Nuclear Physics

Funding Profile by Subprogram

(dollars in thousands)

	FY 2009 Current Appropriation	FY 2009 Current Recovery Act Appropriation[a]	FY 2010 Current Appropriation	FY 2011 Request
Nuclear Physics				
Medium Energy Nuclear Physics	116,873	+15,390	127,590	129,610
Heavy Ion Nuclear Physics	194,957	+12,669	212,000	218,435
Low Energy Nuclear Physics	94,880	+29,667	114,636	113,466
Nuclear Theory	37,776	+17,237	41,574	44,709
Isotope Development and Production for Research and Applications[b]	24,760	+14,837	19,200	19,780
Subtotal, Nuclear Physics	469,246	+89,800	515,000	526,000
Construction	31,061	+65,000	20,000	36,000
Total, Nuclear Physics	500,307[c]	+154,800	535,000	562,000

Public Law Authorizations:

Public Law 95–91, "Department of Energy Organization Act", 1977

Public Law 101–101, "1989 Energy and Water Development Appropriations Act," establishing the Isotope Production and Distribution Program Fund)

Public Law 103–316, "1995 Energy and Water Development Appropriations Act," amending 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.

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

[a] The Recovery Act Appropriation column reflects the allocation of funding as of September 30, 2009.

[b] The Isotope Development and Production for Research and Applications program was transferred to the Office of Science from the Office of Nuclear Energy in FY 2009.

[c] Total is reduced by $11,773,000: $10,512,000 of which was transferred to the Small Business Innovative Research (SBIR) program and $1,261,000 of which was transferred to the Small Business Technology Transfer (STTR) program.

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 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:

- **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

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

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 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 being 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 made 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 by 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 decade 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 world-wide. DOE applies its unique expertise and capabilities to address technology issues associated with the application, production, handling, and distribution 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.

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 TJNAF) 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 of six of the Nuclear Physics program's university Centers of Excellence that has 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 two nuclear science frontiers—Nuclear Structure and Astrophysics and Fundamental Symmetries 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) at Michigan State University (MSU) is a next-generation machine that will advance the understanding of rare nuclear isotopes and the evolution of the cosmos. The subprogram also supports four university Centers of Excellence, three with unique low energy accelerator facilities and one with infrastructure capabilities for developing advanced instrumentation. These university Centers of Excellence provide outstanding hands-on science, technology, and engineering educational opportunities for students at various stages in their career. In addition, the program 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.
- Finally, 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 sited underground to shield them from cosmic background radiation 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 nuclear science subprograms and to

advance new ideas and hypotheses that stimulate experimental investigations. This subprogram supports the one of the program's university Centers of Excellence, 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, national security, and 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 Linac 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, other 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 interfaces with the user community and manages the coordination of isotope production across the many facilities and the business operations of the sale and distribution of isotopes.

Benefits

NP supports a wide range of facilities, instruments, and research that create forefront scientific knowledge and state-of-the-art tools to serve the Nation. Nuclear science basic research and the advancement of knowledge of nuclear matter and its properties are inherently relevant to and intertwined with a broad range of applications including nuclear power, waste disposal, nuclear medicine, commerce, medical physics, space exploration, finance, geology, environmental sciences, and national security. The NP program develops advanced instrumentation, accelerator technologies, and analytical and computational techniques that are needed for nuclear science research and which have broad societal and economic benefits, and supports reliable, timely, and economical delivery of stable and radioactive isotopes for commercial application and research. The development and construction of facilities and advanced instrumentation and accelerator technology needed to reach performance goals of the program not only contribute technically to other research and applied sciences, but educate a next generation of scientists and help to create technical and engineering jobs.

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 isotope availability and nuclear radiation, which made possible the entire field of nuclear medicine used today in both the diagnosis and treatment of disease.

Enhancements in isotope production and processing techniques has fueled the development of new isotopes, 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 research. The various applications resulting from isotope availability have improved the ability of physicians to diagnose illnesses and improved the quality of life and longevity for innumerable patients and strengthened 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. Each year several national laboratory junior scientists within the NP program have been recognized with Presidential Early Career Awards for Scientists and Engineers for their outstanding contributions to nuclear and accelerator physics research and their promise as future leaders of the field. In FY 2009, three junior laboratory researchers at BNL, TJNAF, and LANL were recognized for their efforts by receiving this prestigious award. 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 effectively as possible, the NP program has developed a rigorous and comprehensive system of planning and priority setting that relies heavily on input from groups of outside experts. All activities within the subprograms are peer reviewed and performance is assessed on a regular basis. Priority is given to those research activities which support the most compelling scientific opportunities. 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. NSAC completed a report in April 2009 that identifies *Compelling Research Opportunities Using Isotopes,*[a] and a second report, issued in November 2009, lays out a strategic plan for the Isotope Development and Production for Research and Applications subprogram, *Isotopes for the Nation's Future—A Long Range Plan.*[a] NSAC's most recent charge is to conduct a Committee of Visitors (COV) review of NP management processes in FY 2010.

NP strategic plans are also influenced by National Academies reports, Office of Science and Technology Policy (OSTP) and National Security Council (NSC) Interagency Working Group (IWG) efforts, the

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

latter two under the auspices of the Executive Office of the President. 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) Biological and Environmental Research program, to better coordinate radioisotope production and to address other issues important to nuclear medicine. The National Academies embarked on a new decadal study of nuclear science in 2009. In order to optimize interagency activities, NP is involved in four OSTP or NSC IWG's: *Large Scale Science, Forensic Science, Molybdenum-99 Production,* and *The Physics of the Universe*.

NP 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 NP's assessment of laboratory performance as documented in annual SC laboratory appraisals. The peer reviews result in recommendations and the institutions are held accountable for responding to them. Annual reviews of instrumentation projects, conducted by experts, focus on scientific merit, technical status and feasibility, cost and schedule, and effectiveness of management approach. The NP program conducted 22 such reviews with panels of national and international experts in FY 2009. 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 to determine the allocation of this scarce scientific resource. The Program Advisory Committees 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.

University grants are proposal driven. The NP 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 2009 for the Nuclear Theory 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 nuclear power, waste disposal, nuclear medicine, commerce, medical physics, space exploration, finance, geology, environmental sciences, national security, and others. In FY 2009, NP initiated support for targeted initiatives in Applications of Nuclear Science and Technology, the primary goal of which is to pursue forefront nuclear science research and development important to the NP mission, but inherently relevant to applications. One of the goals of this initiative was to help bridge the gap between basic research and applied science. The response to the first solicitation to this initiative in FY 2009 was extremely successful, with over 200 proposals submitted. A total of 22 awards were made with a combination of appropriated base funding and Recovery Act funds. The proposals supported include nuclear physics research that is relevant to the development of advanced fuel cycles for next generation nuclear power reactors; advanced and cost-effective accelerator technology and

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

particle detection techniques for medical diagnostics and treatment; and research in developing neutron, gamma and particle beam sources with applications in cargo screening and nuclear forensics. These initiatives are peer reviewed with participation from the applied sciences community. The integration of the underpinning nuclear science advances, resulting from innovative basic research with the applied sciences will optimize 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 research isotopes that are important for basic research and applications. 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. To ascertain current and future demands of the research community, NP continues to develop working groups with other federal agencies, foster interactions between researchers and Isotope Program staff, obtain data from site visits, attend society exhibitions, and develop strategic plans and priorities with community input. Recent examples include: forming a DOE and National Institutes of Health (NIH) federal working group to address the recommendations of the recent National Academies report, *Advancing Nuclear Medicine through Innovation*, which identified several areas in isotope production warranting attention; attending the Society of Nuclear Medicine annual meeting in Toronto in June 2009 and sponsoring a workshop dedicated to the use and production of alpha-emitters in medicine; and working with industry to define a path forward for ensuring the long-term availability of californium-252, an isotope of strategic and economic importance to the Nation. NP is also establishing cooperative isotope supply contracts with universities to increase the Department's ability to meet researchers' requests by improving product availability and reliability.

The Isotope Development and Production for Research and Applications subprogram also supports research for the development of alternative production and extraction techniques of stable and radioactive isotopes and the production of research isotopes identified by NSAC as needed for high priority research opportunities across a broad range of scientific disciplines.

Budget Overview

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 2011 budget appropriation 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, facility operations, and investments in advanced technology and capabilities. The increase of $27,000,000 over the FY 2010 appropriation includes a $16,000,000 increase in the baselined funding profile for the 12 GeV CEBAF Upgrade project, an increase in operations of the RHIC facility, and an increase to the rest of the NP program of about 2 percent relative to FY 2010 to maintain research efforts. The completion of the 12 GeV Upgrade is identified by NSAC as the highest priority for the field.

The heart of the program is the group of highly trained scientists who conceive, plan, execute, and interpret the numerous experiments carried out at various nuclear physics facilities. NP supports scientists at both universities and national laboratories and is involved in a variety of international collaborations. The program 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. With the FY 2011 request, research activities are conducted at approximately 90 academic institutions located in 35 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 excellent hands-on training opportunities for junior scientists. The Outstanding Junior Investigator (OJI) program, initiated in FY 2000, made approximately three new awards each year to early career tenure-track faculty through FY 2009 and has been very successful in identifying, recognizing, and supporting promising junior university faculty and future leaders of the field.

Research at nine national laboratories 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 detector and accelerator R&D 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 employing 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 facilities and equipment are large, complex, and expensive to build and operate, and thus they account for a significant portion of the program's budget—approximately 65 percent of the FY 2011 request. It is the planned project profiles that typically drive the funding increases within the NP federal budget requests. 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 scientific facilities provide research beams for a user community of approximately 3,300 scientists from all over the world, with more than 2,500 of the users utilizing RHIC and CEBAF. Approximately 40 percent of the users are from institutions outside of the U.S., and they 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 research programs.

The FY 2011 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 18,910 hours of beam time for research, a decrease of about 650 hours compared with the anticipated beam hours in FY 2010 due to a planned shutdown period at CEBAF associated with the construction of the 12 GeV CEBAF Upgrade project at TJNAF. The major scientific user facilities will be maintained and operated so that the unscheduled operational downtime will be kept to less than 20 percent, on average, of total scheduled operating time. Investments will be made in programmatic infrastructure, facility equipment, and accelerator improvement projects that will increase productivity, reliability, and cost-effectiveness, and provide new capabilities to pursue high discovery science.

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

Construction of the 12 GeV CEBAF Upgrade project continues in FY 2011. The FY 2011 request reflects the final adjustment to the original planned funding profile to account for the advanced funding provided in FY 2009 under the Recovery Act. This project is the highest priority in the NSAC Long Range Plan for Nuclear Science. The 12 GeV CEBAF Upgrade project is expected to create over 500 jobs that are related to the construction of the project. Because the project is of high priority, over $50,000,000 is redirected from the base CEBAF program towards the construction over the lifetime of the project.

Approximately 2 percent of the total NP budget in FY 2011 is invested in a handful of ongoing small-scale Major Items of Equipment (MIE) projects, each 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. In FY 2010, conceptual design, NEPA activities, and R&D are supported for the proposed Facility for Rare Isotope Beams (FRIB), a next-generation nuclear structure and astrophysics machine that will map out the nuclear landscape. This project is supported with operating funds through a Cooperative Agreement with MSU. Although the FRIB property will not be a capital asset to the federal government and will be owned by the university, FRIB will be operated as a DOE national user facility upon completion. In FY 2011, funds are requested for engineering and design activities for FRIB. The FRIB project is expected to create approximately 800 jobs in the state of Michigan during the course of construction.

All of the NP subprograms benefited from Recovery Act funding. In Medium Energy support was provided for: advance funding of the 12 GeV CEBAF Upgrade project to accelerate procurements and reduce cost and schedule risk ($65,000,000); an accelerator improvement project at CEBAF to enhance facility capability ($2,760,000); and infrastructure improvements at TJNAF to accomplish backlogged projects ($10,000,000). In Heavy Ion support was provided for: completion of the PHENIX Silicon Vertex and Forward Vertex Major Items of Equipment (MIEs) ($2,250,000); and accelerator improvement projects to increase the luminosity of the RHIC collider beams ($8,000,000). In Low Energy support was provided for: completion of the Fundamental Neutron Physics Beamline MIE ($600,000); accelerator improvement projects at HRIBF, ATLAS and the 88-Inch Cyclotron to enhance facility capabilities ($14,240,000); and research under the Applications of Nuclear Science and Technology solicitation ($11,420,000). In Nuclear Theory support was provided for: workforce succession planning for the National Nuclear Data Program ($1,944,000); augmentation of the LQCD computing capabilities at TJNAF ($4,965,000); and research under the Applications of Nuclear Science and Technology solicitation ($8,020,000). In Isotope Development and Production for Research and Applications support 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 ($4,617,000); and 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 ($10,000,000).

Significant Program Shifts

There are no significant shifts in the Nuclear Physics program in FY 2011.

Annual Performance Targets and Results

Secretarial Priority: Innovation: Lead the world in science, technology, and engineering.

GPRA Unit Program Goal: Nuclear Physics Program Goal: *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.*

NP contributes to this Secretarial Priority and GPRA goal through strategic investments in science for discovery, science for national need, and national scientific user facilities—the 21st century tools for science, technology, and engineering. NP supports scientific research to discover, explore and understand all forms of nuclear matter focused on three strategic themes:

- Developing a complete understanding of how quarks and gluons assemble themselves into the various forms of nuclear matter, and searching for as yet undiscovered forms of matter.
- Understanding how protons and neutrons combine to form atomic nuclei, and how these nuclei have arisen since the birth of the cosmos.
- Developing a better understanding of the fundamental properties of the neutron and the neutrino, and exploring the implications of their properties for the Standard Model of fundamental particle and interactions.

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

- Make 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;
- Create brief, tiny samples of hot, dense nuclear matter to search for the quark-gluon plasma and characterize its properties;
- Investigate new regions of nuclear structure, study interactions in nuclear matter like those occurring in neutron stars, and determine the reactions that created the nuclei of atomic elements inside stars and supernovae; and
- Measure fundamental properties of neutrinos and fundamental symmetries by using neutrinos from the sun and nuclear reactors and by using radioactive decay measurements.

Annual Performance Measure: Achieve at least 80% of the integrated delivered beam used effectively for all experiments run at each of the Argonne Tandem Linac Accelerator System (ATLAS) and the Holifield Radioactive Ion Beam (HRIBF) facilities measured as a percentage of the scheduled delivered beam considered effective for each facility.[a]

FY 2009	T: ≥ 80% A: Goal not met. ATLAS met the goal by achieving 92.4% of the integrated delivered beam used effectively for all experiments run at the facility. HRIBF achieved 77%, 3% short of the goal, as a result of an operational emergency that occurred near the end of FY 2008.

[a] Measure established in FY 2009

FY 2010–2015	T: ≥ 80% A: TBD

Annual Performance Measure: 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 (CEBAF) measured as a percentage of the scheduled delivered beam considered effective for each Hall. The values from each Hall will be averaged for the end of year result starting in FY 2010.[a]

FY 2009	T: ≥ 80% A: Goal not met. Halls A and B met their goals for the year by achieving 95.9% and 86.6% effective use of their planned integrated delivered beam, respectively. However, because Hall C only achieved 67.4%, thus failing to meet its goal of 80%, the overall goal was "not met." Hall C performance was impacted by the failure of a target provided by outside collaborators that required significant time to repair and a second commissioning period.
FY 2010–2015	T: ≥ 80% A: TBD

Annual Performance Measure: Achieve at least 80% of the projected integrated heavy-ion 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.[a]

FY 2009	T: N/A, Heavy-Ion collision experiments were not planned for FY 2009. A:
FY 2010–2015	T: ≥ 80% A: TBD

Annual Performance Measure: Achieve at least 80% of the projected integrated proton-proton collision luminosity for 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.[a]

FY 2009	T: ≥ 80% A: Goal not met. PHENIX met the goal by achieving 90.5% of sampled integrated proton-proton collision luminosity, while STAR achieved only 65.4%. The STAR detector's low number is due to the fact that RHIC did not achieve its projected integrated luminosity for 200 GeV running. Both detectors were impacted, but only STAR failed to make the 80% goal. The facility was not able to achieve projected increases in the luminosity at 200 GeV that it had achieved in previous years. Beam studies indicated that the 200 GeV luminosity is at a maximum for the present machine configuration.

[a] Measure established in FY 2009

FY 2010–2015	T: Proton-proton collision experiments are not planned for FY 2010. A: N/A

Annual Performance Measure: Achieve at least 80% average operation time of the scientific user facilities as a percentage of the total scheduled annual operating time.

FY 2006	T: 80% of scheduled operating time A: Goal met
FY 2007	T: 80% of scheduled operating time A: Goal met
FY 2008	T: 80% of scheduled operating time A: Goal met
FY 2009	T: 80% of scheduled operating time A: Goal met
FY 2010–2015	T: 80% of scheduled operating time A: TBD

Annual Performance Measure: 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.

FY 2006	T: N/A, no major construction project/MIE tracked this fiscal year. A:
FY 2007	T: N/A, no major construction project/MIE tracked this fiscal year. A:
FY 2008	T: Cost and schedule variance are both less than 10% A: Goal met
FY 2009	T: Cost and schedule variance are both less than 10% A: Goal met
FY 2010–2015	T: Cost and schedule variance are both less than 10% A: TBD

Medium Energy Nuclear Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Medium Energy Nuclear Physics			
Research			
University Research	18,678	19,674	20,796
National Laboratory Research	16,864	18,085	18,590
Other Research[a]	937	7,309	6,979
Total, Research	36,479	45,068	46,365
Operations			
TJNAF Operations	80,394	82,522	83,245
Total, Medium Energy Nuclear Physics	116,873	127,590	129,610

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 also 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? Finally, this subprogram 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?

Funding for this subprogram 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

[a] In FY 2009, $3,665,000 was transferred to the SBIR program and $1,246,000 was transferred to the STTR program. This activity includes $4,034,000 for SBIR and $1,334,000 for STTR in FY 2010 and $4,082,000 for SBIR and $1,354,000 for STTR in FY 2011.

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.

Construction of the 12 GeV CEBAF Upgrade project is a priority. CEBAF operations are reduced from 5,110 to 4,090 hours, the maximum level of operations possible in FY 2011 due to a planned shutdown to accommodate installation of components for the 12 GeV CEBAF Upgrade project.

Selected FY 2009 Accomplishments

- A recent series of measurements from TJNAF show evidence for a possible new excited state of the proton, that if confirmed, would help resolve a major debate concerning whether the three quarks that make up the proton bind together symmetrically or not. Asymmetrical binding was postulated to explain the lack of a large number of excited states predicted by symmetrical binding. If the asymmetrical binding is correct, then this new state should not exist.
- TJNAF researchers are on track to complete one of their major scientific performance milestones to determine the charge and magnetic distributions in the proton and neutron. The data set is of sufficient precision and quantity to allow scientists to separate the contributions of the different flavors of quarks (up, down, and strange) that determine the properties of the proton and neutron. New data on the charge distribution of the neutron have been collected that probe the smallest distances inside the neutron to date.
- TJNAF achieved a top beam energy of 6.0 GeV during their FY 2009 run period. This was a goal of the accelerator cavity refurbishment program that began in FY 2006 to increase the beam energy from the nominal maximum of 5 GeV.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Research	**36,479**	**45,068**	**46,365**
▪ **University Research**	**18,678**	**19,674**	**20,796**

This activity supports about 160 scientists and 125 graduate students at 33 universities in 21 states and the District of Columbia studying QCD and the behavior of quarks inside protons and neutrons. The university scientists conduct experiments at CEBAF and RHIC and participate in the development and fabrication of advanced instrumentation for utilization at these facilities. These state-of-the-art detectors often have relevance to applications in medicine and homeland security. Included in this activity is support for the Massachusetts Institute of Technology's Research and Engineering (R&E) Center that has specialized infrastructure for fabrication of scientific instrumentation. The Center has unique expertise in the study of high current, polarized electron sources. The FY 2011 request starts to build a user community for the new experimental hall scientific program being constructed as part of the 12 GeV CEBAF Upgrade Project.

▪ **National Laboratory Research**	**16,864**	**18,085**	**18,590**

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

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

using laser trapping technology at ANL. Funding decisions are influenced by the results of periodic peer reviews of the national laboratory research groups and their subsequent ranking in terms of performance level.

• **TJNAF Research**	**6,150**	**6,200**	**6,695**

TJNAF staff research efforts include developing experiments, acquiring data, and performing data analysis in the three existing CEBAF experimental Halls. Funding is provided to develop a scientific group for the new experimental Hall D that is being constructed as part of the 12 GeV CEBAF Upgrade project. Scientists also are identifying the scientific opportunities and developing the scientific goals for next generation facilities. The remaining approximately 70 percent of support for experiments at CEBAF is under Experimental Support discussed below. Funding also supports an active visiting scientist program at the laboratory and bridge positions with regional universities, which is a cost-effective approach to augmenting scientific expertise at the laboratory and boosts educational opportunities in the southeast region of the Nation. Detectors developed for nuclear physics research supported at TJNAF have found applications in medical imaging instrumentation.

• **Other National Laboratory Research**	**10,714**	**11,885**	**11,895**

Argonne National Laboratory scientists continue their primary research program at TJNAF and one experiment at Fermilab. Argonne scientists are leading an experiment at Fermilab to distinguish the different quark contributions to the structure of the proton. These measurements are also important to interpreting the RHIC proton spin measurements. 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. This technology at ANL has found practical applications in geology and environmental fields, for example, in tracking ground water flows in Egypt.

Support is provided to the RHIC spin physics research groups at BNL, LBNL, and LANL, which have important roles and responsibilities in the RHIC program. These groups play lead roles in determining the spin structure of the proton by development and fabrication of advanced instrumentation, as well as data acquisition and analysis efforts.

At LANL, support is provided to allow scientists and collaborators to complete the Fermilab MiniBooNE anti-neutrino running and analysis. A present discrepancy between the anti-neutrino and neutrino data needs to be resolved with additional anti-neutrino running. If these results are confirmed, they could unveil new physics beyond the Standard Model. The results of these efforts will drive future research directions of this group.

Modest funding for capital equipment investments at these laboratories is provided in support of the above efforts.

▪ **Other Research**	**937**	**7,309**	**6,979**
• **SBIR/STTR and Other**	**572**	**6,544**	**6,279**

In FY 2009, \$3,665,000 was transferred to the Small Business Innovation Research (SBIR) program and \$1,246,000 was transferred to the Small Business Technology Transfer (STTR) program. This activity includes \$4,034,000 for SBIR and \$1,334,000 for STTR in FY 2010 and

	(dollars in thousands)	
FY 2009	FY 2010	FY 2011

$4,082,000 for SBIR and $1,354,000 for STTR in FY 2011 as well as other established obligations that the Medium Energy Nuclear Physics subprogram must meet.

	FY 2009	FY 2010	FY 2011
• **Accelerator R&D Research**	**365**	**765**	**700**

The Medium Energy Accelerator R&D research at universities and laboratories will develop the knowledge, technologies, and trained scientists to design and build the next-generation NP accelerator facilities. These programmatic activities are of relevance to machines being developed by other domestic and international programs and can lead to technological advances that are relevant to a variety of applications. Allocation of these funds will be determined by peer review and competed amongst university and laboratory proposals.

	FY 2009	FY 2010	FY 2011
Operations	**80,394**	**82,522**	**83,245**
▪ **TJNAF Operations**	**80,394**	**82,522**	**83,245**

Funding supports CEBAF operations and experimental support for 4,090 hours and a 3-Hall operations schedule, a 20 percent decrease from estimated running in FY 2010. The run time is the maximum possible due to a planned several-month shutdown in FY 2011 as part of the 12 GeV CEBAF Upgrade project schedule. The savings realized from reduced operational costs, such as power, are offset by cost of living increases for accelerator staff and materials and supplies needed to operate and maintain the facility. CEBAF is a unique facility with unparalleled capabilities using polarized electron beams to study quark structure; there is no other facility in the world like it and its user community has a strong international component.

	FY 2009	FY 2010	FY 2011
• **TJNAF Accelerator Operations**	**51,335**	**51,755**	**52,675**

Support is provided for the accelerator physicists that operate the facility, operations, power costs, capital infrastructure investments, and accelerator improvements of the CEBAF accelerator complex, and to maintain efforts in developing advances in superconducting radiofrequency (SRF) technology. The core competency in SRF technology that is nurtured at this laboratory plays a crucial role in many DOE projects and facilities outside of nuclear physics and has broad applications in medicine and homeland security. For example, SRF research and development at TJNAF has led to techniques for detection of buried land mines using terahertz radiation and carbon nanotube and nano-structure manufacturing techniques for the manufacture of super-lightweight composites such as aircraft fuselages.

TJNAF also has a core competency in cryogenics and has developed award-winning techniques which have led to more cost-effective operations at TJNAF and several other Office of Science facilities. TJNAF has recently been approached by the national Canadian nuclear physics facility, known as TRIUMF, and CERN for implementation of its cryogenic techniques.

TJNAF accelerator physicists are also strongly engaged in educating the next generation of accelerator physicists, with seventeen graduate students integrated into research programs and eleven staff members with university affiliations. TJNAF has started a Center for Accelerator Science at Old Dominion University (ODU) where staff members teach courses at the Center and the laboratory jointly supports the ODU Director position.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

Investments in accelerator improvement projects are aimed at increasing the productivity, cost-effectiveness, and reliability of the facility. Capital equipment investment is targeted towards instrumentation needed to support the laboratory's core competencies in SRF and cryogenics.

	FY 2009	FY 2010	FY 2011
CEBAF Hours of Operation with Beam			
Achieved Operating Hours	5,117	N/A	N/A
Planned Operating Hours	4,965	5,110	4,090
Optimal Hours	5,980	5,980	5,980[a]
Percent of Optimal Hours	86%	85%	68%
Unscheduled Downtime	8.	N/A	N/A
Number of Users	1,350	1,390	1,430

	FY 2009	FY 2010	FY 2011
• **TJNAF Experimental Support**	**29,059**	**30,767**	**30,570**

Experimental Support is provided for the scientific and technical staff, materials, and services for CEBAF experiments 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. Capital equipment investments for experimental support at TJNAF is maintained relative to FY 2010 to provide scientific instrumentation for the major experiments, including data acquisition computing and supporting infrastructure (e.g., targets, mechanical structures, power supplies, gas systems, and cooling equipment). In FY 2011, TJNAF expects to run experiments distributed among all three halls that address compelling physics including a precision measurement of the weak charge of the proton to help constrain new physics beyond the Standard Model, an important experiment for the laboratory's search for missing excited states of the neutron, and experiments that will help develop the laboratory's research program using the 12 GeV CEBAF Upgrade.

The FY 2011 funding supports efforts to implement high priority experiments before the completion of the current 6 GeV experimental program and prior to the 12 GeV CEBAF Upgrade project installation.

	FY 2009	FY 2010	FY 2011
Total, Medium Energy Nuclear Physics	**116,873**	**127,590**	**129,610**

[a] While the optimal operations for CEBAF remains at 5,980 hours, the maximum number of hours the facility can operate in FY 2011 is 4,090 hours due to a planned shutdown for installation of 12 GeV components. The facility therefore operates at 100% of maximal hours.

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Research	
▪ **University Research**	
The increase in FY 2011 funding maintains the FY 2010 level of research effort at universities and starts to build a user community for the new experimental Hall D being constructed as part of the 12 GeV CEBAF Upgrade Project.	+1,122
▪ **National Laboratory Research**	
The increase maintains National Laboratory Research at roughly the FY 2010 level of effort and develops a scientific group for the new experimental Hall D that is being constructed as part of the 12 GeV CEBAF Upgrade project.	+505
▪ **Other Research**	
• SBIR/STTR and Other decreases at levels required proportionate to research and development activities.	-265
• Accelerator R&D research funding is provided at approximately the FY 2010 level to allow the university and national laboratory community to continue to develop the technologies needed for next generation NP facilities.	-65
Total, Other Research	**-330**
Total, Research	**+1,297**
Operations	
▪ **TJNAF Operations**	
• **TJNAF Accelerator Operations**	
FY 2011 funding operates CEBAF at the maximum allowable schedule, in consideration of planned shutdowns for 12 GeV CEBAF Upgrade project component installation. The requested funding will support completion of the highest priority experiments within the current 6 GeV program and maintain the staff and infrastructure at approximate constant effort.	+920
• **TJNAF Experimental Support**	
Funding is provided to maintain effort in FY 2011 at a level that supports implementation of the highest priority 6 GeV experiments.	-197
Total, Operations	**+723**
Total Funding Change, Medium Energy Nuclear Physics	**+2,020**

Heavy Ion Nuclear Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Heavy Ion Nuclear Physics			
Research			
University Research	14,009	14,474	15,511
National Laboratory Research	26,640	27,308	26,530
Other Research[a]	0	6,998	7,042
Total, Research	40,649	48,780	49,083
Operations			
RHIC Operations	148,684	157,470	163,301
Other Operations	5,624	5,750	6,051
Total, Operations	154,308	163,220	169,352
Total, Heavy Ion Nuclear Physics	194,957	212,000	218,435

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 plasma 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 plasma.

The RHIC facility places 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. U.S. 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 2009, $5,296,000 was transferred to the SBIR program. This activity includes $5,662,000 for SBIR in FY 2010 and $5,673,000 for SBIR in FY 2011.

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?

The funding for this subprogram is increased in FY 2011 to operate RHIC near optimal levels and to maintain research efforts.

Selected FY 2009 Accomplishments

- Scientists continued work to determine the physical characteristics of the perfect liquid produced in the highly energetic nucleus-nucleus collisions at RHIC. The temperature is one of the most important of these characteristics because 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 and are one indicator of temperature. Further, data analysis now suggests that the initial fluid temperature may correspond to an energy greater than 300 MeV which exceeds the critical temperature thought necessary for the formation of the quark-gluon plasma.
- The formation of the anti-hypertriton (a hypertriton is a hypernucleus which is a nucleus that contains at least one hyperon—an unstable particle with a mass greater than a neutron—in addition to nucleons) is a major new discovery at RHIC. This observation could provide important information about the interior structure of neutron stars and the development of the cosmos.
- In FY 2009, RHIC delivered high intensity beams of polarized protons. Polarized protons were successfully accelerated to 250 GeV and first collisions for physics measurements at this energy occurred for several weeks.
- Plans for luminosity improvements for heavy ion collisions by implementing bunched-beam stochastic cooling systems are in progress. Tests have validated modeling codes which predict luminosity enhancement is feasible. Recovery Act funding has accelerated plans for stochastic cooling systems which are expected to be available in each RHIC collider ring by 2012. Accelerator scientists expect the planned implementation of longitudinal and transverse stochastic cooling to both accelerator rings, together with a new 56 MHz storage radio frequency system, will provide a 10-fold increase in gold beam luminosity by 2012. With these technological advances, the previously envisioned RHIC II upgrade is no longer needed and has been canceled by the NP program, saving the federal government approximately $100,000,000.

Detailed Justification

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Research	**40,649**	**48,780**	**49,083**
▪ **University Research**	**14,009**	**14,474**	**15,511**

Research support is provided for about 120 scientists and 100 graduate students at 30 universities in 19 states. Funding supports research efforts at RHIC and the continuation of a modest program at the

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

LHC with heavy ions. The university groups provide scientific personnel and graduate students needed for running 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. For example, university personnel led the effort in the fabrication of the STAR Time-of-Flight detector, an MIE which was completed on cost and schedule in FY 2009.

The FY 2011 request maintains research effort and supports increases targeted towards operations of recently completed scientific instrumentation.

▪ **National Laboratory Research**	**26,640**	**27,308**	**26,530**

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 that supports the high priority scientific goals for the field of heavy ion physics. 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. Some of the new research topics that will be investigated at RHIC in the next several years include determining the speed of sound in the quark-gluon plasma and trying to discover the critical point in the QCD phase diagram. RHIC could revolutionize the quantitative understanding of the QCD phase diagram by discovering the QCD critical point. Funding decisions are influenced by the results of periodic peer reviews of the national laboratory research groups and their subsequent ranking in terms of performance level.

• **BNL RHIC Research**	**9,602**	**9,032**	**10,797**

The FY 2011 budget request allows BNL scientists to continue to develop and implement new instrumentation, to provide maintenance and infrastructure support of the RHIC experiments, to effectively utilize the beam time for research, to train junior scientists, and to develop the computing infrastructure used by the scientific community. The PHENIX Silicon Vertex Tracker (VTX) MIE, a joint project with Japan, received its final funding increment under the Recovery Act and is on track for completion in FY 2010 on cost and schedule. 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 is on track for completion in FY 2011 on cost and schedule. 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), a new MIE initiated in FY 2010, is an ultra-thin, high-precision tracking detector that will provide direct reconstruction of short-lived particles containing heavy quarks. Support for this initiative ramps up in FY 2011 in accordance with project plans and dominates the increase in this funding category relative to FY 2010. Funding supports the efforts of BNL scientists to identify the most compelling scientific opportunities for a possible future electron ion collider. Capital equipment funds are provided to meet the computing obligations of U.S. researchers involved in the LHC program.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
• **Other National Laboratory Research**	**17,038**	**18,276**	**15,733**

Researchers at LANL, LBNL, LLNL, and ORNL provide support for the RHIC and LHC experiments and develop new instrumentation. They also 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 LHC data analysis. LBNL staff are leading 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 heavy ion experiment to provide the capability to study energy loss in the quark-gluon plasma. Support for the EMCal ramps down in FY 2011 according to the planned profile, and is the cause for the decrease in funding in this category relative to FY 2010.

▪ **Other Research**	**0**	**6,998**	**7,042**
• **SBIR and Other**	**0**	**5,728**	**5,742**

In FY 2009, $5,296,000 was transferred to the Small Business Innovative Research (SBIR) program. This activity includes $5,662,000 for SBIR in FY 2010 and $5,673,000 for SBIR in FY 2011 as well as other established obligations that the Heavy Ion Nuclear Physics subprogram must meet.

• **Accelerator R&D Research**	**0**	**1,270**	**1,300**

The Heavy Ion Accelerator R&D research at universities and laboratories will develop the knowledge, technologies, and trained scientists to design and build the next-generation NP accelerator facilities. These programmatic activities are of relevance to machines being developed by other domestic and international programs and can lead to technological advances that are relevant to a variety of applications. Allocation of these funds will be determined by peer review and competed among university and laboratory proposals.

Operations	**154,308**	**163,220**	**169,352**
▪ **RHIC Operations**	**148,684**	**157,470**	**163,301**

RHIC operations are supported for an estimated 3,720 hour operating schedule (91 percent utilization) in FY 2011, an increase of 370 hours over FY 2010 which effectively addresses high priority scientific opportunities and goals. In FY 2011, it is currently planned to conduct the first search at RHIC for discovering the critical point in the QCD phase diagram. This would be the first such measurement of its kind and is important because it would identify when certain phase transitions occur in a medium, such as a region in the interior of a neutron star, or inside the hot and dense fireball created by a heavy ion collision.

The Electron Beam Ion Source (EBIS) construction project will be 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. EBIS will also lead to more cost-effective operations of the

(dollars in thousands)

	FY 2009	FY 2010	FY 2011

facility as it replaces the aging Tandems as part of the RHIC injector. DOE and NASA partnered on the construction of EBIS, and this project will also provide new capabilities to the NASA Space Radiation Program.

- **RHIC Accelerator Operations** **115,560** **121,935** **126,337**

Support is provided for the operations, power costs, capital infrastructure investments, and accelerator improvement projects of the RHIC accelerator complex. This includes EBIS, the Booster, and AGS accelerators that together serve as the injector for RHIC. Measurements of rare particles will require higher integrated beam luminosity and modest support is provided for R&D of electron beam cooling and other luminosity enhancement technologies. Funding is also provided to reduce the backlog of infrastructure items which most impede the cost-effective and efficient operations of the facility. Operations of RHIC also support parallel (and cost-effective) operations of the NASA Space Radiation Program, for the study of space radiation effects applicable to human space flight, and the Brookhaven Linac Isotope Production Facility (BLIP), for the production of research and commercial isotopes needed by the Nation. Funding is increased to operate RHIC close to optimal levels. A slight decrease in accelerator improvement funding in FY 2011 is made possible by the advance of funding under the Recovery Act in FY 2009.

BNL has nurtured core competencies in accelerator physics techniques, which have had applications in industry, medicine, homeland security, and other scientific projects outside of NP. The RHIC accelerator physicists have been leading the effort to address technical feasibility issues which are of relevance to a possible future collider, including beam cooling techniques and energy recovery linacs. RHIC accelerator physicists also play an important role in the education of next generation accelerator physicists, with support of graduate and post-doctoral students. The laboratory supports the Center for Accelerator Science and Education (CASE) in partnership with Stony Brook University. CASE takes advantage of the collaboration with BNL, providing opportunities for students to learn on the state-of-the-art accelerators at BNL and by having BNL staff teach courses and advise students.

	FY 2009	FY 2010	FY 2011
RHIC Hours of Operation with Beam			
Achieved Operating Hours	3,153	N/A	N/A
Planned Operating Hours	2,915	3,350	3,720
Optimal Hours	4,100	4,100	4,100
Percent of Optimal Hours	77%	82%	91%
Unscheduled Downtime	19.7%	N/A	N/A
Number of Users	1,200	1,200	1,200

- **RHIC Experimental Support** **33,124** **35,535** **36,964**

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.

	FY 2009	FY 2010	FY 2011

(dollars in thousands)

Instrumentation advances by this community have led to practical applications. For example, technical developments from the RHIC detectors, especially PHENIX, have recently led to the development of a positron emission tomography scanner to image the brain of an awake animal. Capital equipment funding is provided to maintain computing capabilities at the RHIC Computing Facility.

	FY 2009	FY 2010	FY 2011
▪ **Other Operations**	**5,624**	**5,750**	**6,051**

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 2009	FY 2010	FY 2011
Total, Heavy Ion Nuclear Physics	**194,957**	**212,000**	**218,435**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Research	
▪ **University Research**	
The increase for University Research grants in FY 2011 maintainseffort for data collection with STAR and PHENIX, supports research at the LHC heavy ion program, and provides for operations of recently completed scientific instrumentation.	+1,037
▪ **National Laboratory Research**	
• BNL RHIC Research is increased relative to FY 2010 largely due to an increase for the fabrication of the STAR HFT MIE according to the planned funding profile, as well as supporting research with the STAR and PHENIX detectors.	+1,765
• Other National Laboratory Research decreases in FY 2011 as funding ramps down for the final year of funding to complete the fabrication of the LHC Heavy Ion MIE according to the planned profile.	-2,543
Total, National Laboratory Research	**-778**
▪ **Other Research**	
• SBIR and Other increases at levels required proportionate to R&D activities.	+14

	FY 2011 vs. FY 2010 ($000)
• Accelerator R&D research is increased in FY 2011 to enable the university and national laboratory community to continue to develop the technologies needed for next-generation NP facilities.	+30
Total, Other Research	**+44**
Total, Research	**+303**
Operations	
▪ **RHIC Operations**	
• RHIC Accelerator Operations increases in FY 2011 to maintain operations 370 hours above FY 2010 levels.	+4,402
• RHIC Experimental Support increases in FY 2011 to maintain efforts associated with the implementation of experimental and computing capabilities and infrastructure.	+1,429
Total, RHIC Operations	**+5,831**
▪ **Other Operations**	
Funding increases to maintain laboratory general purpose equipment.	+301
Total, Operations	**+6,132**
Total Funding Change, Heavy Ion Nuclear Physics	**+6,435**

Low Energy Nuclear Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Low Energy Nuclear Physics			
Research			
University Research	20,601	22,186	22,582
National Laboratory Research	31,447	41,448	41,139
Other Research[a]	960	2,011	1,952
Total, Research	53,008	65,645	65,673
Operations	34,872	36,991	37,793
Facility for Rare Isotope Beams	7,000	12,000	10,000
Total, Low Energy Nuclear Physics	94,880	114,636	113,466

Description

The research effort supported by the Low Energy Nuclear Physics subprogram aims primarily at answering the overarching questions associated with the second and third frontiers identified by NSAC. Questions associated with the second frontier, Nuclei and Nuclear Astrophysics, 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? Major goals of this subprogram are to develop a comprehensive description of nuclei across the entire nuclear chart, to utilize rare isotope beams to reveal new nuclear phenomena and structures unlike those gleaned from studies using stable nuclei, and to 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, Fundamental Symmetries and Interactions, using neutrinos and neutrons as primary probes. 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 non-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 (a Majorana particle). These neutrino properties are believed to play a role in the evolution of the cosmos. Beams of cold and ultracold neutrons will be used for precision measurements of neutron lifetime and beta-decay parameters and to investigate the dominance of matter over antimatter in the universe in order to answer fundamental questions in nuclear and particle physics, astrophysics, and cosmology. Funding supports both research and operations of the subprogram’s two national user facilities, HRIBF and ATLAS, which serve an international community of approximately 700 users. These two facilities

[a] In FY 2009, $1,426,000 was transferred to the SBIR program. This activity includes $1,426,000 for SBIR in FY 2010 and $1,528,000 for SBIR in FY 2011.

provide beams for nuclear structure and astrophysics studies and a strong training ground for the next generation Facility for Rare Isotope Beams (FRIB), which will be constructed at MSU. Both HRIBF and ATLAS possess unique capabilities in an international context and have cutting edge instrumentation. Research at these facilities are coordinated and optimized to achieve the high priority scientific goals for this field. Fabrication of the Gamma Ray Energy Tracking In-Beam Nuclear Array (GRETINA) MIE is on track for completion in FY 2011. GRETINA, a segmented germanium detector array with unparalleled position and energy resolution for nuclear structure studies with fast nuclear beams, will rotate amongst the domestic low-energy facilities thereby increasing scientific productivity. Support continues in FY 2011 for efforts in implementing the Rare Isotope Beam Science Initiatives, enabling U.S. researchers to participate in forefront rare isotope beam facilities with unique capabilities around the world. A peer review process, started in August 2009, recently identified eleven initiatives that will be pursued, varying in cost and complexity. These are now undergoing individual peer review; NP will break out and separately describe the selected Major Items of Equipment in future budget narratives. These efforts encourage cooperation and communication on a global level in this quickly evolving field of science. 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 (USAF) provide support towards improvements in radiation hardness of electronic circuit components against damage caused by cosmic rays. In addition, the subprogram 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. At the University of Washington, the subprogram supports infrastructure to develop scientific instrumentation projects and to provide technical and engineering educational opportunities. These university Centers of Excellence each support 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 ATLAS and HRIBF have 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. nuclear physics program, and the NSAC Long Range Plan recommended its construction. In FY 2008, NP announced an open solicitation to universities and laboratories, inviting proposals for FRIB. Following peer review of the submitted proposals, the DOE selected Michigan State University (MSU) as the host institution to establish FRIB. This project is supported with operating funding through a Cooperative Agreement with MSU and will follow the management principles of DOE O 413.3A. Supporting information on the project is provided at the end of this budget narrative. While not a DOE capital asset (the facility will be owned by the university) it will be operated as a DOE national user facility upon completion. In FY 2011, engineering and design activities begin on FRIB.

In the area of neutrino physics, U.S. researchers are involved in several important efforts focused primarily on neutrino mass and whether the neutrino is its own anti-particle. The U.S. continues to participate in the fabrication of 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 and measure or set a limit on the effective mass of the neutrino using the neutrinoless double beta decay (DBD) mechanism. Efforts also continue in FY 2011 on the Majorana Demonstrator R&D effort to determine technical feasibility of using high purity, enriched germanium to explore the nature of the neutrino via DBD. Projects that study DBD with extreme sensitivity such as these will address two fundamental properties of the neutrino, its mass and its particle-antiparticle nature, that are important for understanding the matter-antimatter asymmetry in the universe and the evolution of the cosmos. U.S. university scientists are also participating in the fabrication of 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, U.S. researchers at the Kamioka Large Anti-Neutrino Detector (KamLAND) experiment in Japan are continuing a modest effort 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 a Japanese-funded upgrade of the detector.

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 is on track for completion in FY 2010 on cost and schedule at the SNS. These include the neutron Electric Dipole Moment Experiment MIE currently being fabricated at Oak Ridge National Laboratory, which could shed light on why the universe is composed mostly of matter when the Big Bang Theory of cosmology suggests that the universe should contain equal amounts of matter and anti-matter.

Finally, it is within the Low Energy subprogram, as well as the Theory subprogram, that the Applications for Nuclear Science and Technology initiative is supported. This effort was started in FY 2009 and was augmented with Recovery Act funds. Community response to this initiative was extremely positive with over 200 proposals that were peer reviewed to identify the most compelling opportunities; 14 projects were selected for funding under the Low Energy program. This initiative supports basic nuclear physics research that addresses high priority scientific goals and has practical applications to other fields, such as medicine, next-generation nuclear reactors, and homeland security.

The Low Energy subprogram is the broadest within the NP portfolio, supporting research activities aligned with diverse scientific thrusts. It also currently supports the most instrumentation projects, as well as the Majorana Demonstrator R&D effort and the Cooperative Agreement to construct FRIB; most of these initiatives are international in nature and project profiles are optimized to take advantage of international commitments.

Selected FY 2009 Accomplishments

- A new upper limit on the permanent electric dipole moment of atomic mercury has been reported by University of Washington scientists. The electric dipole moment is generated by interactions that violate time reversal symmetry (i.e., physical laws remain unchanged when time is reversed). The result obtained for mercury-199 is the most sensitive test of time reversal symmetry violation in ordinary matter achieved to date. Measuring time reversal symmetry is important because it constrains possible extensions of the Standard Model of particles and fundamental interactions.
- New precise mass measurements of 55 neutron-rich nuclei have been carried out at the ATLAS facility with the Canadian Penning Trap. The data indicate that nuclei with increasingly higher neutron excess are not as tightly bound as previously thought. This observation affects nucleosynthesis models of the astrophysical *r*-process, the process responsible for the creation of 50 percent of the elements in the Universe.
- The process of beta-delayed neutron emission (b_n) from fission products created in nuclear reactors contributes to the total number of neutrons inducing fission in nuclear fuels. The b_n also shapes the final distribution of nuclei remaining after a supernovae explosion. Scientists at HRIBF have developed unique methods for separating the rare neutron-rich fission products of interest and measuring their decays. Studies of these pure isotopic samples indicate beta-delayed neutron decay rates that are two to five times higher than previously reported. These findings have important

implications for design of next-generation nuclear fuels and modeling of astrophysical nucleosynthesis processes.

- Successes in the synthesis of the heaviest elements with atomic numbers Z=114 to 118 have been reported by Russian scientists using "hot" fusion reactions. These important results, however, had not been confirmed independently. Recently, scientists using beams and experimental facilities at the 88-Inch Cyclotron at LBNL succeeded in reproducing the Russian results for the synthesis of Element 114. This confirmation allows the field of chemistry to claim the discovery of Element 114 and validates the utility of "hot" fusion as an important tool for synthesis of heavier elements.
- Large amounts of radioactive aluminum-26 (^{26}Al) have been detected in the galaxy by satellite observatories, but the source is still unknown. Researchers at ORNL have used intense beams of ^{26}Al at HRIBF to probe important energy levels that elucidate production and subsequent destruction of this nucleus in some massive and exploding stars. These results are being incorporated into models that aim at improved understanding of ^{26}Al production in the galaxy.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Research	**53,008**	**65,645**	**65,673**
▪ **University Research**	**20,601**	**22,186**	**22,582**

Research aimed at addressing high priority scientific goals is supported for about 126 scientists and 98 graduate students at 35 universities; university research is supported in FY 2011 at approximately a constant level of effort relative to FY 2010. About two-thirds of the supported university scientists conduct nuclear structure and astrophysics research using specialized instrumentation at the ATLAS and HRIBF national user facilities.

Accelerator operations are supported for primarily in-house research programs at the facilities at Duke University, TAMU, and Yale University. These Centers of Excellence 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; they also provide excellent training opportunities to junior scientists and engineers.

University scientists are supported to play key roles in the development of experiments using cold neutrons at the SNS FNPB—an experimental program which is being launched in FY 2011. The FY 2011 request also includes support for the international KATRIN project which is led by a university group.

▪ **National Laboratory Research**	**31,447**	**41,448**	**41,139**

Support is provided for the research programs at six national laboratories (ANL, BNL, LBNL, LANL, LLNL, and ORNL). These scientists continue to develop and implement new instrumentation, to provide maintenance and infrastructure support of the ATLAS and HRIBF, to effectively utilize beam time for research, to train junior scientists, to develop and utilize non-accelerator experiments, and to support the development and fabrication of FRIB. Funding decisions are influenced by the results of periodic peer reviews of the national laboratory research groups and their subsequent ranking in terms of performance level.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
• **National Laboratory User Facility Research**	**11,326**	**8,768**	**9,840**

Questions fundamental to the understanding of stellar nucleosynthesis—how the elements are manufactured in stars—requires accelerators with low energy capabilities. In fact, because many nuclear reactions that take place in stars are at very low energies, an accelerator capable of producing stable low energy beams is a requirement. Funding is provided for ANL researchers for nuclear structure studies using stable and selected radioactive beams from ATLAS coupled to specialized instrumentation. Modest capital equipment investments support the fabrication and implementation of small-scale detectors at the facility. The most recent addition to the unique instrumentation at ATLAS is the HELical Orbit Spectrometer (HELIOS), a novel superconducting solenoidal spectrometer that probes the structure of exotic nuclei.

Because stars generate heavier elements from lighter ones in a process that takes place in the cores of stars or through stellar explosions, many of the intermediate nuclei that are produced are short-lived and very unstable. To study them requires accelerators capable of producing beams composed of radioactive ions. ORNL researchers use radioactive beams from the HRIBF and specialized spectrometers to study the nuclear structure of nuclei far from stability. Nuclei far from stability are thought to play a decisive role in those astrophysical processes that build up heavier elements from lighter nuclei, e.g., in supernovae, and thus knowledge about such exotic nuclei can help us understand our own origin. The fabrication and implementation of small-scale detectors at HRIBF are supported with modest capital equipment investments. For example, the recently completed Low-energy Radioactive Ion Beam Spectroscopy Station (LeRIBSS) enables exploitation of the most neutron rich beams at HRIBF to study fission products such as those in nuclear reactors. Increased funding in FY 2011 maintains efforts at ATLAS and HRIBF.

• **Other National Laboratory Research**	**20,121**	**32,680**	**31,299**

Scientists at BNL, LBNL, LLNL, LANL, and ORNL play lead roles in several high-priority accelerator- and non-accelerator-based projects (nEDM, CUORE, RIB Science Initiatives, GRETINA, FNPB, and KamLAND). Both nEDM and CUORE are joint DOE/NSF-supported projects, but managed by DOE-supported scientists. In addition, DOE-supported scientists have the lead role in the R&D to demonstrate a proof of principle for a neutrino-less double beta decay experiment with germanium, the Majorana Demonstrator. The total cost of the Majorana R&D effort over four years is approximately $20,000,000. Researchers are also supported to develop and implement neutron science experiments at the newly completed fundamental neutron physics beamline at the Spallation Neutron Source and to contribute to FRIB project engineering and design efforts.

Research efforts relevant to Applications of Nuclear Science and Technology are decreased by $980,000 in FY 2011 relative to FY 2010 as a result of funding a number of multi-year initiatives under the Recovery Act. This initiative is competed among university and laboratory researchers and supports nuclear science research that is inherently relevant to a broad range of applications. A number of instrumentation MIEs are supported within this activity; the project funding profiles tend to drive the overall funding requests of this subprogram. Capital equipment funding is increased in FY 2010 to support the ongoing instrumentation projects according to planned profiles and to initiate a new MIE. In FY 2011, funding for capital equipment decreases as the result of planned funding profiles.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

- ► The GRETINA MIE, which is scheduled for completion in FY 2011, 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. GRETINA will be shared amongst low-energy facilities in the United States (including an NSF facility) to cost-effectively boost scientific productivity.
- ► Support is provided to ORNL to continue to play a leadership role in the development of the scientific and experimental program with neutrons at the FNPB, a beamline at the SNS. The FNPB, which will be completed in FY 2010, will deliver cold and ultra-cold neutrons at the highest intensities in the world for studying the fundamental properties of the neutron, leading to a refined characterization of the weak force.
- ► In FY 2011, funding continues for the fabrication of the Electric Dipole Moment of the neutron (nEDM) MIE, a high-risk, high-potential discovery experiment at the FNPB. The nEDM experiment is a joint DOE/NSF experiment to measure a non-zero electric dipole moment of the neutron, which will significantly constrain extensions of the Standard Model. Fabrication, scheduled to start in FY 2010, will be initiated once the project completes high-priority R&D, and is baselined and has CD-2 approval.
- ► In FY 2011, funding ramps down to continue fabrication of the international CUORE experiment to search for neutrino-less double beta decay (DBD) of tellurium-130 isotope. This is a joint DOE/NSF project.
- ► In FY 2011, funding increases to continue Rare Isotope Beam Science Initiatives to support forefront scientific instrumentation opportunities at rare isotope beam facilities around the world. A merit peer review was held in August 2009 to identify the most compelling initiatives to fabricate and to guide the optimum balance of funding between R&D activities and fabrication activities in FY 2010 and FY 2011. The selected initiatives are undergoing project-specific peer review, and selected Major Items of Equipment will be broken out and separately described in future budget narratives. No fabrication activities on the MIEs will be supported prior to project baseline or CD-2 approval.

▪ **Other Research**	**960**	**2,011**	**1,952**

In FY 2009, $1,426,000 was transferred to the SBIR program. This activity includes $1,426,000 for SBIR in FY 2010, and $1,528,000 for SBIR in FY 2011. 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	**34,872**	**36,991**	**37,793**
▪ **ATLAS Operations**	**15,180**	**16,093**	**16,196**

The ATLAS Facility is the premiere stable beam facility in the world. ATLAS accelerator operations and experimental support provide for 5,900 beam hours of operation and continued cost-effective 7 day-a-week operations in FY 2011, the same as FY 2010. The slight increase in funding in FY 2011 maintains level of effort support for scientific and technical personnel. The Californium Rare Ion Breeder Upgrade (CARIBU) accelerator improvement project is completed in FY 2010, and will enhance the radioactive beam capabilities and productivity of ATLAS. Accelerator

	FY 2009	FY 2010	FY 2011

(dollars in thousands)

improvement projects in FY 2011 are focused on increasing the reliability and efficiency of operations. Modest capital equipment funding is provided for helium compressors and cryogenics upgrades to improve operations. The ATLAS facility nurtures a core competency in accelerator expertise with superconducting radio frequency cavities for heavy ions that is relevant to the next generation of high-performance proton and heavy-ion linacs, and is important to the Office of Science mission and international stable and radioactive ion beam facilities. ANL accelerator physicists and scientists are working closely with MSU researchers in the development and fabrication of components for FRIB.

	FY 2009	FY 2010	FY 2011
ATLAS Hours of Operation with Beam			
Achieved Operating Hours	5,448	N/A	N/A
Planned Operating Hours	5,200	5,900	5,900
Optimal Hours	6,600	6,600	6,600
Percent of Optimal Hours	83%	89%	89%
Unscheduled Downtime	4.1%	N/A	N/A
Number of Users	360	410	410

- **HRIBF Operations** **15,860** **16,645** **17,174**

HRIBF is the only facility in the U.S. dedicated solely to the production of radioactive beams by the Isotope Separator On-Line (ISOL) technique, which can produce extremely intense beams of rare isotopes, and is the only one that reaccelerates medium mass nuclei to the Coulomb barrier. Accelerator physicists and scientists at this facility have developed core competencies in high power target design and ISOL ion beam production techniques that are recognized in an international context. HRIBF accelerator operations and experimental support provide for 5,200 beam hours of operation and the transition from 5 day to the more cost effective 7 day-a-week operations. The facility begins to commission a second source and transport beamline (IRIS2) for radioactive ions in FY 2010, which will increase operations efficiency and reliability. Accelerator improvement projects target the elimination of single-point failures and increased operations reliability. Capital equipment funding is provided for items such as accelerator power supplies and remote handling systems to enhance performance and increase scientific productivity.

	FY 2009	FY 2010	FY 2011
(dollars in thousands)			

	FY 2009	FY 2010	FY 2011
HRIBF Hours of Operation with Beam			
Achieved Operating Hours	4,653	N/A	N/A
Planned Operating Hours	3,600	5,200	5,200
Optimal Hours	6,100	6,100	6,100
Percent of Optimal Hours	76%	85%	85%
Unscheduled Downtime	14.7%	N/A	N/A
Number of Users	260	260	260

	FY 2009	FY 2010	FY 2011
▪ **Other Operations**	**3,832**	**4,253**	**4,423**

The NRO and USAF will continue to jointly provide support for the 88-Inch Cyclotron for approximately 2,000 hours for their electronics testing program, and NP continues support in FY 2011 for approximately 3,000 hours for the in-house nuclear physics research program at LBNL. Funding is also provided for maintenance of the Oak Ridge Electron Accelerator (ORELA) which is used for criticality measurements supported by DOE/NNSA.

	FY 2009	FY 2010	FY 2011
Facility for Rare Isotope Beams	**7,000**	**12,000**	**10,000**

Funds are requested in FY 2011 to begin engineering and design efforts aimed at developing FRIB. MSU is undertaking a comprehensive R&D plan for FRIB, utilizing core competencies developed at the NP-supported national laboratory groups. 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 (for additional details, see the Supporting Information section). The FY 2011 funding supports the project profile as agreed upon between MSU and DOE in the Cooperative Agreement.

	FY 2009	FY 2010	FY 2011
Total, Low Energy Nuclear Physics	**94,880**	**114,636**	**113,466**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Research	
▪ **University Research**	
FY 2011 funding increases to maintain support for university researchers.	+396
▪ **National Laboratory Research**	

- National Laboratory User Facility Research funding maintains personnel at levels needed to support the highest priority research efforts and implementation of

	FY 2011 vs. FY 2010 ($000)
scientific instrumentation at the ATLAS national user facility and increases staff at HRIBF.	+1,072
• Other National Laboratory Research funding supports a number of MIEs according to their planned project profile, maintaining cost and schedule baselines and meeting international commitments. In FY 2011, funding in total for all of the Low Energy Nuclear Physics MIEs decreases by $3,504,000. Funding for research relevant to Applications of Nuclear Science and Technology decreases by $980,000 relative to FY 2010 as a result of funding a number of multi-year proposals with FY 2009 funding and Recovery Act funding. Offsetting these decreases are increases for the proof of principle Majorana Demonstrator R&D project which begins to ramp up in FY 2011 (+$1,700,000), the development of experiments for the new neutron science program at the FNPB (+$1,000,000), and a modest increase to maintain laboratory research groups (+$403,000).	-1,381
Total, National Laboratory Research	**-309**
▪ **Other Research**	
SBIR and other funded at levels required proportionate to R&D activities.	-59
Total, Research	**+28**
Operations	
▪ ATLAS Operations reflects an increase to maintain staff and effectively operate this national user facility, which is partially offset by a decrease in accelerator improvement project funding as a result of completion of the CARIBU accelerator project in FY 2010.	+103
▪ The increase in HRIBF Operations addresses staffing requirements to effectively operate and maintain this national user facility.	+529
▪ Other Operations increases to provide needed funding for maintenance of operations at the 88-Inch Cyclotron and ORELA at approximately a constant level of effort.	+170
Total, Operations	**+802**
Facility for Rare Isotope Beams	
▪ Funding for the Facility for Rare Isotope Beams is requested to begin engineering and design work; the decrease is consistent with the planned profile in the Cooperative Agreement signed with MSU in June 2009.	-2,000
Total Funding Change, Low Energy Nuclear Physics	**-1,170**

Nuclear Theory

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Nuclear Theory			
Theory Research			
University Research	14,551	15,060	15,753
National Laboratory Research	13,482	16,089	17,587
Scientific Discovery through Advanced Computing (SciDAC)	2,679	2,773	2,870
Total, Theory Research	30,712	33,922	36,210
Nuclear Data Activities	7,064	7,652	8,499
Total, Nuclear Theory	37,776	41,574	44,709

Description

The Nuclear Theory subprogram supports theoretical research at universities and DOE national laboratories with the goal of improving 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 deconfinement. 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). LQCD 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, the joint HEP/NP initiative was operating facilities with an aggregate capacity of 18 sustained teraflops. This LQCD initiative is being replaced by a joint 5-year HEP/NP follow-on project, LQCD-ext, beginning in FY 2010. The NP LQCD computer capability at TJNAF is also being augmented with Recovery Act funding; when fully operational at the end of FY 2010, this computing equipment will have increased the U.S. computing capability for LQCD to a minimum of 45 sustained teraflops.

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; its organizational structure promotes cost effective collaboration and educational opportunities. 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 Nuclear Theory subprogram also supports targeted investments in short-term topical theory collaborations within the university and national laboratory communities to facilitate cooperation and communication on specialized nuclear theory challenges that require concerted effort in order to advance the field.

Another component of the Nuclear Theory subprogram is the National Nuclear Data program which compiles, evaluates, and disseminates nuclear data for basic research and applications in an online database 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.

The FY 2011 increases address staff shortages at the national laboratories, the ramp-up of the second-generation LQCD project in partnership with the DOE Office of High Energy Physics, and additional topical theory collaboration support. Within the Nuclear Data subprogram, support for the recently initiated Applications of Nuclear Science and Technology program is reduced due to opportunities enabled by Recovery Act funding.

Selected FY 2009 Accomplishments

- The quark-gluon plasma (QGP), studied experimentally in relativistic heavy-ion collisions at the RHIC facility at BNL, has continued to be of great interest to nuclear theorists. Advances this past year include a more realistic description of the QGP using viscous fluid dynamics. Lattice Quantum Chromodynamics (LQCD) calculations have provided the value of the viscosity coefficients in a gluon plasma, yielding clear confirmation that the QGP is not a nearly free gas of quarks and gluons but instead behaves as a nearly perfect fluid.

- Meson-baryon interactions play an important role in nuclear physics and potentially also in astrophysics. During the last year, the first fully dynamical LQCD calculation of meson-baryon scattering was performed by the Nuclear Physics LQCD collaboration, demonstrating that the longstanding building blocks of nuclear structure calculations are accountable to the underlying quark-gluon degrees of freedom. This is only the beginning of the LQCD effort in this area, but it is an important step towards determining meson-baryon interaction strengths and quantifying the associated systematic uncertainties.

- In Low Energy Nuclear Physics, the question of "How far does the periodic table go?" and the accompanying technical challenge of how best to form new elements experimentally have been the focus of great attention. Recent calculations using microscopic density functional theory suggest possibly very favorable experimental approaches for creating new heavy elements and may also provide a wider context for understanding fission reactions such as those exploited in energy-producing nuclear reactors. These studies have also led to a better theoretical understanding of aspects of nuclear structure that were already known experimentally, including the mass differences between nuclei with even and odd numbers of neutrons and protons and properties of the excited states of even nuclei. This work includes many predictions that can be tested at the planned FRIB facility.

- In recent observations of the Sun, improved analyses of absorption lines in the solar spectrum have lowered estimates of the Sun's surface metal content (metallicity). These new results lead to a puzzling discrepancy with predictions of the speed of sound in the solar interior using the standard solar model. This demonstrates the importance of developing improved three-dimensional solar models using the next generation of supercomputers. It was also recently shown that new solar neutrino flux experiments could resolve this solar metallicity puzzle by directly determining the metal content of the gas cloud from which our solar system formed.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Theory Research	**30,712**	**33,922**	**36,210**
▪ **University Research**	**14,551**	**15,060**	**15,753**

The University Research activity supports the research of approximately 160 academic scientists and 120 graduate students through 65 research grants at 45 universities in 29 states and the District of Columbia, and will allow the start of several new research grants in specific growth areas of nuclear theory in FY 2011. Funding will support the necessary level of theoretical effort needed for interpretation of experimental results obtained at the NP facilities and the training of next-generation nuclear theorists. The overall nuclear theory effort is aligned with the experimental program through the program performance milestones established by NSAC.

▪ **National Laboratory Research**	**13,482**	**16,089**	**17,587**

Research programs in nuclear theory are supported at seven national laboratories (ANL, BNL, LANL, LBNL, LLNL, ORNL, and TJNAF) to achieve high priority scientific goals and interpret experimental results. The theoretical research at a given laboratory is primarily aligned to the experimental program at that laboratory, or in some cases to take advantage of the unique facilities or programs at that laboratory. In FY 2011, funding is provided for staffing at several of the national laboratories, and investments in LQCD computer capabilities are increased slightly in a joint effort with High Energy Physics, LQCD-ext. Additional topical theory collaboration support is also provided. Funds for topical theory collaborations are reflected in National Laboratory Research, but are awarded after open competition between university and laboratory groups; awards are determined by peer review. In FY 2009, the seven laboratory groups were evaluated on the significance of their accomplishments and planned future program; scientific leadership, creativity and productivity of the personnel; and the overall cost-effectiveness of the group. The results of this review will influence final budget allocations in FY 2010 and FY 2011.

▪ **Scientific Discovery through Advanced Computing (SciDAC)**	**2,679**	**2,773**	**2,870**

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. The NP SciDAC program currently supports research projects in nuclear astrophysics, grid

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

computing, lattice quantum chromodynamics, low energy nuclear structure and nuclear reaction theory, and advanced accelerator design, which are jointly funded with ASCR, HEP, and NNSA. The portfolio of NP-supported SciDAC projects will be re-competed in FY 2010 and FY 2011, and a new set of these computationally intensive projects of nuclear theory will be under investigation in FY 2011.

Nuclear Data Activities	**7,064**	**7,652**	**8,499**

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 addresses long-standing staffing issues. The NNDC relies on the U.S. Nuclear Data Network, 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 cycles. This initiative is funded from both the Low Energy Program and the Nuclear Data Program; while funding increases in this subprogram, overall the support for this initiative decreases in FY 2011 as compared to FY 2010.

Total, Nuclear Theory	**37,776**	**41,574**	**44,709**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Theory Research	
▪ **University Research**	
In FY 2011, increased support is provided to university nuclear theory groups to continue research on the topics in theoretical nuclear physics that were identified in the previous NSAC report on performance measures and milestones and to implement recommendations from the NSAC Subcommittee on Nuclear Theory.	+693
▪ **National Laboratory Research**	
FY 2011 funding provides an increase above cost of living for the theoretical efforts at the seven NP-supported national laboratory theory groups to allow these groups to achieve the scientific goals of the Nuclear Physics program. These activities include increasing staff, additional topical collaboration support, and the increased support of the LQCD initiative, LQCD-ext, which is jointly funded with HEP.	+1,498
▪ **Scientific Discovery through Advanced Computing (SciDAC)**	
The portfolio of NP-supported SciDAC projects will be re-competed in FY 2010 and FY 2011. Funding in FY 2011 will allow support for the newly defined set of	

	FY 2011 vs. FY 2010 ($000)
computationally intensive SciDAC projects in nuclear theory that require terascale and petascale computing capabilities.	+97
Total, Theory Research	**+2,288**
Nuclear Data Activities	
FY 2011 funding will continue to support the activities of the National Nuclear Data Center and institutions that collaborate on the Nuclear Data project at a near constant level of effort (+$325,000), and support for the Applications of Nuclear Science and Technology initiative increases in this subprogram (+$522,000).	+847
Total Funding Change, Nuclear Theory	**+3,135**

Isotope Development and Production for Research and Applications

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Isotope Development and Production for Research and Applications			
Research			
National Laboratory Research	1,500	1,500	1,560
University Research	3,360	1,500	1,560
Other Research[a]	0	84	90
Total, Research	4,860	3,084	3,210
Operations			
University Operations	200	250	262
Isotope Production Facility Operations	2,790	1,068	1,111
Brookhaven Linear Isotope Producer Operations	770	500	520
National Isotope Data Center (NIDC)	1,024	1,915	1,992
Other National Laboratory Operations	15,116	12,383	12,685
Total, Operations	19,900	16,116	16,570
Total, Isotope Development and Production for Research and Applications	24,760	19,200	19,780

Description

The primary goal of this subprogram is to support research, development, and production of research and commercial isotopes that are of critical importance to the Nation and in short supply. 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 isotope production component of the Isotope Development and Production for Research and Applications subprogram include the availability of research and commercial isotopes that would have otherwise not be possible, reduced dependence on foreign supplies, new scientific applications for isotopes not currently supplied, the development of more effective isotope production and processing techniques, and the ability to meet both present and future research needs for isotopes. The subprogram places an emphasis on the R&D efforts associated with developing new and more cost-effective and efficient production and processing techniques, and the production of isotopes needed for research purposes.

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 produced by the program are utilized by Federal agencies, including the National Institutes of Health and their grantees, National

[a] In FY 2009, $125,000 was transferred to the SBIR program and $15,000 was transferred for the STTR program. This activity includes $75,000 for SBIR and $9,000 for STTR in FY 2010 and $80,000 for SBIR and $10,000 for STTR in FY 2011.

Institute of Standards and Technology, Environmental Protection Agency, Department of Agriculture, National Nuclear Security Administration, Department of Homeland Security, other DOE Office of Science programs, and other Federal agencies.

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 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 to detect terrorist threats.

Isotopes are made available by using the Department's unique facilities, the Brookhaven Linac Isotope Producer (BLIP) at BNL and the Isotope Production Facility (IPF) at LANL, for which the subprogram has stewardship responsibilities. In FY 2009, the subprogram also explored production capabilities at university and other laboratory facilities in order to make high priority isotopes more available and cost-effective. 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 the production of isotopes at the reactors at Oak Ridge and Idaho National Laboratories and 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 Program was transferred to the Office of Nuclear Physics with the FY 2009 Appropriation, and much effort has been expended on establishing long-term strategies, priorities, peer review mechanisms, and effective lines of communication with isotope stakeholders. The Nuclear Science Advisory Committee (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. The first NSAC report, released in April 2009, includes federal, commercial, and community input and establishes priorities for the production of research isotopes. Following release of the report, NP issued a broad call to university, laboratory, and commercial facilities, inviting them to submit proposals describing their capabilities for producing these high priority research isotopes. These proposals were reviewed and selections were made based on cost and products in short supply; the result is that the Isotope Program will establish new production capabilities at other laboratory sites and university facilities to optimize its ability to supply reliable sources of research isotopes at more affordable prices. A data call is now planned to the broad research community announcing the isotopes that can be produced at the increased suite of facilities and soliciting interest in the demand for these isotopes so that production schedules can be developed and coordinated. The second NSAC report on a long-range strategic plan was released in November 2009.[a]

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

NP continues to work in close collaboration with other federal agencies in the development of strategic plans regarding isotope production. A goal of the program is to establish effective communication with federal agencies to better forecast isotope needs and leverage resources. For example, NP continues to work with the National Institutes of Health (NIH) on a federal working group NP assembled to address the recommendations of the recent National Academies report, *Advancing Nuclear Medicine through Innovation*, which identified several areas in isotope production warranting attention. A five-year production strategy has been generated which identifies the isotopes and projected quantities needed by the medical community in the context of the Isotope Program capabilities. While the Isotope Program is not responsible for the production of molybedenum-99 (Mo-99), it recognizes the importance of this isotope for the Nation and is working closely with DOE/NNSA, the lead entity responsible for domestic Mo-99 production, by offering technical and management support. NP has also facilitated the formation of a federal working group on the He-3 supply issue involving staff from NP, NNSA, the Department of Homeland Security, and the Department of Defense. The Isotope Program's role in helium-3 (He-3) is limited to packaging and distribution of the isotope. However, the objective of this working group is to ensure that the limited supply of He-3 will be distributed to the highest priority applications and basic research.

In addition, NP held many discussions during FY 2009 with the Californium-252 (Cf-252) source manufacturers and users, conducted a full bottom-up evaluation of the costs associated with Cf-252 production, and considered more effective approaches to produce this isotope to meet projected demands. The result is that a four-year contract was signed with the source manufacturers in May 2009 to continue Cf-252 production and ensure its availability in the outyears.

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 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 at more affordable rates, with research isotopes sold at a unit price. 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.

In FY 2011,emphasis is placed on supporting and organizing a stable and efficient workforce for the production of isotopes and R&D efforts. The suite of isotope production facilities is increased to include university facilities and other capabilities at national laboratories. Starting in FY 2010, the Isotope Program will increase productivity by broadening its suite of facilities to include university accelerator and reactor facilities, as well as other agency facilities, which can provide cost-effective and unique capabilities; these include cyclotron facilities at the National Institutes of Health, the Washington University cyclotron, the University of California at Davis cyclotron and the Missouri University Research Reactor. Partnerships with industrial counterparts are pursued to leverage resources. Under the research category, FY 2009 funding reflects the outcome of decisions based upon peer review regarding production of isotopes at university and national laboratory facilities, and their corresponding balance. It is expected that in FY 2010 and FY 2011 that balance will be optimized based on merit peer review.

Selected FY 2009 Accomplishments

- Copper-67 is an attractive radioisotope for application in therapy of various cancers when attached to the appropriate carrier molecule, such as a monoclonal antibody. In an ongoing effort to improve the specific activity of copper-67, BNL has investigated the use of a highly enriched zinc-68 target in place of natural zinc. A test irradiation with zinc-68 improved the specific activity three-fold over the best previous result. In order to improve the economics of this process, a method to recover and reuse the enriched material from the process waste was successfully developed.

- A Drug Master File for the tungsten-188/rhenium-188 generator system, used in cancer research, is now on file with the Food and Drug Administration. Coupled with the hot cells at ORNL now being approved for current Good Manufacturing Practices, the tungsten-188/rhenium-188 generator will be suitable for human clinical trials.
- Recent major equipment purchases of stable isotope processing equipment at ORNL will greatly enhance stable isotope supply. A new high vacuum/induction heating system replaced one that was over 40 years old and contained legacy thorium contamination, and a new scanning electron microscope with an x-ray energy dispersive analyzer will allow for enhanced chemistry and materials product and process evaluation.
- Yttrium-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. Currently this isotope is in short supply. A number of activities have been undertaken to increase the reliable supply of yttrium for use in research: investigations to improve product purity using very low energy protons; development of a method to recover irradiated strontium-86 for reuse; design of a new target capsule that can be sealed and opened in a hotcell; and development of a new accelerator tune to reduce the BLIP facility beam energy from the maximum of 200 MeV to 66 MeV in order to more effectively produce the isotope.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Research	**4,860**	**3,084**	**3,210**

Research is supported to identify, design, and optimize production targets and separation methods. Examples for planned research include 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 and treat diseases spread through acts of bioterrorism, the development of production methods for alpha-emitting radionuclides that exhibit great potential in 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 is being used to support R&D in alternative isotope production techniques, which complements these research efforts in FY 2010.

▪ **National Laboratory Research**	**1,500**	**1,500**	**1,560**

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 more affordable rates. R&D activities also utilize the reactors at INL and ORNL and the accelerators at LANL and BNL. Researchers provide unique expertise and facilities for data analysis. Funding in FY 2009 reflects the selection of national laboratory proposals following peer review. Amounts

	FY 2009	FY 2010	FY 2011

(dollars in thousands)

reflected in FY 2010 and FY 2011 are estimates; the actual split of funding between National Laboratory Research and University Research will be determined based on merit peer review. Additional funding was provided in FY 2009 under the Recovery Act for R&D on alternative isotope production and processing techniques.

	FY 2009	FY 2010	FY 2011
▪ **University Research**	**3,360**	**1,500**	**1,560**

Support is provided for scientists at universities and with industry 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 more affordable rates. Funding in FY 2009 reflects the selection of university and industry proposals. Amounts reflected in FY 2010 and FY 2011 are estimates; the actual split of funding between University Research and National Laboratory Research will be determined based on merit peer review.

	FY 2009	FY 2010	FY 2011
▪ **Other Research**	**0**	**84**	**90**

In FY 2009, $125,000 was transferred to the Small Business Innovation Research (SBIR) program and $15,000 was transferred to the Small Business Technology Transfer (STTR) program. This activity includes $75,000 for SBIR and $9,000 for STTR in FY 2010 and $80,000 for SBIR and $10,000 for STTR in FY 2011.

	FY 2009	FY 2010	FY 2011
Operations	**19,900**	**16,116**	**16,570**

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

	FY 2009	FY 2010	FY 2011
▪ **University Operations**	**200**	**250**	**262**

Funding is provided to academic institutions with reactors and cyclotrons for providing capabilities in the production and processing of isotopes to complement or increase the subprogram's isotope portfolio. Research isotope production at universities and national laboratories is supported under the research category above.

	FY 2009	FY 2010	FY 2011
▪ **Isotope Production Facility (IPF) Operations**	**2,790**	**1,068**	**1,111**

The IPF operates in a parallel-mode in accordance with the Los Alamos Neutron Science Center (LANSCE) for about 22 weeks in FY 2011; the IPF is completely dependent upon the operations of LANSCE. The IPF produces isotopes such as germanium-68, strontium-82, and arsenic-73. Support is provided in FY 2011 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 and with Recovery Act funding.

	FY 2009	FY 2010	FY 2011
▪ **Brookhaven Linac Isotope Producer (BLIP) Operations**	**770**	**500**	**520**

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,

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

and strontium-82. Support is provided in FY 2011 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 and with Recovery Act funding.

	FY 2009	FY 2010	FY 2011
▪ **National Isotope Data Center (NIDC)**	**1,024**	**1,915**	**1,992**

The National Isotope Data Center (NIDC) is a newly created 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 in FY 2010 and FY 2011 to support the staff that are needed to oversee these activities.

	FY 2009	FY 2010	FY 2011
▪ **Other National Laboratory Operations**	**15,116**	**12,383**	**12,685**

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 2011 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. In addition, several upgrade projects were supported with Recovery Act funding. FY 2011 funding maintains efforts at approximately constant effort, relative to FY 2010.

	FY 2009	FY 2010	FY 2011
Total, Isotope Development and Production for Research and Applications	**24,760**	**19,200**	**19,780**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Research	
Funding for research and development, which is guided by priorities in research isotope production developed by NSAC, is maintained at constant effort in FY 2011. R&D efforts benefited significantly from Recovery Act funding for R&D on alternative isotope production techniques.	+126
Operations	
▪ **University Operations**	
Funding maintains constant effort.	+12

	FY 2011 vs. FY 2010 ($000)
▪ **Isotope Production Facility (IPF) Operations**	
Funding maintains constant effort.	+43
▪ **Brookhaven Linac Isotope Producer (BLIP) Operations**	
Funding maintains constant effort.	+20
▪ **National Isotope Data Center (NIDC)**	
An increase is provided to maintain constant effort for the NIDC to meet its mission to coordinate isotope activities and customer data.	+77
▪ **Other National Laboratory Operations**	
Funding maintains constant effort at the hot cell facilities.	+302
Total, Operations	**+454**
Total Funding Change, Isotope Development and Production for Research and Applications	**+580**

Construction

Funding Schedule by Activity

	FY 2009	FY 2010	FY 2011
	(dollars in thousands)		
Construction			
07-SC-02, Electron Beam Ion Source, BNL	2,438	0	0
06-SC-01, 12 GeV CEBAF Upgrade (PED/Construction), TJNAF	28,623	20,000	36,000
Total, Construction	31,061	20,000	36,000

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 2009	FY 2010	FY 2011
	(dollars in thousands)		
07-SC-02, Electron Beam Ion Source, BNL	**2,438**	**0**	**0**

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 was jointly supported by NP and NASA.

06-SC-01, 12 GeV CEBAF Upgrade (PED/Construction), TJNAF	**28,623**	**20,000**	**36,000**

In FY 2011, 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 addition to the funding reflected above, the project also received Recovery Act funding of $65,000,000 in FY 2009 which advanced a portion of the original FY 2010 and FY 2011 planned funding. The FY 2010 and FY 2011 requests reflect a total of $65,000,000 in reductions to the originally planned funding profile to account for the advanced Recovery Act funding.

Total, Construction	**31,061**	**20,000**	**36,000**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($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 after taking into account advanced funding provided under the Recovery Act, and the FY 2010 Appropriation.	+16,000

Supporting Information

Operating Expenses, Capital Equipment and Construction Summary

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Operating Expenses	421,951	463,951	481,208
Capital Equipment	38,810	42,571	37,497
General Plant Projects	2,330	2,000	2,000
Accelerator Improvement Projects	6,155	6,478	5,295
Construction	31,061	20,000	36,000
Total, Nuclear Physics	500,307	535,000	562,000

Funding Summary

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Research	157,709	185,233	196,235
Scientific User Facilities Operations	260,118	272,730	279,916
Other Facility Operations	23,732	20,369	20,993
Projects			
Major Items of Equipment	15,063	18,918	12,805
Facility for Rare Isotope Beams[a]	7,000	12,000	10,000
Construction Projects	31,061	20,000	36,000
Total Projects	53,124	50,918	58,805
Other	5,624	5,750	6,051
Total Nuclear Physics	500,307	535,000	562,000

Scientific User Facilities Operations and Research

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
RHIC (BNL)			
Operations	148,684	157,470	163,301
Facility Research/MIEs	10,427	9,032	10,797
Total RHIC	159,111	166,502	174,098

[a] FRIB is being funded with operating expense dollars through a Cooperative Agreement with Michigan State University (MSU).

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
CEBAF (TJNAF)			
Operations	80,394	82,522	83,245
Facility Research/MIEs	10,301	9,799	10,648
Total CEBAF	90,695	92,321	93,893
HRIBF (ORNL)			
Operations	15,860	16,645	17,174
Facility Research/MIEs	6,103	4,068	4,805
Total HRIBF	21,963	20,713	21,979
ATLAS (ANL)			
Operations	15,180	16,093	16,196
Facility Research/MIEs	5,223	4,700	5,035
Total ATLAS	20,403	20,793	21,231
Scientific User Facilities			
Operations	260,118	272,730	279,916
Facility Research/MIEs	32,054	27,599	31,285
Total Scientific User Facilities	292,172	300,329	311,201

Total Facility Hours and Users

	FY 2009	FY 2010	FY 2011
Hours of Operation with Beam			
RHIC (BNL)			
Achieved Operating Hours	3,153	N/A	N/A
Planned Operating Hours	2,915	3,350	3,720
Optimal Hours	4,100	4,100	4,100
Percent of Optimal Hours	77%	82%	91%
Unscheduled Downtime	19.7%	N/A	N/A
Number of Users	1,200	1,200	1,200

	FY 2009	FY 2010	FY 2011
CEBAF (TJNAF)			
Achieved Operating Hours	5,117	N/A	N/A
Planned Operating Hours	4,965	5,110	4,090
Optimal Hours	5,980	5,980	5,980[a]
Percent of Optimal Hours	86%	86%	68%
Unscheduled Downtime	8.5%	N/A	N/A
Number of Users	1,350	1,390	1,430
HRIBF (ORNL)			
Achieved Operating Hours	4,653	N/A	N/A
Planned Operating Hours	3,600	5,200	5,200
Optimal Hours	6,100	6,100	6,100
Percent of Optimal Hours	76%	85%	85%
Unscheduled Downtime	14.7%	N/A	N/A
Number of Users	260	260	260
ATLAS (ANL)			
Achieved Operating Hours	5,488	N/A	N/A
Planned Operating Hours	5,200	5,900	5,900
Optimal Hours	6,600	6,600	6,600
Percent of Optimal Hours	83%	89%	89%
Unscheduled Downtime	4.1%	N/A	N/A
Number of Users	360	410	410
Total Facilities			
Achieved Operating Hours	18,411	N/A	N/A
Planned Operating Hours	16,680	19,560	18,910
Optimal Hours	22,780	22,780	22,780
Percent of Optimal Hours	81%	86%	83%
Unscheduled Downtime	11%	<20%	<20%
Total Number of Users	3,170	3,260	3,300

[a] While the optimal operations for CEBAF remains at 5,980 hours, the maximum number of hours the facility can operate in FY 2011 is 4,090 hours due to a planned shutdown for installation of 12 GeV components. The facility therefore operates at 100% of maximal hours.

Major Items of Equipment

	Prior Years	FY 2009	FY 2009 Recovery Act Appropriation	FY 2010	FY 2011	Outyears	Total
Heavy Ion Nuclear Physics							
Heavy Ion LHC Experiments, LBNL							
TEC	3,000	4,000	0	5,000	1,205	0	13,205
OPC	295	0	0	0	0	0	295
TPC	3,295	4,000	0	5,000	1,205	0	13,500
PHENIX Silicon Vertex Tracker, BNL							
TEC/TPC	3,599	851	250	0	0	0	4,700
PHENIX Forward Vertex Detector, BNL							
TEC/TPC	700	2,200	2,000	0	0	0	4,900
STAR Heavy Flavor Tracker, BNL							
TEC	0	0	0	1,400	2,900	TBD	TBD
OPC	0	0	0	0	0	TBD	TBD
TPC	0	0	0	1,400	2,900	TBD	11,000–17,000
Low Energy Nuclear Physics							
GRETINA, Gamma-Ray Detector, LBNL							
TEC	14,570	2,000	0	430	0	0	17,000
OPC	1,200	300	0	300	0	0	1,800
TPC	15,770	2,300	0	730	0	0	18,800
Fundamental Neutron Physics Beamline, ORNL							
TEC	7,100	1,500	600	0	0	0	9,200
OPC	88	0	0	0	0	0	88
TPC	7,188	1,500	600	0	0	0	9,288
Neutron Electric Dipole Moment (nEDM), LANL							
TEC	2,947	1,100	0	4,500	2,900	TBD	TBD
OPC	933	0	0	0	0	TBD	TBD
TPC	3,880	1,100	0	4,500	2,900	TBD	17,600–19,000

	Prior Years	FY 2009	FY 2009 Recovery Act Appropriation	FY 2010	FY 2011	Outyears	Total
Cryogenic Underground Observatory for Rare Events (CUORE), LBNL							
TEC	400	3,112	0	3,088	800	186	7,586
OPC	764	0	0	0	0	350	1,114
TPC	1,164	3,112	0	3,088	800	536	8,700
Rare Isotope Beam Science Initiatives							
TEC	0	0	0	4,200	5,000	TBD	TBD
OPC	0	0	0	0	0	TBD	TBD
TPC	0	0	0	4,200	5,000	TBD	2,000–20,000
Total MIEs							
TEC		14,763	2,850	18,618	12,805		
OPC		300	0	300	0		
TPC		15,063	2,850	18,918	12,805		

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 FY 2011. The project received its final funding of $2,000,000 under the Recovery Act.

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. The scope funded with Recovery Act funding was completed in November 2009.

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. Engineering design and R&D efforts continued in FY 2009 and FY 2010 for this high-risk project. Fabrication, scheduled to start in FY 2010, will be initiated once the project completes high priority R&D and is baselined and has CD-2 approval. This is a joint DOE/NSF project with NSF contributing additional funds.

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-2/3 approval in December 2009 and is scheduled to finish in FY 2013. This is a joint DOE/NSF project with NSF contributing additional funds.

Rare Isotope Beam Science Initiatives: These initiatives consist of multiple initiatives, each ranging in TPC between $2–20 million, 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 were selected following peer review of solicited proposals. Eleven initiatives were selected and are undergoing individual peer review in FY 2010; NP will break out and separately describe selected Major Items of Equipment in future budget narratives. No fabrication activities will be supported prior to project baseline or CD-2 approval.

Construction Projects

(dollars in thousands)

	Prior Years	FY 2009 Current Appropriation	FY 2009 Recovery Act Appropriation	FY 2010	FY 2011	Outyears	Total
12 GeV CEBAF Upgrade, TJNAF							
TEC	20,877	28,623	65,000	20,000	36,000	117,000	287,500
OPC	10,500	0	0	0	0	12,000	22,500
TPC	31,377	28,623	65,000	20,000	36,000	129,000	310,000
Electron Beam Ion Source, BNL							
TEC	11,262	2,438	0	0	0	0	13,700
OPC	800	300	0	0	0	0	1,100
TPC	12,062	2,738	0	0	0	0	14,800

(dollars in thousands)

	Prior Years	FY 2009 Current Appropriation	FY 2009 Recovery Act Appropriation	FY 2010	FY 2011	Outyears	Total
Total Construction							
TEC		31,061	65,000	20,000	36,000		
OPC		300	0	0	0		
TPC		31,361	65,000	20,000	36,000		

Scientific Employment

(estimated)

	FY 2009	FY 2010	FY 2011
# University Grants	190	200	200
Average Size per year	$340,000	$345,000	$345,000
# Laboratory Projects	33	33	34
# Permanent Ph.Ds	779	790	790
# Postdoctoral Associates	364	370	375
# Graduate Students	516	515	515
# Ph.D.s awarded	85	80	80

Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan

1. Introduction

In 2008, DOE issued a Funding Opportunity Announcement (FOA) for the establishment, operations, and management of a rare isotope beam facility for nuclear structure and astrophysics research with overall technical capabilities as described in a 2007 Nuclear Science Advisory Committee (NSAC) study.[a] Michigan State University (MSU) was selected to design and establish the Facility for Rare Isotope Beams (FRIB) based on the evaluation of their application. MSU was awarded a Cooperative Agreement in June 2009.

FRIB is not a DOE line item construction project or capital asset and is being funded with operating expense dollars through a cooperative agreement with MSU. Although cooperative agreements are excluded under DOE O 413.3A, the management principles of DOE O 413.3A will be followed, including the approval of Critical Decisions. When completed, FRIB will be operated as a DOE National User Facility. Consistent with 10 CFR 600, real property and equipment acquired with Federal funds shall be vested with MSU. However, such items will not be encumbered by MSU for as long as the Federal government retains an interest. When the property and equipment are no longer of interest to the government, MSU will be responsible for decontamination and decommissioning.

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

The most recent Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on February 9, 2004, with a preliminary cost estimate range of $900,000,000 to $1,100,000,000. However, as part of an alternatives analysis, the technical scope as originally conceived has changed and the new preliminary cost estimate range to the federal government is now $450,000,000 to $550,000,000 with a proposed completion date (CD-4) range of FY 2017 to FY 2019. The cooperative agreement between DOE and MSU identifies MSU providing $94.5 million in cost share. The final DOE federal investment will be determined when the project is more mature and ready to be baselined at CD-2.

While the requirements in DOE Order 413.3A are not applicable to cooperative agreements covered by 10 CFR 600, MSU is required to implement a project management system that is consistent with the widely accepted industry or DOE project management principles and standards/practices. Funds were appropriated in FY 2010 to continue work on R&D, conceptual design activities, and NEPA requirements. The FY 2011 request will initiate engineering and design activities.

2. Design and Construction Schedule[a]

	CD-0	CD-1	Design Complete	CD-2	CD-3	CD-4
FY 2011	02/09/2004	4Q 2010	TBD	TBD	TBD	FY 2017–FY 2019

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

3. Baseline and Validation Status[b]

(dollars in thousands)

	TEC, Engineering and Design	TEC, Construction	TEC, Total	OPC	TPC
FY 2011	58,000	TBD	TBD	19,000	TBD

4. Project Description, Justification, and Scope

FRIB is based on a heavy-ion linac with a minimum energy of 200 MeV/u for all ions at beam power of 400 kW. The proposed facility will have a production area, three-stage fragment separator, three ion stopping stations, and post accelerator to reach at least 12 MeV/u for all ions.

This proposed facility is to provide intense beams of rare isotopes for a wide variety of studies in nuclear structure, nuclear astrophysics, and fundamental symmetries. This facility will impact the study of the origin of the elements and the evolution of the cosmos, and offers a laboratory for exploring the limits of nuclear existence and identifying new phenomena, with the possibility that a more broadly applicable theory of nuclei will emerge. The facility will offer new glimpses into the origin of the elements by leading to a better understanding of key issues by creating exotic nuclei that, until now, have existed only in nature's most spectacular explosion, the supernova. Experiments addressing questions of the

[a] This project does not have a performance baseline. The CD-4 schedule range is a preliminary estimate.
[b] This project does not have a performance baseline. The preliminary DOE total project cost (TPC) range is $450,000,000 to $550,000,000, not including the MSU cost share. The amounts shown reflect the requested DOE appropriations only and do not include the planned cost share from MSU.

fundamental symmetries of nature will similarly be conducted through the creation and study of certain exotic isotopes.

5. Financial Schedule (DOE only)

(dollars in thousands)

	Appropriations	Obligations	Costs
Total Estimated Cost (TEC)			
FY 2011	10,000	10,000	9,874
FY 2012	30,000	30,000	28,000
FY 2013	18,000[a]	18,000[b]	18,000[b]
FY 2014	TBD	TBD	2,126
Total, TEC[b]	58,000[b]	58,000[b]	58,000[b]
Other Project Cost (OPC)			
FY 2009	7,000	7,000	1,874
FY 2010	12,000	12,000	13,000
FY 2011	0	0	4,126
Total, OPC[c]	19,000	19,000	19,000
Total Project Cost			
FY 2009	7,000	7,000	1,874
FY 2010	12,000	12,000	13,000
FY 2011	10,000	10,000	14,000
FY 2012	30,000	30,000	28,000
FY 2013	18,000[a]	18,000[a]	18,000[a]
FY 2014	TBD	TBD	2,126
Outyears	TBD	TBD	TBD
Total, TPC[d]	TBD	TBD	TBD

[a] In addition to the TEC funding of $18,000,000 reflected for engineering and design in FY 2013, funding will be requested for construction in FY 2013 and the outyears and will be included upon CD-2 approval.
[b] The funding reflected in the operating funded TEC profile is for DOE's share of engineering and design activities only. The total engineering and design cost is estimated to be $64,100,000; the DOE share shown is in anticipation that MSU will provide an additional $6,100,000 as their cost share. MSU's annual cost share may change as the project matures.
[c] The funding reflected in the OPC profile is for DOE's share of R&D, conceptual design, and NEPA activities only. The total OPC for these activities is estimated to be $25,500,000; the DOE share shown is in anticipation that MSU will provide an additional $6,500,000 as their cost share during this period. MSU's annual cost share may change as the project matures.
[d] The preliminary DOE total project cost (TPC) range is $450,000,000 to $550,000,000, not including the MSU cost share. The amounts shown reflect the requested DOE appropriations only and do not incude the planned cost share from MSU

6. Details of Cost Estimate (DOE only)

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Estimate
Total Estimated Cost (TEC)[a]			
Design and engineering	42,500	N/A	N/A
Construction	TBD	N/A	N/A
Contingency	15,500	N/A	N/A
Total, Total Estimated Cost	58,000	N/A	N/A
Other Project Cost (OPC)			
Conceptual Design / NEPA	6,500	N/A	N/A
R&D	12,500	N/A	N/A
Contingency	0	N/A	N/A
Total, OPC[b]	19,000	N/A	N/A
Total, TPC[c]	TBD	N/A	N/A
Total, Contingency	TBD	N/A	N/A

7. Funding Profile History

(dollars in thousands)

Request Year		FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	Outyears	Total
FY 2010	TEC[d]	0	0	10,000	33,000	18,000[e]	TBD	TBD
	OPC[f]	7,000	9,000	0	0	0	TBD	TBD
	TPC[g]	7,000	9,000	10,000	33,000	18,000	TBD	TBD
FY 2011	TEC[a]	0	0	10,000	30,000	18,000[b]	TBD	TBD
	OPC[c]	7,000	12,000	0	0	0	TBD	TBD
	TPC[d]	7,000	12,000	10,000	30,000	18,000	TBD	TBD

[a] The TEC funding is for DOE's share of engineering and design activities only at this time.
[b] The OPC funding is for DOE's share of R&D, conceptual design, and NEPA activities only at this time.
[c] The preliminary DOE total project cost (TPC) range is $450,000,000 to $550,000,000, not including the MSU cost share. The amounts shown reflect the requested DOE appropriations only and do not incude the planned cost share from MSU.
[d] The TEC funding is for DOE's share of engineering and design activities only at this time.
[e] In addition to the TEC funding of $18,000,000 reflected for engineering and design in FY 2013, funding will be requested for construction in FY 2013 and the outyears and will be included upon CD-2 approval.
[f] The OPC funding is for DOE's share of R&D, conceptual design, and NEPA activities only at this time.
[g] The preliminary DOE total project cost (TPC) range is $450,000,000 to $550,000,000, not including the MSU cost share. The amounts shown reflect the requested DOE appropriations only and do not include the planned cost share from MSU.