory Research [a]	75,973	89,654	102,353
University Research [a]	63,794	69,516	78,467
Other Research [b]	4,319	14,134	15,841
Total Research	144,086	173,304	196,661
Scientific User Facilities Operations	234,266	258,648	277,232
Other Facility Operations	5,350	23,672	20,363
Major Items of Equipment	13,147	13,651	20,030
Construction Projects	17,539	31,061	22,000
Other [c]	9,283	11,744	15,714
Total Nuclear Physics	423,671	512,080	552,000

Scientific User Facilities Operations and Research

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
RHIC (BNL)			
Operations	137,041	148,859	160,180
Facility Research/MIEs	9,819	10,377	8,982
Total RHIC	146,860	159,236	169,162

[a] Funding for SciDAC and Nuclear Data activities is split between National Laboratory Research and University Research.
[b] Funding shown in Other Research for Accelerator R&D and Generic Rare Isotope Beam R&D will be distributed to National Laboratories and Universities.
[c] Other includes BNL GPE and FRIB Other Project Costs (R&D and Conceptual Design).

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
CEBAF (TJNAF)			
Operations	71,740	78,959	83,854
Facility Research/MIEs	9,952	10,229	11,190
Total CEBAF	81,692	89,188	95,044
HRIBF (ORNL)			
Operations	13,081	15,650	16,645
Facility Research/MIEs	5,272	4,327	4,121
Total HRIBF	18,353	19,977	20,766
ATLAS (ANL)			
Operations	12,404	15,180	16,553
Facility Research/MIEs	5,730	4,700	4,865
Total ATLAS	18,134	19,880	21,418
Total Scientific User Facilities			
Operations	234,266	258,648	277,232
Facility Research/MIEs	30,773	29,633	29,158
Total Scientific User Facilities	265,039	288,281	306,390

Total Facility Hours and Users

	FY 2008	FY 2009	FY 2010
Hours of Operation with Beam			
RHIC (BNL)			
Optimal Hours	4,100	4,100	4,100
Planned Operating Hours	3,192	2,480	3,720
Achieved Operating Hours	2,566	N/A	N/A
Unscheduled Downtime	16.7%	N/A	N/A
Number of Users	1,200	1,200	1,200
CEBAF (TJNAF)			
Optimal Hours	5,600	5,980	5,980
Planned Operating Hours	3,500	4,965	5,110
Achieved Operating Hours	3,914	N/A	N/A
Unscheduled Downtime	8.0%	N/A	N/A
Number of Users	1,313	1,350	1,390

	FY 2008	FY 2009	FY 2010
HRIBF (ORNL)			
Optimal Hours	6,100	6,100	6,100
Planned Operating Hours	3,800	5,000	5,200
Achieved Operating Hours	4,431	N/A	N/A
Unscheduled Downtime	17.6%	N/A	N/A
Number of Users	257	260	260
ATLAS (ANL)			
Optimal Hours	6,600	6,600	6,600
Planned Operating Hours	5,200	5,200	5,900
Achieved Operating Hours	5,672	N/A	N/A
Unscheduled Downtime	5.5%	N/A	N/A
Number of Users	387	360	410
Total Facilities			
Optimal Hours	22,400	22,780	22,780
Planned Operating Hours	15,692	17,645	19,930
Achieved Operating Hours	16,583	N/A	N/A
Unscheduled Downtime	11.4%	<20%	<20%
Total Number of Users	3,157	3,170	3,260

Major Items of Equipment

(dollars in thousands)

	Prior Years	FY 2008	FY 2009	FY 2009 Additional Approp.	FY 2010	Outyears	Total
Heavy Ion Nuclear Physics							
Heavy Ion LHC Experiments, LBNL							
TEC	1,000	2,000	4,000	—	5,000	1,205	13,205
OPC	295	—	—	—	—	—	295
TPC	1,295	2,000	4,000	—	5,000	1,205	13,500
PHENIX Silicon Vertex Tracker, BNL							
TEC/TPC	1,599	2,000	851	250	—	—	4,700

(dollars in thousands)

	Prior Years	FY 2008	FY 2009	FY 2009 Additional Approp.	FY 2010	Outyears	Total
PHENIX Forward Vertex Detector, BNL							
TEC/TPC	—	700	2,200	2,000	—	—	4,900
PHENIX Nose Cone Calorimeter, BNL[a]							
TEC/TPC	—	200	—	—	—	—	N/A
STAR Heavy Flavor Tracker, BNL							
TEC	—	—	—	—	1,400	TBD	TBD
OPC	—	—	—	—	—	TBD	TBD
TPC	—	—	—	—	1,400	TBD	11,000-15,000
Low Energy Nuclear Physics							
GRETINA, Gamma-Ray Detector, LBNL							
TEC	10,400	4,170	2,000	—	430	—	17,000
OPC	1,200	—	300	—	300	—	1,800
TPC	11,600	4,170	2,300	—	730	—	18,800
Fundamental Neutron Physics Beamline, ORNL							
TEC	5,600	1,500	1,500	600	—	—	9,200
OPC	88	—	—	—	—	—	88
TPC	5,688	1,500	1,500	600	—	—	9,288
Neutron Electric Dipole Moment (nEDM), LANL							
TEC	770	2,177	1,100	—	4,500	TBD	TBD
OPC	430	323	—	—	—	TBD	TBD
TPC	1,200	2,500	1,100	—	4,500	TBD	17,600-19,000
Cryogenic Underground Observatory for Rare Events (CUORE), LBNL							
TEC	—	400	2,000	—	4,500	TBD	TBD
OPC	464	300	—	—	—	TBD	TBD
TPC	464	700	2,000	—	4,500	TBD	8,000-10,000

[a] Based on scientific merit review, and in the context of constrained resources, it was decided to cancel this MIE.

(dollars in thousands)

	Prior Years	FY 2008	FY 2009	FY 2009 Additional Approp.	FY 2010	Outyears	Total
Rare Isotope Beam Science Initiatives							
TEC	—	—	—	—	4,200	TBD	TBD
OPC	—	—	—	—	—	TBD	TBD
TPC	—	—	—	—	4,200	TBD	2,000-20,000
Total MIEs							
TEC		13,147	13,651	2,850	20,030		
OPC		623	300	—	300		
TPC		13,770	13,951	2,850	20,330		

Heavy Ion Nuclear Physics MIEs

Heavy Ion LHC Experiment (ALICE EMCal), LBNL: This MIE fabricates a large electromagnetic calorimeter (EMCal) for the ALICE experiment at the LHC, and is a joint project with France and Italy. It received CD-2/3 approval in February 2008 and is scheduled to finish in FY 2011.

PHENIX Silicon Vertex Tracker (VTX), BNL: This MIE fabricates a barrel of silicon pixel and strip detectors for high-precision tracking and vertexing and is a joint project with Japan. The TPC was baselined at a technical, cost, schedule, and management review in May 2006 and the project is scheduled to finish in FY 2010. The project received its final funding of $250,000 under the Recovery Act.

PHENIX Forward Vertex Detector (FVTX), BNL: This MIE fabricates two silicon endcaps to extend the VTX tracking and vertexing capabilities. The TPC was baselined at a technical, cost, schedule, and management review in November 2007. The project is scheduled to finish in FY2011. The project received its final funding of $2,000,000 under the Recovery Act.

PHENIX Nose Cone Calorimeter (NCC), BNL: Based on scientific merit review, and in the context of constrained resources, it was decided to cancel this MIE. Funds that had been allocated to the project in FY 2008 have been redirected to other high priority instrumentation needs at BNL.

STAR Heavy Flavor Tracker (HFT), BNL: This MIE will fabricate a high-precision tracking and vertexing device based on ultra-thin silicon pixel and pad detectors in the STAR detector. It received CD-0 approval in February 2009 and is scheduled for initiation in FY 2010 and completion in FY 2014.

Low Energy Nuclear Physics MIEs

GRETINA Gamma-Ray Detector, LBNL: This MIE fabricates an array of highly-segmented germanium crystals for gamma ray detection. It received CD-2/3 approval in October 2007 and is scheduled to finish in FY 2011. This detector will be shared by the Nation's low energy accelerator facilities operated by both DOE and NSF.

Fundamental Neutron Physics Beamline (FNPB), ORNL: This MIE fabricates two beam lines at the SNS to deliver record peak currents of cold and ultra-cold neutrons for studies of fundamental neutron properties. It received CD-4a approval in September 2008 and is scheduled to finish in FY 2010. The project received its final funding of $600,000 under the Recovery Act.

Neutron Electric Dipole Moment (nEDM), LANL: This MIE fabricates a cryogenic apparatus to measure the neutron electric dipole moment using ultra-cold neutrons from the FNPB. It received CD-1 approval in February 2007 and is scheduled to finish in FY 2015. The NSF expects to contribute $7.3 million to this project.

Cryogenic Underground Observatory for Rare Events (CUORE), LBNL: This MIE fabricates the U.S. contribution to the Italian-led CUORE experiment to measure fundamental neutrino properties. It received CD-1 approval in February 2008 and is scheduled to finish in FY 2013.
The NSF expects to contribute $1.3 million to this project.

Rare Isotope Beam Science Initiatives: These initiatives consist of one or more MIEs to fabricate instrumentation creating forefront science opportunities at leading rare isotope beam facilities around the world. They received CD-0 approval in February 2009 and are scheduled for initiation in FY 2010 and completion between FY 2012 and FY 2017. The projects will be selected following peer review of solicited proposals.

Construction Projects

(dollars in thousands)

	Prior Years	FY 2008	FY 2009	FY 2009 Additional Approp.	FY 2010	Outyears	Total
12 GeV CEBAF Upgrade, TJNAF							
TEC	7,500	13,377	28,623	65,000	22,000	151,000	287,500
OPC	9,500	1,000	—	—	—	12,000	22,500
TPC	17,000	14,377	28,623	65,000	22,000	163,000	310,000
Electron Beam Ion Source, BNL							
TEC	7,100	4,162	2,438	—	—	—	13,700
OPC	800	100	200	—	—	—	1,100
TPC	7,900	4,262	2,638	—	—	—	14,800
Total Construction							
TEC		17,539	31,061	65,000	22,000		
OPC		1,100	200	—	—		
TPC		18,639	31,261	65,000	22,000		

Scientific Employment

	(estimated)		
	FY 2008	FY 2009	FY 2010
# University Grants	184	190	200
Average Size per year	$310,000	$335,000	$345,000
# Laboratory Projects	28	33	33
# Permanent Ph.Ds	733	698	720
# Postdoctoral Associates	365	342	390
# Graduate Students	493	490	510
# Ph.D.s awarded	89	80	80

06-SC-01, 12 GeV CEBAF Upgrade, Thomas Jefferson National Accelerator Facility
Newport News, Virginia
Project Data Sheet is for PED/Construction

1. Significant Changes

This Project Data Sheet (PDS) is an update of the FY 2009 PDS.

The most recent DOE O 413.3A approved Critical Decision (CD) is CD-3, Approve Start of Construction, which was signed on September 15, 2008, with a Total Project Cost (TPC) of $310,000,000. Construction was authorized to begin under the FY 2009 Continuing Resolution at FY 2008 funding levels. In March 2009, the project received funding from the American Recovery and Reinvestment Act of 2009 (ARRA) that advances a portion of future FY 2010 and FY 2011 appropriations. The funding is anticipated to reduce project risks. There have been no changes in project scope, cost, or schedule since the project was baselined. There is one high risk and three moderate risks associated with this project, each with a mitigation plan to achieve successful completion. A Federal Project Director (FPD) with certification Level III was assigned to this project as required.

2. Design, Construction, and D&D Schedule[a]

(fiscal quarter or date)

	CD-0	CD-1	PED Complete	CD-2	CD-3	CD-4	D&D Start	D&D Complete
FY 2007	03/31/2004	1Q 2007	4Q 2009	4Q 2007	4Q 2008	1Q 2014	N/A	N/A
FY 2008	03/31/2004	2/14/2006[a]	4Q 2009	4Q 2007	4Q 2008	1Q 2015	N/A	N/A
FY 2009	03/31/2004	2/14/2006	4Q 2009	11/09/2007	4Q 2008	3Q 2015	N/A	N/A
FY 2010	03/31/2004	2/14/2006	4Q 2009	11/09/2007	09/15/2008	3Q 2015	N/A	N/A

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
CD-3 – Approve Start of Construction
CD-4 – Approve Start of Operations or Project Closeout D&D Start – Start of Demolition & Decontamination (D&D) work
D&D Complete –Completion of D&D work

[a] CD-1 was approved on 2/14/2006. Engineering and design activities started in 4Q FY 2006 after Congress approved the Department of Energy's request to reprogram $500,000 within the FY 2006 funding for Nuclear Physics, per direction contained in H.Rpt 109–275.

3. Baseline and Validation Status

(dollars in thousands)

	TEC, PED	TEC, Construction	TEC, Total	OPC Except D&D	OPC, D&D	OPC, Total	TPC
FY 2007	21,000	TBD	TBD	11,000	TBD	TBD	TBD
FY 2008	21,000	TBD	TBD	10,500	TBD	TBD	TBD
FY 2009	21,000	266,500	287,500	22,500	N/A	22,500	310,000
FY 2010	21,000	266,500	287,500	22,500	N/A	22,500	310,000[a]

4. Project Description, Justification, and Scope

The Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility, or Jefferson Laboratory, is today the world-leading facility in the experimental study of hadronic matter. An energy upgrade of CEBAF has been identified by the nuclear science community as a compelling scientific opportunity that should be pursued. In particular, the Nuclear Science Advisory Committee (NSAC) stated in the 1996 Long Range Plan that "…the community looks forward to future increases in CEBAF's energy, and to the scientific opportunities that would bring." In the 2007 Long Range Plan, NSAC concluded that completion of the 12 GeV CEBAF Upgrade project was the highest priority for the Nation's nuclear science program.

- The 12 GeV CEBAF Upgrade directly supports the Nuclear Physics mission and addresses the objective to measure properties of the proton, neutron, and simple nuclei for comparison with theoretical calculations to provide an improved quantitative understanding of their quark substructure. The upgrade is identified as a near-term priority in the Office of Science Twenty-Year Outlook.

The scope of the project includes upgrading the electron energy capability of the main accelerator from 6 GeV to 12 GeV, building a new experimental hall (Hall D) and associated beam-line, and enhancing the capabilities of the existing experimental halls to support the most compelling nuclear physics research.

Key Performance Parameters to achieve CD-4, *Approve Start of Operations or Project Closeout*, are phased around the accelerator and conventional facilities (CD-4A) and the experimental equipment in Halls B, C, and D (CD-4B). The deliverables defining completion are identified in the Project Execution Plan and have not changed since CD-2. Mitigation plans exist to help ensure that the one high risk associated with the breadth of the vendor pool for the cyrogenics work required and three moderate risks associated with the unforeseen technical problems with the superconducting magnets in two experimental Halls and the fabrication of the Silicon Vertex Tracker will not impact the planned completion dates.

---

[a] The Governor of Virginia signed House Bill 1600, the appropriation bill amending the 2008-2010 biennial budget for the Commonwealth of Virginia on March 30, 2009, which provided "$6,000,000 for Jefferson Science Associates, LLC to leverage a federal investment of $310 million for an upgrade of the Jefferson Lab's research facilities, which will maintain its leadership in the study of nuclear physics and secure the benefits of such a facility for the Commonwealth." This funding will be paid in $500,000 monthly increments beginning in July 2009. It is anticipated that this funding will reduce project cost risks and schedule risks and help ensure timely completion of the project. The SC Office of Project Assessment's annual review planned for September 21, 2009, will evaluate any adjustments to the federal government's share of the TPC as a result of the funding from the Commonwealth of Virginia.

The project is being conducted in accordance with the project management requirements in DOE O 413.3A, *Program and Project Management for the Acquisition of Capital Assets*, and all appropriate project management requirements have been met.

5. Financial Schedule

(dollars in thousands)

	Appropriations	Obligations	Recovery Act Costs	Costs
Total Estimated Cost (TEC)				
PED				
FY 2006	500	500	—	88
FY 2007	7,000	7,000	—	6,162
FY 2008	13,377[a]	13,377	—	9,108
FY 2009	123[a]	123	—	5,642
Total, PED	21,000	21,000	—	21,000
Construction				
FY 2009	28,500	28,500	—	2,878
FY 2009 Recovery Act	65,000	65,000	12,520	—
FY 2010	22,000	22,000	32,200	29,000
FY 2011	34,000	34,000	14,485	29,000
FY 2012	66,000	66,000	4,400	58,622
FY 2013	40,500	40,500	1,395	53,000
FY 2014	10,500	10,500	—	26,500
FY 2015	—	—	—	2,500
Total, Construction	266,500	266,500	65,000	201,500
TEC				
FY 2006	500	500	—	88
FY 2007	7,000	7,000	—	6,162
FY 2008	13,377	13,377	—	9,108
FY 2009	28,623	28,623	—	8,520
FY 2009 Recovery Act	65,000	65,000	12,520	—
FY 2010	22,000	22,000	32,200	29,000
FY 2011	34,000	34,000	14,485	29,000
FY 2012	66,000	66,000	4,400	58,622
FY 2013	40,500	40,500	1,395	53,000
FY 2014	10,500	10,500	—	26,500
FY 2015	—	—	—	2,500
Total, TEC	287,500	287,500	65,000	222,500

[a] The baseline FY 2008 PED funding was reduced by $123,000 as a result of the FY 2008 rescission. This reduction is restored in FY 2009 to maintain the TEC and project scope.

	(dollars in thousands)			
	Appropriations	Obligations	Recovery Act Costs	Costs
Other Project Cost (OPC)				
OPC except D&D				
FY 2004	700	700	—	77
FY 2005	2,300	2,300	—	2,142
FY 2006	4,000	4,000	—	3,508
FY 2007	2,500	2,500	—	2,751
FY 2008	1,000	1,000	—	1,802
FY 2009	—	—	—	220
FY 2013	2,500	2,500	—	2,400
FY 2014	7,500	7,500	—	7,000
FY 2015	2,000	2,000	—	2,600
Total, OPC	22,500	22,500	—	22,500
Total Project Cost				
FY 2004	700	700	—	77
FY 2005	2,300	2,300	—	2,142
FY 2006	4,500	4,500	—	3,596
FY 2007	9,500	9,500	—	8,913
FY 2008	14,377	14,377	—	10,910
FY 2009	28,623	28,623	—	8,740
FY 2009 Recovery Act	65,000	65,000	12,520	—
FY 2010	22,000	22,000	32,200	29,000
FY 2011	34,000	34,000	14,485	29,000
FY 2012	66,000	66,000	4,400	58,622
FY 2013	43,000	43,000	1,395	55,400
FY 2014	18,000	18,000	—	33,500
FY 2015	2,000	2,000	—	5,100
Total, TPC	310,000	310,000	65,000	245,000

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Estimate
Total Estimated Cost (TEC)			
Design (PED)			
Design	20,150	19,200	19,200
Contingency	850	1,800	1,800
Total, PED (PED no. 06-SC-01)	21,000	21,000	21,000
Construction Phase			
Civil Construction	29,290	27,450	27,450
Accelerator/ Experimental Equipment	171,810	174,150	174,150
Contingency	65,400	64,900	64,900
Total, Construction	266,500	266,500	266,500
Total, TEC	287,500	287,500	287,500
Contingency, TEC	66,250	66,700	66,700
Other Project Cost (OPC)			
OPC except D&D			
Conceptual Design	3,445	3,500	3,500
R&D	7,020	6,400	6,400
Start-up	7,385	7,450	7,450
Contingency	4,650	5,150	5,150
Total, OPC	22,500	22,500	22,500
Contingency, OPC	4,650	5,150	5,150
Total, TPC	310,000	310,000	310,000
Total, Contingency	70,900	71,850	71,850

7. Schedule of Project Costs

For schedule of project costs, see Section 5, "Financial Schedule."

8. Related Operation and Maintenance Funding requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	3Q FY 2015
Expected Useful Life (number of years)	15
Expected Future start of D&D for new construction (fiscal quarter)	N/A

(Related Funding requirements)

(dollars in thousands)

	Annual Costs		Life cycle costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Total Project Costs	N/A	N/A	310,000	310,000
Operations	150,000	150,000	2,250,000[a]	2,250,000[a]
Maintenance	Included above	Included above	Included above	Included above
Total, Operations & Maintenance	150,000	150,000	2,560,000	2,560,000

9. Required D&D Information

	Square Feet
Area of new construction	31,500
Area of existing facility(ies) being replaced	N/A
Area of any additional D&D space to meet the "one-for-one" requirement	31,500

The "one-for-one" requirement is met by offsetting 31,500 square feet of the 80,000 square feet of banked space that was granted to TJNAF in a Secretarial waiver.

10. Acquisition Approach

The Acquisition Strategy was approved in 2Q FY 2006 with CD-1 approval. All acquisitions will be managed by Jefferson Science Associates with appropriate Department of Energy oversight. Cost, schedule and technical performance will be monitored using an earned-value process that is described in the Jefferson Lab Project Control System Manual. The procurement practice is to use firm fixed-price purchase orders and subcontracts for supplies, equipment and services, and to make awards through competitive solicitations. Project and design management, inspection, coordination, tie-ins, testing and checkout witnessing, and acceptance will be performed by TJNAF and A-E subcontractors as appropriate.

[a] The total operations and maintenance (O&M) is estimated at an average annual cost of ~$150,000,000 (including escalation) over 15 years. Almost 90% of the O&M cost would still have been required had the existing accelerator not been upgraded and instead continued operations at 6 GeV.