Nuclear Physics

Funding Profile by Subprogram

(dollars in thousands)

	FY 2007 Current Appropriation	FY 2008 Original Appropriation	FY 2008 Adjustments	FY 2008 Current Appropriation	FY 2009 Request
Nuclear Physics					
Medium Energy Nuclear Physics	109,052	113,327	-938[a]	112,389	121,046
Heavy Ion Nuclear Physics	179,900	186,012	-829[a]	185,183	201,557
Low Energy Nuclear Physics	78,053	84,705	-1,120[a]	83,585	96,562
Nuclear Theory	33,205	34,956	-926[a]	34,030	39,954
Isotope Production and Applications[b]	—	—	—	—	19,900
Subtotal, Nuclear Physics	400,210	419,000	-3,813[a]	415,187	479,019
Construction	12,120	17,700	-161[a]	17,539	31,061
Total, Nuclear Physics	412,330[c]	436,700	-3,974[a]	432,726	510,080

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

Mission

The mission of the Nuclear Physics (NP) program is to foster fundamental research in nuclear physics that will provide new insights and advance our knowledge on the nature of matter and energy, and to develop the scientific knowledge, technologies and trained workforce that will be needed to underpin the Department of Energy's missions for nuclear-related national security, energy, and environmental quality. The program provides world-class, peer-reviewed research results and operates user accelerator facilities in the scientific disciplines encompassed by the Nuclear Physics mission areas under the mandate provided in Public Law 95-91 that established the Department.

Description

Nuclear science began by studying the structure and properties of atomic nuclei as assemblages of protons and neutrons. Research focused on nuclear reactions, the nature of radioactivity, and the synthesis of new isotopes and new elements heavier than uranium. Significant benefits, especially to

[a] Reflects a reduction for the 0.91% rescission in P.L. 110-161, the Energy and Water Development and Related Agencies Appropriation Act, 2008.
[b] The Isotope Production and Applications program is transferred to the Office of Science from the Office of Nuclear Energy starting in FY 2009.
[c] Total is reduced by $10,436,000: $9,318,000 of which was transferred to the Small Business Innovative Research (SBIR) program and $1,118,000 of which was transferred to the Small Business Technology Transfer (STTR) program.

medicine, emerged from these basic research efforts. Today, the reach of nuclear science extends from the quarks and gluons that form the substructure of protons and neutrons, once viewed as elementary particles, to the most dramatic of cosmic events—supernovae. At its heart, nuclear physics attempts to understand the composition, structure, and properties of atomic nuclei; however, the field is driven by the following broad nuclear science frontiers as identified by the scientific community in the NSAC LRP—*The Frontiers of Nuclear Science (2007)*. The Nuclear Physics program is central to the development of various technologies relevant to nuclear energy, nuclear medicine, and national security. The highly trained scientific and technical personnel in fundamental nuclear physics that are a product of the program are a valuable human resource for many applied fields.

- *Quantum Chromodynamics: from the structure of hadrons to the phases of nuclear matter.* A fundamental quest of modern science is the exploration of matter in all its possible forms. Over the past century, as this quest has taken us further and further inward, scientists have discovered that all matter is composed of atoms; that each atom contains a tiny, ultra-dense core called the nucleus; that the nucleus is composed of particles called protons and neutrons (often referred to collectively as nucleons); and that these nucleons are members of a broader class of particles called hadrons, which are complex bound states of nearly massless quarks and massless gluons. The quest has even yielded a set of mathematical equations known as quantum chromodynamics (QCD), which gives us a theoretical framework for understanding how quarks, gluons, and all these hadrons behave.
- *Nuclei and Nuclear Astrophysics: from structure to exploding stars.* At the core of every atom is an ultra-dense kernel of matter called the atomic nucleus. Comprising some 99.9 percent of the atom's mass—the other 0.1 percent resides in the outer cloud of electrons—the nucleus is a tightly bound cluster of positively charged protons and electrically neutral neutrons, known generically as nucleons. The forces that bind these nucleons are immensely strong, which is why nuclear processes are able to release a prodigious amount of energy; witness the thermonuclear fusion reactions that power our Sun and most other stars in the universe. But the forces between the nucleons are also quite complex, which is why nuclear matter displays a remarkably diverse variety of phenomena.
- *Fundamental Symmetries and Neutrino: in search of the New Standard Model.* The quest to explain nature's fundamental interactions, and how they have shaped the evolution of the cosmos, is among the most compelling in modern science. A major triumph in that quest came in the latter part of the 20^{th} century with the development of the standard model—a comprehensive and detailed picture of the electroweak and strong interactions. Nuclear physicists have played a key role in that success, starting five decades ago with their observation of parity-violation in nuclear beta decay, and continuing to the present day with their increasingly precise experimental tests of the standard model's predictions. The model has survived these tests with remarkable resiliency—which is why it is now accepted as the fundamental framework for three of the four known forces of nature.

Starting in FY 2009, the Isotope Production and Applications subprogram is transferred to the Nuclear Physics Program. This subprogram, with its importance to applied programs including the medical uses of isotopes, is a substantial beneficiary of the basic research conducted within Nuclear Physics.

Strategic and GPRA Unit Program Goals

The Department's Strategic Plan identifies five Strategic Themes (one each for nuclear, energy, science, management, and environmental aspects of the mission) plus 16 Strategic Goals that tie to the Strategic Themes. The NP program supports the following goals:

Strategic Theme 3, Scientific Discovery and Innovation

- Strategic Goal 3.1, Scientific Breakthroughs: Achieve the major scientific discoveries that will drive U.S. competitiveness; inspire America; and revolutionize our approaches to the Nation's energy, national security, and environmental quality challenges.
- Strategic Goal 3.2, Foundations of Science: Deliver the scientific facilities, train the next generation of scientists and engineers, and provide the laboratory capabilities and infrastructure required for U.S. scientific primacy.

The NP program has one GPRA Unit Program Goal that contributes to Strategic Goals 3.1 and 3.2 in the "goal cascade":

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

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

The NP subprograms (Medium Energy, Heavy Ion, Low Energy, Nuclear Theory, and Isotope Production) contribute to this goal by supporting innovative, peer-reviewed scientific research to advance knowledge and provide insights into the nature of energy and matter, and in particular, to investigate the fundamental forces that hold the nucleus of the atom together, and determine the detailed structure and behavior of atomic nuclei. The NP program contributes by building and supporting world-leading scientific facilities and state-of-the-art instruments necessary to carry out its basic research agenda. Investments maintain and develop critical infrastructure for safe, forefront research at these facilities. Scientific discoveries at the frontiers of nuclear physics further the Nation's energy-related research capacity, which in turn, provides for the Nation's security, economic growth and opportunities, and improved quality of life. In developing strategies to pursue these research opportunities, the NP program has been guided by the Long Range Plan (LRP) reports prepared by its primary advisory panel, the Nuclear Science Advisory Committee (NSAC). The most recent NSAC LRP, *The Frontiers of Nuclear Science,* was developed and submitted in 2007.

The Medium Energy subprogram investigates the quark and gluon substructure inside the nucleon. Although protons and neutrons can be separately observed, their quark constituents cannot because they are permanently confined inside the nucleons. Measurements are carried out using electron beams with the Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility (TJNAF or JLab) and using polarized proton collisions at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL), as well as at other facilities worldwide.

The Heavy Ion subprogram searches for and characterizes predicted novel forms of matter and other new phenomena that might occur in extremely hot, dense bulk nuclear matter. The quarks and gluons that compose each proton and neutron are normally confined within these nucleons. However, if nuclear matter is compressed and heated sufficiently, quarks should become deconfined: individual nucleons will melt into a hot, dense plasma of quarks and gluons. Such plasma is believed to have filled the universe about a millionth of a second after the "Big Bang." Measurements are carried out primarily using relativistic heavy ion collisions at RHIC. Important measurements will also be made at the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN). Participation in the heavy ion program at the LHC 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 a piece of the puzzle regarding the matter that existed during the infant universe.

The Low Energy subprogram studies nuclei at the limits of stability, nuclear astrophysics reactions, the nature of neutrinos, and fundamental symmetry properties in nuclear systems. The coming decade in nuclear physics may reveal new nuclear phenomena and structure unlike anything known from the stable nuclei of the world around us. Nuclear physics research is essential if we are to solve important problems in astrophysics—the origin of the chemical elements, the behavior of neutron stars, the origin of the highest-energy cosmic rays, core-collapse supernovae and the associated neutrino physics, and galactic and extragalactic gamma-ray sources. Measurements of nuclear structure and nuclear reactions are carried out primarily at the Argonne Tandem Linac Accelerator System (ATLAS) at Argonne National Laboratory (ANL) and the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory (ORNL). Neutrinos are elusive particles that permeate the universe and hardly interact with matter, yet are believed to play a key role in the explosion of stars. Recent experiments have shown that a neutrino oscillates among all of its three known types as it travels from its source—something that can only happen if neutrinos have tiny masses. Studies to better understand the properties of neutrinos, and in particular their masses, are primarily carried out with specialized detectors located deep underground or otherwise heavily shielded against background radiation. Measurements of symmetry properties, particularly of the neutron, are being developed by nuclear physicists at the Spallation Neutron Source (SNS) at ORNL. The following indicators establish specific long-term goals in Scientific Discovery that the NP program is committed to, and progress can be measured against:

- investigating new regions of nuclear structure, studying interactions in nuclear matter like those occurring in neutron stars, and determining the reactions that created the nuclei of the chemical elements inside stars and supernovae; and
- determining the fundamental properties of neutrinos and fundamental symmetries by using neutrinos from the sun and nuclear reactors and by using radioactive decay measurements.

The Nuclear Theory subprogram provides the theoretical underpinning needed to support the interpretation of a wide range of data obtained from all the other NP subprograms, with the ultimate aim of advancing knowledge and providing insights into the most promising avenues for future research. A major theme of this subprogram is an understanding of the mechanism of quark confinement and de-confinement—while it is expected to be explained by Quantum Chromodynamics (QCD), a quantitative description remains one of this subprogram's great intellectual challenges. New theoretical tools will be developed to describe nuclear many-body phenomena, with important applications to condensed matter and other areas of physics. Understanding what consequences neutrino mass has for nuclear astrophysics and for the current theory of elementary particles and forces is also of prime importance. Computing resources are being developed to tackle challenging calculations of sub-atomic structure, such as those of Lattice Gauge QCD.

The Nuclear Theory subprogram also supports an effort in nuclear data that collects, evaluates and disseminates nuclear physics data for basic nuclear research and for applied nuclear technologies. These extensive nuclear databases are a national resource consisting of carefully organized scientific information that has been gathered over 50 years of low-energy nuclear physics research worldwide.

The Low Energy and Theory subprograms support experimental, nuclear data, and theory R&D that is relevant to the implementation of advanced fuel cycles in nuclear reactors. NP will support these efforts in FY 2009 addressing scientific opportunities where there are basic research questions and where the expertise and capabilities in the NP program can be utilized to address the needs of DOE's Nuclear Energy program in developing the next generation of nuclear reactors. Among the opportunities of high priority and impact are the development of cross-section covariance data that will allow for the establishment of uncertainties in model calculations, the development of the research capabilities (techniques and instrumentation) for important cross section measurements that cannot now be done or done to the precision needed, and the development of more robust and fundamental theoretical approaches for modeling reactions. These activities are being coordinated with the DOE Nuclear Energy and DOE SC Advanced Scientific Computing Research (ASCR) programs.

The Isotope Production and Applications subprogram supports the research and development and production of radioisotopes and making them more readily available for domestic U.S. needs. Radioisotopes represent high-priority commodities that are essential for successful energy, medical and national security applications and outcomes. Historically, DOE R&D investment has fueled the development of new isotopes and applications, including heart imaging; cancer therapy; smoke detectors; neutron detectors; isotopic and explosive detection; oil exploration; industrial radiography; and tracers for climate change. With federal support over the last several decades, use of isotopes has reduced health care costs, improved the ability of physicians to diagnose illnesses and improved the quality of life for innumerable patients, and strengthened national security. Support will be provided for research activities associated with the development and production of commercially unavailable research isotopes, in response to the needs of the community and based upon peer review.

Funding by Strategic and GPRA Unit Program Goal

(dollars in thousands)

	FY 2007	FY 2008	FY 2009
Strategic Goals 3.1, Scientific Breakthroughs, and 3.2, Foundations of Science			
GPRA Unit Program Goal 3.1/2.47.00 Explore Nuclear Matter - from Quarks to Stars			
Nuclear Physics	412,330	432,726	510,080

Annual Performance Results and Targets

FY 2004 Results	FY 2005 Results	FY 2006 Results	FY 2007 Results	FY 2008 Targets	FY 2009 Targets
GPRA Unit Program Goal 3.1/2.47.00 – Explore Nuclear Matter, from Quarks to the Stars					
Maintained and operated Nuclear Physics scientific user facilities so the unscheduled operational downtime was 12%, on average, of total scheduled operating time. [Met Goal]	Maintained and operated Nuclear Physics scientific user facilities so the unscheduled operational downtime was 13%, on average, of total scheduled operating time. [Met Goal]	Maintained and operated Nuclear Physics scientific user facilities so the unscheduled operational downtime was 6%, on average, of total scheduled operating time. [Met Goal]	Maintained and operated Nuclear Physics scientific user facilities so the unscheduled operational downtime was 10.4%, on average, of total scheduled operating time. [Met Goal]	Achieve at least 80% average operation time of the scientific user facilities as a percentage of the total scheduled annual operating time.	Achieve at least 80% average operation time of the scientific user facilities as a percentage of the total scheduled annual operating time.
				Achieve within 10% for both the cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects.	Achieve within 10% for both the cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects.
Medium Energy Nuclear Physics					
As elements of the electron beam program, (a) collected first data with the BLAST detector at MIT/Bates, studying the structure of nucleons and few body nuclei and (b) collected first data to map out the strange quark contribution to nucleon structure using the G0 detector, utilizing the high intensity polarized electron beam developed at TJNAF. [Met Goal]	Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments in Hall A (2.83), Hall B (8.06), and Hall C (2.11), respectively, at the Continuous Electron Beam Accelerator Facility. [Met Goal]	Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments in Hall A (1.77), Hall B (9.9), and Hall C (1.9), respectively, at the Continuous Electron Beam Accelerator Facility. [Met Goal]	Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments in Hall A (2.49), Hall B (12.42), and Hall C (3.01) at the Continuous Electron Beam Accelerator Facility. [Met Goal]	Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments in Hall A, Hall B, and Hall C at the Continuous Electron Beam Accelerator Facility. FY 2008 Baseline: Hall A: 4.0; Hall B: 20.0; and Hall C: 5.0.	Weighted average number (2ithin 20% of baseline estimate) of billions of events recorded by experiments in Hall A, Hall B, and Hall C at the Continuous Electron Beam Accelerator Facility. FY 2009 Baseline: Hall A: 3.7; Hall B: 18.7; and Hall C: 4.7.
			The Relativistic Heavy Ion Collider plans no proton running in FY 2007.	The Relativistic Heavy Ion Collider plans no significant proton running in FY 2008.	Weighted average number (within 30% of baseline estimate) of millions of proton collision events sampled by the PHENIX and recorded by the STAR detectors, respectively, at the Relativistic Heavy Ion Collider. FY 2009 Baseline: PHENIX sample=500,000; STAR recorded=50.

FY 2004 Results	FY 2005 Results	FY 2006 Results	FY 2007 Results	FY 2008 Targets	FY 2009 Targets
Heavy Ion Nuclear Physics					
Initiated first round of experiments with collisions with other ions to compare to results of gold-gold collisions. [Met Goal]	Weighted average number (within 30% of baseline estimate) of millions of events sampled by the PHENIX (900) and recorded by the STAR (40) detectors, respectively, at the Relativistic Heavy Ion Collider. [Met Goal]	No Target. (The Relativistic Heavy Ion Collider did not operate in heavy ion mode during FY 2006)	Weighted average number (within 30% of baseline estimate) of millions of events sampled by PHENIX (5,100) and recorded by the STAR (86.6) detectors during the heavy ion run at the Relativistic Heavy Ion Collider. [Met Goal]	Weighted average number (within 30% of baseline estimate) of millions of heavy-ion collision events sampled by the PHENIX and recorded by the STAR detectors, respectively, at the Relativistic Heavy Ion Collider. FY 2008 Baseline: PHENIX sample=7,500; STAR recorded=60.	Weighted average number (within 30% of baseline estimate) of millions of heavy-ion collision events sampled by the PHENIX and recorded by the STAR detectors, respectively, at the Relativistic Heavy Ion Collider. FY 2009 Baseline: PHENIX sample=6,000; STAR recorded=0.
Low Energy Nuclear Physics					
	Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments at the Argonne Tandem Linac Accelerator System (28.1) and Holifield Radioactive Ion Beam (3.76) facilities, respectively. [Met Goal]	Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments at the Argonne Tandem Linac Accelerator System (24.6) and Holifield Radioactive Ion Beam (7.1) facilities. [Met Goal]	Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments at the Argonne Tandem Linac Accelerator System (27.6) and Holifield Radioactive Ion Beam (7.1) facilities. [Met Goal]	Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments at the Argonne Tandem Linac Accelerator System and Holifield Radioactive Ion Beam facilities, respectively. FY 2008 Baseline: ATLAS-22; HRIBF-2.4.	Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments at the Argonne Tandem Linac Accelerator System and Holifield Radioactive Ion Beam facilities, respectively. FY 2009 Baseline: ATLAS-23.2; HRIBF-2.3.

Means and Strategies

NP supports innovative, peer-reviewed scientific research to advance knowledge and provide insights into the nature of energy and matter, in particular to investigate the fundamental forces that hold the nucleus of the atom together and determine the detailed structure and behavior of atomic nuclei; and starting in FY 2009, is responsible for the production of stable and radioactive isotopes important for the Nation. The program builds, supports, and maintains the forefront scientific facilities and instruments necessary to carry out that research. All research projects undergo regular peer review and merit evaluation based on procedures set down in 10 CFR 605 for the extramural grant program and under a similar process for laboratory programs and scientific user facilities. All new projects are selected through peer review and merit evaluation.

Radioisotope production is of interest to several federal agencies, including the National Institute of Health (NIH) and the Office of Biological and Environmental Research (BER) in the DOE Office of Science. The NP program will closely coordinate the research and isotope production activities within the Radioisotopes Production subprogram with relevant federal agencies.

Scientists supported by NP collaborate with researchers from many countries. Large numbers of foreign scientists, who provide monetary and equipment support, heavily utilize all of the NP National User Facilities. The program also supports collaborative work at foreign accelerator facilities, as well as joint development of instrumentation. The program promotes the transfer of the results of its basic research to a broad set of technologies involving advanced materials, national defense, medicine, space science and exploration, advanced computing, and industrial processes. In particular, nuclear reaction data are an important resource for these programs. NP user facilities are utilized by other SC programs, other DOE Offices (e.g., National Nuclear Security Administration and Nuclear Energy), other Federal agencies (e.g., NSF, NASA, and Department of Defense), and industry to carry out their programs.

The program is also cognizant of opportunities identified elsewhere; e.g., *Connecting Quarks with the Cosmos (2003)*, a report prepared by the National Research Council and sponsored by DOE, the National Science Foundation (NSF), and National Aeronautics and Space Administration (NASA), and the interagency response to this report, *The Physics of the Universe, a Strategic Plan for Federal Research at the Intersection of Physics and Astronomy*, prepared by the National Science and Technology Council. The program is informed by the advice of the National Academies concerning the scientific opportunities with rare isotope beams in its report *Scientific Opportunities with a Rare-Isotope Facility in the United States (2007).*

Although the NP program will use various means and strategies to achieve its program goals, a variety of external factors may impact the ability to achieve these goals. External factors that affect the programs and performance include: changing mission needs as described by the DOE and SC mission statements and strategic plans; evolving scientific opportunities, which sometimes emerge in a way that revolutionizes disciplines; results of external program reviews and international benchmarking activities of entire fields or subfields, such as those reviews performed by the National Academy of Sciences; unanticipated failures, for example, in critical components of scientific user facilities, that cannot be mitigated in a timely manner; and strategic and programmatic decisions made by other Federal agencies and by international entities.

Validation and Verification

Progress against established plans is evaluated by periodic internal and external performance reviews. These reviews provide an opportunity to verify and validate performance. Periodic assessments and annual reviews consistent with specific program management plans are held to ensure technical progress, cost and schedule adherence, and responsiveness to program requirements.

Program Assessment Rating Tool (PART)

The Department has implemented a tool, the PART Assessment, to evaluate selected programs. PART was developed by the Office of Management and Budget (OMB) to provide a standardized way to assess the effectiveness of the Federal Government's portfolio of programs. The structured framework of the PART provides a means through which programs can assess their activities differently than through traditional reviews. The NP program has incorporated feedback from OMB into the FY 2009 Budget Request and is taking the necessary steps to continue to improve performance.

In the FY 2005 PART assessment, OMB gave the NP program a rating of "Effective". OMB found the program's management to be excellent with a relatively transparent budget justification and a fully engaged advisory committee that produces fiscally responsible advice. The assessment found that NP has developed a limited number of adequate performance measures that are continued for FY 2009. These measures have been incorporated into this budget request, NP grant solicitations, and the performance plans of senior managers. As appropriate, they will be incorporated into the performance based contracts of M&O contractors. NSAC reviews the progress towards achieving the long-term performance measures every five years; the results of the most recent assessment started in 2007 will be completed in 2008. The Annual Performance Targets are tracked through the Department's Joule system and reported in the Department's Annual Performance and Accountability Report.

OMB has provided NP with three recommendations to further improve performance:

- Respond to the recommendations of recent advisory committee reports, including implementing a budget-constrained and phased plan for the future of its research facilities. NP responded by:
- Engaging its advisory committee in a manner that produces responsible strategic advice within realistic budget scenarios. DOE and NSF charged NSAC to develop a new LRP for nuclear science. The plan, The Frontiers of Nuclear Science (December 2007), outlines the options for research, instrumentation, and facility development at different constrained levels of funding. NSAC also delivered a report in FY 2007 that evaluated the options and made recommendations for a next generation facility for rare isotope beams that can be constructed for approximately half the cost of the originally envisioned one billion dollar facility. The FY 2009 NP budget request and 5-year plan have been developed utilizing the guidance of the recommendations of these recent NSAC reports.
- Continuing to use external expert assessments (Committee of Visitors [COV]) to review the quality, relevance, and performance of the program's research portfolio and grant management process. The most recent COV review was held on January 9-11, 2007.
- Engage the National Academies, including experts outside of nuclear physics, to study the scientific capabilities of a proposed rare isotope accelerator in an international context. NP responded by engaging the National Academies to study the scientific opportunities of a proposed rare isotope beam facility and has encouraged broad representation from the scientific community. The Academies report entitled *Scientific Opportunities with a Rare-Isotope Facility in the United States (2007)* is posted at http://www.sc.doe.gov/np/.
- Maximize operational efficiency of major experimental facilities in response to increasing power costs. NP responded by conducting a focused review on optimizing operational efficiency of its four National User Facilities in the summer of 2006 to maximize the utilization and efficiency of major experimental facilities to ensure that the Nation's Nuclear Physics program achieves maximum

results. This was in addition to annual science and technology reviews of each of its National User Facilities.

To improve public access to PART assessments and follow up actions, OMB has created the ExpectMore.gov website. Information concerning NP PART assessments and current follow up actions can be found by searching on "nuclear physics" at http://www.ExpectMore.gov.

Basic and Applied R&D Coordination

The NP program is requesting $6,603,000 to support basic research in the characterization of radioactive waste through the advanced fuel cycle activities. NP supported a small on-going effort in basic research in FY 2007 and FY 2008 important for the NP mission and relevant to the issues involved with radioactive waste and related advanced fuel cycles. The NP program areas are structured as scientific disciplines with goals to understand fundamental nuclear physics. FY 2009 funding, if appropriated, will support research projects in experimental nuclear physics, nuclear theory, and nuclear data to support advanced nuclear fuel cycles. Nuclear data efforts will lead to improvements in nuclear reaction cross sections to reduce uncertainties needed to calculate the transmutation behavior of actinide elements for proposed advanced fuel cycles. The experimental effort will use appropriate research facilities and associated instrumentation to produce new data and reduce measured uncertainties in existing nuclear data for essential long-lived nuclear isotopes.

Funding requested in the outyears will significantly expand research in areas relevant to advanced reactor fuel cycles. The data produced will be input to existing models, as well as new models that are under development, to allow predictions of basic quantities such as fission product yield distributions. The National Nuclear Data Center is well positioned to lead the national nuclear data effort in the evaluation of reaction cross sections and covariance matrix development. Experimentalists will use a variety of nuclear instrumentation, NP supported facilities, and facilities operated by other institutions to make measurements.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Characterization of Radioactive Waste			
Low Energy Nuclear Physics	—	—	4,537
Nuclear Theory	200	200	2,066
Total, Basic and Applied R&D Coordination	200	200	6,603

Advisory and Consultative Activities

In FY 2009, the DOE Nuclear Physics program will provide about 90% of the federal support for fundamental nuclear physics research in the Nation. The NSF provides most of the remaining support. To ensure that resources are allocated to the most scientifically promising research, the DOE and its National User Facilities actively seek external input using a variety of advisory bodies.

The NSAC provides advice to the DOE and the NSF on a continuing basis regarding the direction and management of the national nuclear sciences basic research program. NP develops its strategic plan for the field with input from the scientific community via the NSAC long-range plans, which serve as a framework for the coordinated advancement of the field for the coming decade. These plans are undertaken every five to six years to review the scientific opportunities in the field, perform retrospective assessments of the major accomplishments by the field, and set priorities for the future. The plan provides guidance and recommends priorities for new construction projects. For example, the

2002 Long Range identified a facility for rare isotope beams as the highest priority for new construction and recommended proceeding with the 12 GeV upgrade of CEBAF as soon as possible. In the FY 2009 budget request, construction funds are requested for the 12 GeV CEBAF Upgrade project, and funding to begin conceptual design activities is requested for a facility for rare isotope beams.

Guidance from the NSAC long-range plans is augmented by NSAC reviews of subfields. Priorities identified in NSAC reviews of the Medium Energy and Low Energy subprograms were important input for the programmatic decisions to terminate user facilities operations of the 88-Inch Cyclotron at Lawrence Berkeley National Laboratory (LBNL) in FY 2004 and of the Bates Linear Accelerator Center at the Massachusetts Institute of Technology in FY 2005. NSAC guidance on scientific opportunities and priorities provided in reviews of neutron science, the Nuclear Theory subprogram and the Heavy Ion subprogram, along with guidance from the FY 2007 NP review of the Low Energy subprogram, is reflected in the programmatic decisions in the FY 2008 and FY 2009 budget requests. NSAC's guidance from its review of the entire program in the context of constrained funding, transmitted in a June 2005 report, is reflected in the breadth of the NP program and in the ongoing budget requests. These decisions have been made to maximize the scientific impact, productivity, quality and cost-effectiveness of the program within the resources available.

In 2005, DOE and NSF requested that NSAC and the High Energy Physics Advisory Panel (HEPAP) jointly appoint a Neutrino Science Assessment Group (NuSAG) to assess and make recommendations concerning opportunities in neutrino science. NuSAG has responded with reports on these opportunities: experiments to search for neutrino-less double beta decay and hence discover if the neutrino is its own anti-particle, and determine or limit the neutrino mass; and the measurement of neutrino oscillation mixing parameters utilizing neutrinos produced by reactors and accelerators. In 2007, NuSAG provided its last report assessing the opportunities for long baseline accelerator experiments to probe non-conservation of CP (charge-parity symmetry) in the neutrino sector, in which the recommendations included that the U.S. proceed with a long baseline neutrino oscillation program and pursue R&D towards the development of an intense, conventional neutrino beam to support the experiment.

In 2006, NSAC appointed a Committee of Visitors (COV) to review NP management processes; the COV conducted its review and reported on its findings in early 2007. Recommendations included the generation of a common database of reviewers for university grants and a more extensive database of the information contained in the university grants to facilitate tracking of the overall health of the program, and the addition of needed personnel to NP.

In FY 2006, NP and NSF charged NSAC to develop a long-range plan for nuclear physics, and to appoint a task force to evaluate the scientific reach and technical options for a facility for rare isotope beams to inform the on-going planning process and define technical options for such a facility. The task force provided its findings in a report in the summer 2007. The NSAC long-range planning process resulted in a report, *The Frontiers of Nuclear Science,* detailing the vision for nuclear physics for the next ten years. Published NSAC reports can be found at http://www.sc.doe.gov/np/nsac/nsac.html. The National Academy of Sciences (NAS) was charged with carrying out an independent assessment of the importance of the science portfolio available to a next generation facility for rare isotope beams. The report, *Scientific Opportunities with a Rare Isotope Facility in the United States (2007)*, addresses the role of a U.S. world-class facility for rare isotope beams for the future of the U.S. and international nuclear physics.

Facility directors seek advice from Program Advisory Committees (PACs) to determine the allocation of scarce scientific resources—the available beam time. The committees are comprised of members mostly external to the host laboratory who are appointed by the facility director. PACs review research proposals requesting time at the facilities and technical resources, and provide advice on a proposal's scientific merit, technical feasibility, and personnel requirements. The PACs also provide recommendations for proposals to be approved, conditionally approved, deferred, or rejected.

In order to better coordinate interagency activities, NP continues to participate in the Interagency Working Group (IWG) that developed the *National Science and Technology Council (NSTC) Report: A 21st Century Frontier for Discovery: The Physics of the Universe—A Strategic Plan for Federal Research at the Intersection of Physics and Astronomy*. NP is playing a leading role in two of the major scientific thrusts identified in this report: Origin of Heavy Elements and High Density and Temperature Physics. Funding in FY 2009 partially supports the thrust on the Origin of the Heavy Elements at existing low energy facilities and supports High Energy Density Nuclear Physics with heavy ions at RHIC and participation in the heavy ion program at the LHC, all in the context of the Nuclear Physics mission.

Facility Reviews

Science and Technology (S&T) Reviews of the NP program's four National User Facilities—RHIC, CEBAF, ATLAS, and HRIBF—are conducted annually with external experts from U.S. and foreign institutions to assess the operations, performance, and scientific productivity of the facilities. The results of the reviews are compared to goals defined in approved Laboratory Performance Evaluation Management Plans, and the NP program's assessment of the laboratory performance is documented in annual Laboratory appraisals. NP also periodically conducts focused facility operations reviews to analyze all aspects of facility operations. During the summer of 2006, NP conducted a review focused on assessing the operating efficiency of NP accelerator facilities; all four facilities were reviewed simultaneously so that facility representatives could benefit from "lessons learned" at other facilities.

In addition, the NP program reviews proposed and ongoing instrumentation projects to assess project plans and performance. These reviews, conducted by international experts, focus on scientific merit, technical status and feasibility, cost and schedule, and effectiveness of management organizations. Such reviews are used to establish mission need, and to provide important input in establishing cost and schedule profiles necessary for budget formulation and execution, and on an annual basis, to assess project performance.

Research

Nuclear physics has made important contributions to our knowledge about the universe in which we live and has had great impact on human life. Knowledge and techniques developed in pursuit of fundamental nuclear physics research are extensively utilized in our society today. The understanding of nuclear spin enabled the development of magnetic resonance imaging for medical use. Radioactive isotopes produced by accelerators are used for medical imaging, cancer therapy, and biochemical studies. Particle beams are used for cancer therapy and in a broad range of materials science studies. Advances in cutting-edge instrumentation developed for nuclear physics experiments, such as high-resolution gamma ray detectors, have relevance to technological needs in combating terrorism.

Significant Program Shifts

Operations of the MIT/Bates Linear Accelerator Center were phased out and pre-D&D activities started in FY 2005. The final funding increment for transfer of ownership of the facility was provided in FY 2008, turning ownership of the facility over to MIT in FY 2009 in exchange for MIT assuming responsibility for all future D&D activities and liability for the facility.

Starting in FY 2009, there is a new subprogram within the Nuclear Physics program entitled Isotope Production and Applications, consisting of the transferred Medical Isotopes Infrastructure program contained in the Radiological Facilities program within the Office of Nuclear Energy, plus support for research isotope development and production. A major objective of this program is to improve the availability and reliability of research isotopes at predictable prices needed for medical, national security, and industrial applications. A portfolio of research isotopes will be established with guidance from scientific advisory committees, in consultation with all segments of the research community interested in using stable and radioactive isotopes.

Medium Energy Nuclear Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Medium Energy Nuclear Physics			
Research			
University Research	17,469	18,219	19,182
National Laboratory Research	16,218	15,585	18,081
Other Research[a]	702	5,431	5,936
Total, Research	34,389	39,235	43,199
Operations			
TJNAF Operations	72,663	71,154	77,847
Bates Facility	2,000	2,000	—
Total, Operations	74,663	73,154	77,847
Total, Medium Energy Nuclear Physics	109,052	112,389	121,046

Description

The Medium Energy Nuclear Physics subprogram supports fundamental research directed primarily at answering the overarching questions that define the first frontier identified by the nuclear science community—quantum chromodynamics:

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?

The subprogram also supports investigations into aspects of several of the overarching questions that define the second and third frontiers—nuclei and nuclear astrophysics, and fundamental symmetries and neutrinos:

What is the nature of nuclear force that binds protons and neutrons into stable nuclei?

and

Why is there now more visible matter that antimatter in the universe?

What are the unseen forces that were present at the dawn of the universe, but disappeared from view as it evolved?

[a] In FY 2007, $3,584,000 was transferred to the SBIR program and $1,118,000 was transferred to the STTR program. This activity includes $3,652,000 for SBIR and $1,126,000 for STTR in FY 2008 and $3,689,000 for SBIR and $1,250,000 for STTR in FY 2009.

The matter that makes up our world is the result of a unique property of the strong interaction called "confinement" that binds quarks and gluons together to form nucleons, the building blocks of atomic nuclei. Confinement prevents quarks or gluons from ever existing in isolation; they always bind in complex structures to form subatomic particles. Characterizing confinement and how it gives these subatomic particles, specifically protons and neutrons, their particular properties is the focus of the Medium Energy subprogram. For example, the laws of quantum physics require that the angular momenta of quarks and gluons add up to the proton's known spin (intrinsic angular momentum), but experimental data so far have only been able to determine that about 20% of the proton's spin comes from the quarks. Further measurements are needed to determine the contribution from the gluons and the internal orbital angular momenta.

To achieve an experimental description of the nucleon's substructure, the Medium Energy subprogram supports different experimental approaches that focus on determining: the distribution of up, down, and strange quarks in the nucleons, the roles of the gluons that bind the quarks and the "sea" of virtual quarks and gluons (which makes a significant contribution to the properties of protons and neutrons) and the dynamic degrees of freedom of the quarks by measuring the excited states of hadrons (any composite particle made of quarks, such as nucleons), the effects of the quark and gluon spins within the nucleon, and the effect of the nuclear environment on the quarks and gluons; and the properties of simple, few-nucleon systems, with the aim of describing them in terms of their fundamental components.

Most of this work has been done at the subprogram's primary research facility, CEBAF, as well as a major research effort at RHIC. Individual experiments are supported at the High Intensity Gamma Source (HIGS) at Triangle University Nuclear Laboratory, Fermi National Accelerator Laboratory (Fermilab), and facilities in Europe. All these facilities produce beams of sufficient energy (small enough wavelength) to probe at a distance scale within the size of a nucleon. CEBAF annually serves a nationwide community of about 800 DOE and National Science Foundation (NSF) supported scientists and students from over 80 U.S. institutions and about 400 scientists and students from 19 foreign countries. The NSF and foreign collaborators have made significant investments in experimental equipment. Allocation of beam time at CEBAF has been based on guidance from a Program Advisory Committee that reviews and evaluates proposed experiments regarding their merit and scientific priority.

FY 2007 Research Accomplishments

Scientists supported by this subprogram have made important discoveries in the past decade with advances in both theory and experiments that spurred interest in quantitatively understanding nucleons in terms of the quarks and gluons of QCD. Recent Medium Energy subprogram developments include:

- Studies of the excited states of the proton using the CEBAF Large Acceptance Spectrometer (CLAS) detector at CEBAF are providing new information on what is believed to be a radial excitation of the quarks having the same quantum numbers as the ground state proton. These data reveal distinct roles of the virtual quarks and the valence quarks in the excited states.
- Recent unparalleled high precision measurements of electron parity violation scattering from the proton and the ^{4}He nucleus at CEBAF have constrained the magnitude of the contributions of strange quarks to be less than 3% of the charge radius and less than 9% of the magnetization of the proton. These results have also been used to improve by a factor of two existing limits on new physics beyond the Standard Model previously set by atomic parity violation experiments.
- The first statistically significant measurements using polarized protons at RHIC indicate that the contribution of the gluons to the proton's spin is consistent with zero but do not exclude a possible

negative contribution. The data also have provided the first determinations of parton spin–orbit correlations. These results fulfill one of the subprogram's science milestones for FY 2008.

- The MiniBooNE neutrino oscillation experiment (Fermilab) has announced its initial result that excludes the existence of a possible sterile neutrino that was implied from the results of the earlier Liquid Scintillator Neutrino Detector (LSND) experiment. These data are important for further constraining the possible mass hierarchies of the neutrino family.
- The TRIUMF Weak Interaction Symmetry Test Detector (TWIST) experiment at TRIUMF in Canada has published results of precision measurements of the muon decay parameters to test the parity-violating nature of the weak interaction. The results are consistent with the Standard Model.
- The MuCAP experiment at the Paul Scherrer Institute (PSI) in Switzerland has successfully completed a precision measurement of muon capture by the proton that will resolve an inconsistency of our understanding of the weak interaction in nuclei.

FY 2007 Facility and Technical Accomplishments

- TJNAF staff has developed a novel solution to the problem of higher order frequency modes in superconducting cavities that limits high power operations. The modified design allows heat generated in the coupler to flow away from the accelerator cavity, using a superconducting niobium RF probe that is kept thermally anchored via a single-crystal sapphire dielectric that is brazed between the niobium probe and an externally accessible copper collar.
- TJNAF has built a high resolution gamma camera ideally suited for small animal Single Photon Emission Computed Tomography (SPECT) with x-ray computed tomography (CT) capability. Tracking of an awake mouse's head is done through the use of infrared (IR) reflectors attached to the mouse's head. This technique may help researchers study human physiology and disease processes.

Detailed Justification

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Research	**34,389**	**39,235**	**43,199**
▪ **University Research**	**17,469**	**18,219**	**19,182**

These activities comprise a broad program of research, and include support of about 180 scientists and 150 graduate students at 38 universities in 22 states and the District of Columbia. The research efforts utilize not only the accelerator facilities supported under the Medium Energy subprogram, but also other U.S. and foreign accelerator laboratories. Support funds personnel at levels needed to support the national Nuclear Physics program.

Support is provided for university researchers and groups to effectively carry out the CEBAF and RHIC research programs. Of this amount, $2,000,000 supports the MIT Research and Engineering (R&E) Center that is an integral component of MIT's medium energy research effort and utilizes the infrastructure remaining at the MIT/Bates facility for fabrication of instrumentation. University efforts at TJNAF are largely focused on studies of nucleon structure and its internal dynamics. In FY 2009, these include research efforts on the Q_{weak} experiment (an NSF/DOE effort with international contributions); a precision determination of the weak mixing angle as a constraint on new physics beyond the Standard Model; and photoproduction from a polarized target using the

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009

CLAS detector. Efforts at RHIC will continue running of the 200 GeV spin program in preparation for a transition to the 500 GeV spin program.

▪ **National Laboratory Research**	**16,218**	**15,585**	**18,081**

Support for experimental groups at TJNAF restores CEBAF efforts at the level needed to effectively carry out the research program at the facility. Research efforts at Argonne, Brookhaven, and Los Alamos National Laboratories not associated with TJNAF are supported at levels that will allow these groups to achieve their planned NP goals. Funding decisions are influenced by the results of periodic peer reviews of the national laboratory research efforts in Medium Energy Physics. In FY 2006, the reviewers evaluated each laboratory research group based on the significance of their accomplishments and future four-year program, the scientific leadership, creativity, and productivity of the personnel, and the overall cost-effectiveness of the group, which included support by the respective laboratory. Any issues associated with a group were identified. Each group was evaluated individually and then comparatively ranked. The highest performers received requested increases, where merited, and based on budgetary constraints. Low performing groups received recommendations to address issues identified in the review before any funding increases or decreases would be made, depending on their response to the recommendations.

• **TJNAF Research**	**6,254**	**6,391**	**7,220**

Scientists at TJNAF, with support of the user community, assembled the large and complex experimental detectors for Halls A, B, and C. TJNAF scientists provide necessary experimental support and operation of the detectors for safe and effective utilization by the user community. TJNAF scientists play a lead role in the laboratory's research program and their level of effort is increased in FY 2009 to support additional scientists for the development of the 12 GeV scientific program.

• **Other National Laboratory Research**	**9,964**	**9,194**	**10,861**

Support for national laboratory research activities at accelerator and non-accelerator facilities reflects the planned phase-out of the Laser Electron Gamma Source (LEGS) group at BNL while maintaining other laboratory research group efforts, with resources directed towards the highest priority activities that include those described below:

- Argonne National Laboratory scientists will continue their research program at TJNAF, the theme of which is the search for a detailed understanding of the internal quark-gluon structure of the nucleon. ANL scientists have also successfully trapped radium, using their unique laser atom-trapping technique at ANL, which is a necessary step toward their goal to make a precision measurement of the atomic electric dipole moment that could shed light on the matter over antimatter excess in the universe.
- Support will be provided to the RHIC spin physics Medium Energy research groups at BNL and LANL. Both of these groups have important roles and responsibilities in the RHIC spin physics program.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009

- ► The LEGS experiment at BNL was completed in 2006. The polarized target technology along with the necessary staff has been transferred to TJNAF for use in the CEBAF Large Acceptance Spectrometer (CLAS) program. Support is provided to complete analysis of data taken in 2006.
- ► At LANL, support is provided to allow scientists and collaborators to complete the MiniBooNE anti-neutrino analysis and develop a transition plan for future neutrino research. The level of support in FY 2009 is dependent on the result of the transition plan.

	FY 2007	FY 2008	FY 2009
▪ **Other Research**	**702**	**5,431**	**5,936**
• **SBIR/STTR and Other**	**702**	**5,431**	**5,686**

In FY 2007, $3,584,000 was transferred to the Small Business Innovation Research (SBIR) program and $1,118,000 was transferred to the Small Business Technology Transfer (STTR) program. This activity includes $3,652,000 for SBIR and $1,126,000 for STTR in FY 2008 and $3,689,000 for SBIR and $1,250,000 for STTR in FY 2009 as well as other established obligations that the Medium Energy Nuclear Physics subprogram must meet.

	FY 2007	FY 2008	FY 2009
• **Accelerator R&D Research**	—	—	**250**

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

	FY 2007	FY 2008	FY 2009
Operations	**74,663**	**73,154**	**77,847**
▪ **TJNAF Operations**	**72,663**	**71,154**	**77,847**

Funding supports CEBAF operations and Experimental Support for an approximate 30-week, 3-Hall operations schedule, after some funds are redirected towards the 12 GeV CEBAF project.

	FY 2007	FY 2008	FY 2009
• **TJNAF Accelerator Operations**	**46,499**	**44,724**	**50,499**

CEBAF operations are supported for a 4,400 hour running schedule, a 26% increase from estimated running in FY 2008, increasing the utilization of the facility from 56% with the FY 2008 Appropriation to 74%. Support in FY 2008 did not permit adequate staging of experiments and preparations for the start of the 2009 operations run, which is anticipated to negatively impact levels of operation in FY 2009. Beams can be provided to all three of the experimental halls simultaneously. Support is also provided for accelerator improvement projects (AIP) and General Plant Project (GPP) infrastructure improvements ($2,200,000) and to maintain efforts in developing advances in superconducting radiofrequency technology ($1,584,000).

		(dollars in thousands)	
	FY 2007	FY 2008	FY 2009

	FY 2007	FY 2008	FY 2009
CEBAF Hours of Operation with Beam			
Optimal Hours	5,400	5,600	5,980
Planned Operating Hours	4,985	3,500	4,400
Achieved Operating Hours	5,719	N/A	N/A
Unscheduled Downtime	5.4%	N/A	N/A
Number of Users[a]	800	1,200	1,280

With the FY 2007 Appropriated funding, CEBAF focused on experiments requiring very low beam energy, which are significantly cheaper than the higher energy runs and easy to produce, leading to a large number of operating hours in FY 2007.

Funding for R&D activities for the upgrade of CEBAF to 12 GeV is completed in 2008. Funds are requested to begin construction in the Construction section of this budget.

- **TJNAF Experimental Support** **26,164** **26,430** **27,348**

  The FY 2009 request supports Experimental Support efforts at the level needed for a 30-week, 3-Hall operations schedule. Support is provided for the scientific and technical staff, materials, and services needed to support three hall operations and to integrate rapid assembly, modification, and disassembly of large and complex experiments for optimization of schedules. This includes the delivery or dismantling of cryogenic systems, electricity, water for cooling, radiation shielding, and special equipment for specific experiments.

  FY 2009 funds for capital equipment ($5,700,000) are used for assembly and installation of ancillary equipment items such as polarized targets for experimental Halls A, B, and C; spectrometer systems and the continuation of the fabrication of second generation experiments. The Q_{weak} detector system has been fabricated to perform a precision measurement of the weak charge of the proton. This support is necessary to implement high priority experiments in the current 6 GeV experimental program prior to the 12 GeV CEBAF Upgrade project installation.

- **Bates Facility** **2,000** **2,000** **—**

  Guidance from the NSAC long-range plans is augmented by NSAC reviews of subfields. Priorities identified in NSAC review of the Medium Energy subprogram were important input for the programmatic decision to terminate user facilities operations of the Bates Linear Accelerator Center at the Massachusetts Institute of Technology in FY 2005. Pre-D&D activities were started in FY 2005. The final funding increment for transfer of ownership of the facility in the amount of $2,000,000 is provided in FY 2008 as part of the agreement that turns ownership of the facility

[a] Counting of users at the NP facilities has been improved to ensure consistent counting methodology from one facility to the next and to remove possible double counting. The more accurate count is reflected for FY 2008 and FY 2009.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
over to MIT in FY 2009 in exchange for MIT assuming responsibility for all future D&D activities and liability for the facility.			
Total, Medium Energy Nuclear Physics	**109,052**	**112,389**	**121,046**

Explanation of Funding Changes

	FY 2009 vs. FY 2008 ($000)
Research	
▪ **University Research**	
FY 2009 funding increases to support the personnel of the national Nuclear Physics program.	+963
▪ **National Laboratory Research**	
FY 2009 funding increases to support the personnel of the national Nuclear Physics program.	+2,496
▪ **Other Research**	
• SBIR/STTR and Other: Increase supports SBIR/STTR at levels proportionate to research and development activities.	+255
• Accelerator R&D Research: Funds are provided for accelerator R&D to develop the knowledge, technologies and trained scientists needed to design and build the accelerator facilities in order to accomplish the programmatic mission in nuclear physics and of the Department.	+250
Total, Other Research	**+505**
Total, Research	**+3,964**
Operations	
▪ **TJNAF Operations**	
• **TJNAF Accelerator Operations**	
FY 2009 funding restores CEBAF to operating levels needed to carry out the highest priority experiments within the current CEBAF 6 GeV program. Support for R&D for the 12 GeV CEBAF Upgrade is reduced according to the planned profile as the project moves into final design, and funding is redirected towards the 12 GeV CEBAF Upgrade. With this support, operating hours are increased by 26% (+900 hours).	+5,775

	FY 2009 vs. FY 2008 ($000)
• **TJNAF Experimental Support** FY 2009 funding is increased compared to FY 2008, funding personnel at levels needed for CEBAF experimental support activities that will support the facility running schedule. Experimental capital equipment support is increased to carry out the highest priority experiments within the current CEBAF 6 GeV program.	+918
Total, TJNAF Operations	**+6,693**
▪ **Bates Facility** The final funding increment for D&D activities at MIT/Bates was provided in FY 2008.	-2,000
Total, Operations	**+4,693**
Total Funding Change, Medium Energy Nuclear Physics	**+8,657**

Heavy Ion Nuclear Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Heavy Ion Nuclear Physics			
Research			
University Research	12,998	13,149	14,644
National Laboratory Research	22,151	22,263	27,598
Other Research[a]	—	4,454	5,612
Total, Research	35,149	39,866	47,854
Operations			
RHIC Operations	135,468	136,034	148,859
Other Operations	9,283	9,283	4,844
Total, Operations	144,751	145,317	153,703
Total, Heavy Ion Nuclear Physics	179,900	185,183	201,557

Description

The Heavy Ion Nuclear Physics subprogram supports fundamental research directed primarily at answering the overarching questions that define the first frontier identified by the nuclear science community—quantum chromodynamics:

What are the phases of strongly interacting matter, and what roles do they play in the cosmos?

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?

What determines the key features of QCD, and what is their relation to the nature of gravity and spacetime?

The subprogram also supports investigations into aspects of several of the overarching questions that define the second and third frontiers—nuclei and nuclear astrophysics, and fundamental symmetries and neutrinos:

What is the nature of neutron stars and dense nuclear matter?

and

Why is there now more visible matter that antimatter in the universe?

[a] In FY 2007, $4,390,000 was transferred to the SBIR program. This activity includes $4,390,000 for SBIR in FY 2008 and $5,296,000 for SBIR in FY 2009.

Historically, the first major milestone in establishing the idea for the formation of heated nuclear matter was marked in 1984 when scientists working at the LBNL Bevalac accelerator found the first direct evidence that nuclear matter can be compressed to high temperature and density using accelerated heavy ion beams. This observation led to the studies of hot and extremely dense hadronic matter created in heavy ion collisions with gold beams at the BNL Alternating Gradient Synchrotron (AGS) in 1992 and at the CERN Super Proton Synchrotron (SPS) in 1994. These tiny "fireballs" equilibrated rapidly, suggesting that the right conditions should exist at even higher beam energies to create a new phase of metamorphosed matter called the quark-gluon plasma (QGP)—named in the popular press as the mini "Big Bang," since this primordial form of matter is thought to have existed shortly after the birth of the universe.

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. The RHIC facility presently puts heavy ion research at the energy frontier and is also the only facility in the world that provides collisions of polarized protons with polarized protons. This latter unique capability allows information to be obtained on the intrinsic arrangement of gluons that bind quarks into a nucleon (a proton or a neutron). At the opposite end of the temperature scale, limited studies into the conditions for inducing the liquid-to-gas phase transition in nuclear matter are underway at the NSF National Superconducting Cyclotron Laboratory at Michigan State University, at Texas A&M University, and at foreign laboratories.

The construction of RHIC was completed in August 1999 and RHIC has operated over seven highly successful running periods: Run 1 in FY 2000 with gold beams; Run 2, in FY 2001-2002, with gold beams and commissioning of polarized protons; Run 3 in FY 2003, with deuteron-gold collisions and the first physics results with polarized proton collisions; Run 4 in FY 2004 with high luminosity gold beams and polarized protons; Run 5 in FY 2005 with high luminosity copper beams and polarized protons; Run 6 in FY 2006 devoted to high statistics polarized proton operations; and Run 7 in FY 2007 with gold beams. This facility is utilized by about 1,200 DOE, NSF, and foreign agency supported researchers.

The NSAC Subcommittee Review of Heavy Ion Nuclear Physics in 2004 found the long-term plans for expanding the scientific reach of the U.S. program were well formulated and had excellent prospects for new discoveries and for developing a deeper understanding of the properties of nuclear matter and of the origins of the universe.

The Large Hadron Collider (LHC), nearing full operation at CERN, offers opportunities for new discoveries in relativistic heavy ion physics, driven by a 30-fold increase in center-of-mass energy, which generates different initial conditions and a larger kinematic reach for hard probes. A modest U.S. research and detector development effort at the LHC is supported that will build upon the discoveries made at RHIC. The LHC is expected to commence heavy ion operations in the 2008-2009 timeframe.

FY 2007 Research Accomplishments

In the seventh running period in FY 2007, RHIC delivered high intensity beams of gold ions for important measurements.

The wealth of heavy ion data from the years of operation of the RHIC collider has appeared in over 185 scientific publications. The results are leading to a developing paradigm of the matter produced in highly energetic nucleus–nucleus collisions as a "perfect liquid" with minimum viscosity.

- First measurements have been made of the viscosity/entropy ratio of hot dense partonic matter. This ratio was found to be small by an observation of large energy loss and significant hydrodynamic flow of mesons containing a charm quark. Data suggest heavy quarks may diffuse readily in a strongly-interacting Quark Gluon Plasma (sQGP) medium with minimum viscosity.
- Recent results show the response of hot dense partonic matter to energy deposited by transiting quarks or gluons is in the emission of additional particles at larger angles with lower momenta more typical of the medium than of normal hadron jets in proton-proton collisions. This striking modification of particle production depends on the amount of partonic matter traversed but is nearly independent of the colliding system and energy.
- Researchers continue to observe that the anisotropic collective flow of hadrons scales with the quark content of the hadron, even for composite nuclei such as deuterons. Phi mesons, a particle resonance or extremely short-lived particle, have a very similar mass to protons, but follow the flow pattern of other hadrons with two quarks, while deuterons behave as other baryons. This observation provides further evidence that the flow is built up early in the collision, when the degrees of freedom of the matter are those of quarks and gluons.
- New results on the relative production of particles containing charm and beauty at RHIC energies substantiates the discovery, contrary to theoretical prediction, that heavy quarks lose energy much the same as light quarks do in the new state of matter created in relativistic heavy ion collisions at RHIC.
- Experimental observations indicate the possible discovery that a shock front (mach-cone) is created by energetic particles that traverse the new state of matter created in relativistic heavy ion collisions at RHIC. The three-particle correlation data indicate a cone-like emission pattern, rather than a deflected jet topology, redolent of shock waves or Cherenkov radiation. Such observations could help to constrain the value of the speed of sound or the dielectric constant of the plasma.

FY 2007 Facility and Technical Accomplishments

- RHIC successfully operated with gold beams with over 100 bunches circulating in each collider ring. A new integrated luminosity record of ~ 2.8 nb^{-1} at 100 GeV per nucleon beam energy was achieved. This record is twice the luminosity of the previous Gold beam Run 4 in 2004.
- The first successful test of stochastic cooling of high energy, bunched heavy ion beams was accomplished in one ring at RHIC by using state-of-the-art fiber optic technology for signal processing and powerful narrow-band beam kickers. Actual longitudinal cooling of a gold beam at RHIC has been observed.
- The STAR Forward Meson Spectrometer Upgrade, a hodoscope of approximately 1,000 lead glass cells, was completed, and will be used for a definitive search for the Colored Glass Condensate in d+ Au collisions in a future run.

Detailed Justification

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Research	**35,149**	**39,866**	**47,854**
▪ **University Research**	**12,998**	**13,149**	**14,644**

Support is provided for the research of about 120 scientists and 90 graduate students at 27 universities in 21 states. Funding provides support for university researchers to conduct research efforts at RHIC and the continuation of a modest program at the LHC. Support restores the NP workforce to levels needed to support the national Nuclear Physics program.

Researchers using relativistic heavy ion beams are focused on the study of the properties of hot, dense nuclear matter created at experiments at RHIC, next generation instrumentation for RHIC, and implementing new experiments at the LHC. The university groups provide scientific personnel and graduate students needed for running the RHIC experiments, data analysis and publishing RHIC results, and designing and fabricating the RHIC and LHC heavy ion detector upgrades.

Support is provided for a small-scale research program conducted at the NSF-supported National Superconducting Cyclotron Laboratory at Michigan State University, at the DOE-supported Texas A&M University, and at facilities in France and Italy.

▪ **National Laboratory Research**	**22,151**	**22,263**	**27,598**

Support is restored for scientists at five national laboratories (BNL, LBNL, LANL, ORNL, and Lawrence Livermore National Laboratory [LLNL]). 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; integrating electronics designs for high bandwidth data acquisition systems and software technologies; designing, fabricating, and operating LHC detectors; 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. Funding decisions are influenced by the results of periodic peer reviews of the national laboratory research efforts in Heavy Ion Energy Physics. In FY 2004, the five laboratory groups were evaluated based on the significance of their accomplishments and future program, the scientific leadership, creativity and productivity of the personnel, and the overall cost-effectiveness of the group, which included support by the respective laboratory. The report findings included an adjectival rating for these criteria along with an indication of the relative ranking of a particular laboratory group compared to the other groups. In response to the review, out-year funding guidance was provided to each group based on performance and availability of funds. BNL/RHIC management responded to this review with the development of mid-term (10-year) strategic plans for the Heavy Ion and Spin physics programs.

• **BNL RHIC Research**	**10,322**	**9,538**	**12,126**

BNL scientists play a major role in planning and carrying out research using the data acquired from the detectors at RHIC as well as having major responsibilities for maintaining, improving and developing the computing infrastructure for use by the scientific community. The FY 2009 budget request allows BNL scientists to continue to provide adequate maintenance and infrastructure support of the experiments and to effectively utilize the beam time for research and to train junior scientists. The PHENIX Silicon Vertex Tracker (VTX) MIE (TEC = $4,700,000), a

	FY 2007	FY 2008	FY 2009
	(dollars in thousands)		

joint project with the Japanese, is continued in FY 2009 for planned completion in FY 2010. The PHENIX VTX 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. Capital equipment funds support the continuing fabrication in FY 2009 of two MIE's initiated in FY 2008, the PHENIX Nose Cone Calorimeter (NCC) and the PHENIX Forward Vertex Detector (FVTX). These new detectors are important for both the heavy ion and spin programs and have international partners. The NCC (preliminary TEC $4,500,000 - $4,700,000) is a fine grained silicon-tungsten sampling calorimeter that will measure the production of heavy quarks in order to characterize the new states of matter created at RHIC. The FVTX (TEC ~ $4,900,000) will provide vertex tracking capabilities to PHENIX and adds two silicon endcaps to the ongoing PHENIX VTX upgrade MIE. The support for these MIE's was reduced in the FY 2008 Appropriation, stretching the project schedule out and increasing project risk. Studies directed at developing the scientific case for a potential electron-heavy ion collider facility are supported.

	FY 2007	FY 2008	FY 2009
• **Other National Laboratory Research**	**11,829**	**12,725**	**15,472**

Researchers at LANL, LBNL, LLNL, and ORNL provide unique expertise and facilities for RHIC and LHC detector upgrades and analyses of data. For example, at LBNL, the large scale computational system, Parallel Distributed Systems Facility (PDSF), is a major resource used for the analysis of RHIC and LHC data, in alliance with the National Energy Research Scientific Computing Center (NERSC), and at LLNL computing resources are made available for the PHENIX data analysis. Research efforts are maintained at a level needed to support the national Nuclear Physics program. Capital Equipment funding is provided to continue U.S. participation in the heavy ion program at the LHC according to planned profiles. The LHC Heavy Ion MIE (preliminary TPC $13,000,000-$16,000,000) is a joint project with France and Italy that adds a calorimeter to the CERN A Large Ion Collider Experiment (ALICE) to provide the capability to study jet physics.

	FY 2007	FY 2008	FY 2009
▪ **Other Research**	—	**4,454**	**5,612**
• **SBIR and Other**	—	**4,454**	**5,362**

In FY 2007, $4,390,000 was transferred to the Small Business Innovative Research (SBIR) program. This activity includes $4,390,000 for SBIR in FY 2008 and $5,296,000 for SBIR in FY 2009 as well as other established obligations that the Heavy Ion Nuclear Physics subprogram must meet.

	FY 2007	FY 2008	FY 2009
• **Accelerator R&D Research**	—	—	**250**

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

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Operations	**144,751**	**145,317**	**153,703**
▪ **RHIC Operations**	**135,468**	**136,034**	**148,859**

RHIC operations are supported for an estimated 25-week running schedule (76% utilization) in FY 2009 that greatly expands the opportunities to vary the initial conditions (parameters) for forming the observed new state of matter. Reduced support in the FY 2008 Appropriation impacts preparations for the start of the FY 2009 operations run, which is anticipated to negatively impact levels of operation in FY 2009. The implementation of EBIS and 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—the “perfect liquid”—and to establish whether other phenomena, such as a “Color Glass Condensate” or Chiral Symmetry Restoration exist in nature.

• **RHIC Accelerator Operations**	**104,839**	**104,700**	**115,460**

Support is provided for the operation ($111,160,000), capital investments ($1,000,000), and improvement ($3,000,000) of the RHIC accelerator complex. This includes the Tandem (that will be replaced by the Electron Beam Ion Source, under construction), Booster, and AGS accelerators that together serve as the injector for RHIC. FY 2009 operating funding will support about 25 weeks (3,100 hours) of operations, a 6 week increase compared to the FY 2008 Appropriation. The initial survey work will be largely completed and the experimental program will be dominated by measurement of yields of rarer signals and characterization of “jets”. These measurements will require higher integrated luminosity and support is provided for R&D of electron beam cooling and other luminosity enhancement technologies.

	FY 2007	FY 2008	FY 2009
RHIC Hours of Operation with Beam			
Optimal Hours	4,500	4,100	4,100
Planned Operating Hours	3,430	2,230	3,100
Achieved Operating Hours	2,006	N/A	N/A
Unscheduled Downtime	30.3%	N/A	N/A
Number of Users[a]	900	1,200	1,200

• **RHIC Experimental Support**	**30,629**	**31,334**	**33,399**

Support is provided for the operation, maintenance, improvement, and enhancement of the RHIC experimental complex, including detectors, experimental halls, computing center, and support for users. The RHIC detectors have reached their initial planned potential and about 1,200 scientists and students from 82 institutions and 19 countries will participate in the RHIC research program in FY 2009. Two detectors will operate in FY 2009: STAR and PHENIX. These detectors

[a] Counting of users at the NP facilities has been improved to ensure consistent counting methodology from one facility to the next and to remove possible double counting. The more accurate count is reflected for FY 2008 and FY 2009.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
provide complementary measurements, but with some overlap in order to cross-calibrate the measurements. FY 2009 funding will support Experimental Support efforts at the level needed for an estimated 25-week running schedule and to pursue important detector R&D activities, essential for developing the future capabilities of the experimental program. Base capital equipment funding is increased relative to FY 2008 to provide the support for maintaining computing capabilities at the RHIC Computing Facility (RCF) and for instrumentation.			
▪ **Other Operations**	**9,283**	**9,283**	**4,844**
The Nuclear Physics program provides funding to BNL for minor new fabrications, needed laboratory equipment (including general purpose equipment (GPE)), 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.			
Total, Heavy Ion Nuclear Physics	**179,900**	**185,183**	**201,557**

Explanation of Funding Changes

	FY 2009 vs. FY 2008 ($000)
Research	
▪ **University Research**	
The increase for University Research grants in FY 2009 restores support to a level needed to support the Nuclear Physics program. The major focus of research will be at the RHIC program with data taking with STAR and PHENIX. A modest effort is directed towards research at the LHC heavy ion program at CERN.	+1,495
▪ **National Laboratory Research**	
• BNL RHIC Research: The FY 2009 budget request restores support to a level needed to support the national Nuclear Physics program. Funding for capital equipment is provided to continue the fabrication of the PHENIX Vertex Tracker (VTX), the PHENIX Nose Cone Calorimeter (NCC) and the PHENIX Forward Vertex (FVTX) detector MIEs.	+2,588
• Other National Laboratory Research: The FY 2009 increase restores research efforts at a level needed to support the national Nuclear Physics program and provides funding for additional capital equipment investments, in particular an increase of $2,000,000 for the Electromagnetic Calorimeter upgrade to the LHC ALICE experiment. These funds will ensure that National Laboratory researchers continue to provide adequate support to the RHIC and LHC experiments and its upgrades, and to effectively utilize the beam time for research and to train students and young scientists.	+2,747
Total, National Laboratory Research	**+5,335**

	FY 2009 vs. FY 2008 ($000)
▪ **Other Research**	
• SBIR and Other: Increase reflects required SBIR obligations.	+908
• Accelerator R&D Research: Funds are provided for accelerator R&D to develop the knowledge, technologies and trained scientists needed to design and build accelerator facilities to accomplish its DOE programmatic mission in nuclear physics.	+250
Total, Other Research	**+1,158**
Total, Research	**+7,988**
Operations	
▪ **RHIC Operations**	
• RHIC Accelerator Operations: The FY 2009 request supports an approximate 25 week running schedule to meet the program's scientific goals and performance measures. An increase of $1,100,000 is provided for accelerator improvement projects (AIP) to impact operational efficiency and provide new capabilities. Capital Equipment is increased by $300,000 to restore to FY 2007 levels.	+10,760
• RHIC Experimental Support: Funding is provided for experimental scientific/technical staff and materials and supplies, and capital equipment that effectively support the maintenance and operation of the PHENIX and STAR detectors at RHIC for a 25-week operating schedule. Base capital equipment funding is increased by $500,000 compared to FY 2008.	+2,065
Total, RHIC Operations	**+12,825**
▪ **Other Operations**	
The FY 2009 general plant project (GPP) funds are reallocated to the Science Laboratory Infrastructure program in support of renovating the infrastructure across SC's laboratory complex to achieve SC's strategy for mission readiness. Support of general plant project activities will be accomplished using institutional general plant project funding.	-4,439
Total, Operations	**+8,386**
Total Funding Change, Heavy Ion Nuclear Physics	**+16,374**

Low Energy Nuclear Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Low Energy Nuclear Physics			
Research			
University Research	18,787	19,621	20,440
National Laboratory Research	27,203	30,192	35,137
Other Research[a]	4,175	5,519	8,822
Total, Research	50,165	55,332	64,399
Operations	27,888	28,253	32,163
Total, Low Energy Nuclear Physics	78,053	83,585	96,562

Description

The Low Energy Nuclear Physics subprogram supports fundamental research directed primarily at answering the overarching questions that define the second and third frontiers identified by the nuclear science community—nuclei and nuclear astrophysics, and fundamental symmetries and neutrinos:

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?

and

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 are present at the dawn of the universe, but disappeared from view as it evolved?

Research in the Low Energy subprogram continues to evolve to address forefront scientific questions. The 1990's began with research efforts at the 88-Inch Cyclotron, ATLAS, and other facilities to identify and characterize rapidly rotating superdeformed nuclei that have elongated football shapes. These spectroscopic studies have led to a deeper understanding of nuclear structure at high spin and large deformation. Spectroscopic studies are now probing the stability and structure of nuclei at the proton

[a] In FY 2007, $1,344,000 has been transferred to the SBIR program. This activity includes $1,344,000 for SBIR in FY 2008, and $1,426,000 for SBIR in FY 2009.

dripline, the structure of neutron-rich nuclei, and the surprising stability of rapidly spinning very heavy nuclei. Stable beams and the first radioactive beams in the mid-1990's enabled nuclear structure and cross-section experiments to determine the nuclear reaction paths and some rates for the breakout from the stellar carbon-nitrogen-oxygen (CNO) cycle that leads to production of heavier elements. In the 2000's the pace of nuclear physics experiments important for nuclear astrophysics has quickened. Current experiments are determining the production and destruction rates for long-lived radioactive species produced by supernovae and measured by gamma-ray observatories in space. New experimental programs are beginning to explore the *r*-process and *rp*-process pathways for nucleosynthesis. The HRIBF facility now produces over 150 proton-rich and neutron-rich radioactive beams for research. New radioactive beams are being developed to increase the scientific reach of the facility. The CAlifornium Rare Isotope Breeder Upgrade (CARIBU) is being developed at ATLAS to provide accelerated rare isotope beams that will complement the capabilities of HRIBF.

The National User Facilities, HRIBF and ATLAS, are utilized by DOE, NSF, and foreign-supported researchers. Capital equipment funds are provided for detector systems, for data acquisition and analysis systems, and for accelerator instrumentation. Accelerator improvement project (AIP) funds are provided to improve the reliability and efficiency of operations, and to provide new accelerator capabilities. The LBNL 88-Inch is being supported to test electronic circuit components for radiation "hardness" to cosmic rays by the National Reconnaissance Office (NRO) and U.S. Air Force (USAF), and for a small in-house nuclear physics research program by the NP program. A Memorandum of Agreement between NP, NRO, and the USAF provides for joint support of the 88-Inch Cyclotron through 2011. In FY 2009, fabrication continues at LBNL for the Gamma Ray Energy Tracking In-Beam Nuclear Array (GRETINA) MIE, a segmented germanium detector array with improved position resolution and efficiency for studies with fast fragment nuclear beams.

Progress in both nuclear structure and nuclear astrophysics studies depends in part upon the availability of rare isotope beams to produce and characterize nuclei that lie in unstudied regions of the nuclear chart and that are involved in important astrophysics processes. While the U.S. today has facilities with capabilities for these studies, the Department has determined that a facility with next generation capabilities for short-lived radioactive beams will be needed for the U.S. to maintain a leadership role. A National Academy of Sciences (NAS) study provided an independent scientific assessment and concluded that "the science addressed by a rare isotope facility, most likely based on a heavy ion driver using a linear accelerator, should be a high priority for the United States" (*Scientific Opportunities with a Rare Isotope Facility in the United States* available at http://www.sc.doe.gov/np/). Guidance has been obtained from NSAC regarding the technical options for a U.S. world-class facility that complements capabilities available elsewhere in the world and that can be built with the resources available. The construction of a U.S. facility for rare isotope beams is a major recommendation of the 2007 NSAC Long Range Plan. A solicitation in FY 2008 will identify the most promising path forward and a site for the facility. In FY 2009, funding is requested to support rare isotope beam R&D and Conceptual Design activities.

University-based research is an important feature of the Low Energy subprogram. Accelerator operations are supported at Texas A&M University (TAMU), the Triangle Universities Nuclear Laboratory (TUNL) at Duke University, and at Yale University; infrastructure is supported at the University of Washington to enable scientific instrumentation projects to be undertaken. Each of these university Centers of Excellence has a critical mass of nuclear physics faculty involved in research that is conducted both on and off campus and about 15-25 graduate students at different stages of their education. These students historically have been an important source of leaders in the field. Many of these scientists, after obtaining their Ph.D.s, contribute to a wide variety of nuclear technology programs of interest to the DOE and the Nation.

In neutrino physics, the Sudbury Neutrino Observatory (SNO) experiment was designed and built to search for neutrino flavor oscillations with solar neutrinos. It was spectacularly successful, showing that neutrinos produced in the core of the sun change their character (oscillate) as they traverse solar matter, and thus have mass. SNO concluded its data taking phase in FY 2007 and the collaboration continues data analysis and reporting in FY 2008 and FY 2009. SNO's results confirm that the sun indeed draws its energy from nuclear reactions and the number of neutrinos measured agrees well with solar neutrino emission calculated with current models of the sun. The KamLAND detector in Japan is continuing to study the properties of anti-neutrinos produced by nuclear power reactors, while entering a new experimental phase to measure lower energy solar neutrinos following an upgrade of the detector. Together, SNO and KamLAND, along with other neutrino oscillation experiments, have led to significant progress in understanding the nature of neutrinos. In FY 2008, a U.S. laboratory and university collaboration joined the Italian-lead Cyrogenic Underground Observatory for Rare Events (CUORE) experiment at the Gran Sasso Laboratory, contributing to the fabrication of the detector that is planned to become operational in approximately FY 2012. This experiment will search for evidence that the neutrino is its own antiparticle (a Majorana particle), and determine or set a limit on the effective Majorana mass of the neutrino. In FY 2007, a U.S. university collaboration began limited but crucial participation in the German-lead KArlsruhe TRitium Neutrino (KATRIN) experiment to determine kinematically the mass of the electron neutrino by measuring the beta decay spectrum of tritium. This experiment will become operational in approximately 2011.

The Low Energy subprogram also supports studies of fundamental interactions and symmetries in selected nuclei: "laboratories" that allow precise measurements to test the present understanding of the Standard Model. Some experiments use accelerators in conjunction with special apparatus to study fundamental nuclear and nucleon properties, such as reactions with and decays of cold neutrons. Such experiments are being mounted at cold and ultra-cold beam lines at the SNS, or are being prepared. In FY 2009, fabrication continues for the Fundamental Neutron Physics Beamline (FNPB) MIE at the SNS in preparation for these measurements of fundamental properties of the neutron including the electric dipole moment of the neutron (nEDM).

FY 2007 Research Accomplishments

The Low Energy subprogram has significant achievements in FY 2007 that are related to the central questions about nuclear structure, nuclear astrophysics, and fundamental interactions and symmetries. The basic knowledge and understanding in these areas have been further extended by these recent highlights:

- Evidence for neutron-proton pairing has been recently found in experiments at ATLAS at ANL. Starting with nuclei such as ^{66}As (N=Z=33) up to ^{86}Tc, a "pairing gap" appears in the low-lying level spectrum that is similar to the gaps found for even-even nuclei. These neutron-proton pairing correlations have been predicted to have a major impact on nuclear properties that influence the *rp*-process in nucleosynthesis in stars.
- The use of neutron-rich radioactive beams may enhance the production rate of heavy element synthesis. At HRIBF, the fusion of neutron-rich radioactive ^{132,134}Sn beams with ^{64}Ni has been compared with the fusion of stable $^{112\text{-}124}$Sn beams with the same target, measuring the yield of evaporation residues in each case. The yield for producing evaporation residues of the same mass is

higher in the reactions with more neutron-rich Sn beams. This suggests that neutron-rich radioactive beams could be effectively utilized to synthesize new neutron-rich isotopes of heavy elements.

- Certain atomic nuclei with special numbers of both protons and neutrons, referred to as "doubly-magic" nuclei, have unusually stable configurations, and serve as fundamental benchmarks in the development of the basic theory of nuclei. Some of these doubly-magic nuclei, such as ^{132}Sn, are unstable and can only be studied using radioactive beam techniques. At HRIBF, experiments have started using radioactive Sn nuclei to determine the properties of nuclei near ^{132}Sn. These experiments not only provide important information for the development of nuclear theory, but also data critical to understanding how the heavy elements are formed in stellar explosions.
- Understanding how simple and coherent collective motions arise from individual particles is an exciting challenge for all quantum systems, from the quark level to quantum dots. A breakthrough method using projectile Coulomb excitation experiments with ATLAS and Gammasphere at ANL has been used to selectively populate and identify for the first time a mixed symmetry state in ^{138}Ce. This technique opens the way to survey the development of neutron-proton collectivity across whole regions of nuclei.

FY 2007 Facility and Technical Accomplishments

- The Versatile ECR for NUclear Science (VENUS) electron-cyclotron resonance (ECR) ion source, developed at LBNL, is the first fully functional superconducting ECR ion source in operation with magnetic confinement fields strong enough for optimized operation at 28 GHz. Performance is a factor of 8 to 10 higher than reported for conventional ion sources, and makes possible the high beam powers at lower beam energy now being considered for a future U.S. facility for rare isotope beams.
- A high intensity gas catcher is a central component required to produce reaccelerated beams of radioactive nuclei at a future facility for rare isotope beams in the U.S. The performance of the gas catcher has been improved by a new design, which uses a radio-frequency structure that surrounds the ion cloud to selectively focus and guide radioactive ions to the extraction nozzle of the gas catcher. With this design, the bulk of the ionization density, mostly helium ions, is rapidly neutralized on the electrodes. The device was successfully operated with high efficiency at incident ion rates four orders of magnitude higher than previously demonstrated. These intensities meet the requirements for the proposed U.S. facility for rare isotope beams.
- The High Power Target Laboratory (HPTL) project was completed and commissioned at the HRIBF in FY 2006. The HPTL advances the state of the art of Isotope Separator On-Line (ISOL) radioactive ion beam production, including the development of targets, ion sources, and beam production and purification techniques. Currently, the HPTL is being utilized to develop a target and ion source for the production of radioactive aluminum beams that will enable studies of nuclear cross sections relevant to the interpretation of the aluminum gamma-ray distribution in the galaxy that is observed by orbiting observatories.
- The construction and commissioning of the High Intensity Gamma-ray Source (HIγS) at Duke University was completed in FY 2007. The (HIγS) facility will provide unique capabilities to use photonuclear interactions for studies of nucleon and nuclear structure, nuclear astrophysics, and nuclear applications.

Detailed Justification

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Research	**50,165**	**55,332**	**64,399**
▪ **University Research**	**18,787**	**19,621**	**20,440**

Support is provided for the research of about 123 scientists and 97 graduate students at 35 universities. Nuclear Physics university scientists perform research as users at national laboratory facilities, at on-site facilities, and at other specifically fabricated experiments. These activities address a broad range of fundamental issues as diverse as the properties of nuclei, the nature of the weak interaction, the production mechanisms of the chemical elements in stars and supernovae, and the properties of neutrinos. Support restores the NP workforce to levels needed to support the national Nuclear Physics program.

FY 2009 funding for operation of university accelerator facilities and for researchers and students provides support at levels needed to support the national Nuclear Physics program. Capital equipment at the university accelerator facilities is modestly increased (+$105,000) relative to FY 2008 levels for investments in experimental instrumentation and enhanced capabilities.

- University researchers conduct programs using the low energy heavy ion beams and specialized instrumentation at the ATLAS and HRIBF National User Facilities. These efforts at the user facilities involve about two-thirds of the university scientists supported by this subprogram.
- Accelerator operations are supported for in-house research programs at the TUNL facility at Duke University, TAMU, and Yale University. These small university facilities have well-defined and unique physics programs, providing photons, neutrons, light ion beams, or heavy ion beams, specialized instrumentation, and opportunities for long-term measurements that complement the capabilities of the national laboratory user facilities. Modest equipment funds are provided for new instruments and capabilities.
- Involvement in other accelerator and non-accelerator experiments directed at fundamental measurements are supported, such as measurements and analyses of data for solar and reactor neutrino rates and the neutrino mass at SNO, KamLAND (jointly with the High Energy Physics program), and Karlsruhe Tritium Neutrino (KATRIN), and development of the fundamental neutron program at the SNS with the Fundamental Neutron Physics Beamline.

▪ **National Laboratory Research**	**27,203**	**30,192**	**35,137**

Support is provided for the research programs of scientists at six national laboratories (ANL, BNL, LBNL, LANL, LLNL, and ORNL). Support restores the NP workforce to levels needed to support the national Nuclear Physics program. Funding decisions are influenced by the results of periodic peer reviews of the national laboratory research efforts in the Low Energy Nuclear Physics sub-program. In FY 2007, the reviewers evaluated each laboratory research group based on the significance of their accomplishments and future program, the scientific leadership, creativity and productivity of the personnel, and the overall cost-effectiveness of the group, which included support by the respective laboratory. Any issues associated with a group were identified. Each group was evaluated individually and then comparatively ranked. The highest performers received increases where merited and based on budgetary constraints. Low performing groups received

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009

recommendations to address issues identified in the review before any funding increases or decreases would be made, depending on their response to the recommendations.

• **National Laboratory User Facility Research**	**10,540**	**11,016**	**12,040**

Scientists at ANL and ORNL have major responsibilities for maintaining, improving, and developing instrumentation for research by the user communities at the ATLAS and HRIBF National User Facilities, as well as playing important roles in carrying out research that addresses the NP program's priorities. In FY 2009, funding for ANL and ORNL research at the user facilities is provided to restore to levels needed to support the national Nuclear Physics program for nuclear structure and astrophysics research with emphasis on high priority projects. Support is provided for the following research activities.

- ► At ANL the research focuses on the use of stable and selected radioactive beams from ATLAS coupled to ion traps; Gammasphere and the Fragment Mass Analyzer to study fundamental processes and properties of nuclei; and the study of nuclei at the extremes of excitation energy, angular momentum, deformation, and isotope stability. Studies are undertaken with the Advanced Penning Trap to measure atomic masses with high precision and search for effects in beta decay outside the standard decay model.
- ► At ORNL the research focuses on the use of radioactive beams from the HRIBF and specialized spectrometers to study the nuclear structure of nuclei far from stability. Measurements are made of reaction cross sections and nuclear properties, such as beta-delayed neutron branching ratios, which are crucial input to detailed astrophysics models that calculate the production of the elements in stars. Specialized equipment is employed, such as a system that integrates gamma-ray and charged-particle detectors with a recoil mass separator. The high-pressure gas target for nuclear astrophysics experiments is being utilized in an experimental program in nuclear astrophysics.

• **Other National Laboratory Research**	**16,663**	**19,176**	**23,097**

Scientists at BNL, LBNL, LLNL, LANL, and ORNL play important roles in several high-priority accelerator- and non-accelerator-based experiments (e.g.; SNO, KamLAND, nEDM and CUORE) directed toward fundamental questions. Double Beta Decay (DBD) experiments, such as CUORE, will search for the neutrino-less double beta decay mode, to measure, or determine an upper limit for, the absolute mass of the neutrino and determine whether the neutrino is its own antiparticle. R&D activities are supported for another neutrino-less DBD experiment, based on a different technology.

Capital equipment funding is provided to support the ongoing GRETINA, FNPB, CUORE and nEDM MIEs. Funding for scientific/technical staff is provided to increase levels of effort in selected areas compared to FY 2008 and is directed at the highest priority research, as described below:

	(dollars in thousands)	
FY 2007	FY 2008	FY 2009

- Support is provided for a LBNL research effort that uses beams from the 88-Inch Cyclotron to conduct an in-house research program that includes heavy element nuclear physics and chemistry, and fundamental symmetry studies, for testing and leadership in the fabrication of the GRETINA detector, for R&D efforts in advanced accelerator technologies and techniques, and for neutrino astrophysics and neutrino properties including KamLAND and the neutrino-less DBD experiment CUORE. Reductions to the radioactivity backgrounds of the KamLAND detector allow it to detect lower energy solar neutrinos and to initiate a second generation experiment that will explore the mechanism by which neutrinos oscillate.
- The GRETINA MIE, for which fabrication began in FY 2004, is especially important for the study of the nuclear decay and structure of rare isotope nuclei in fast fragmentation beams. The improved position resolution and higher efficiency for high-energy gamma rays compared with presently available gamma-ray detector arrays enable this new detector system to utilize fragmented nuclear beams to open up a new frontier for understanding rare isotope nuclei that may exist in stars and supernovae, but live only fractions of a second. In FY 2009, funding of $2,000,000 is provided to continue fabrication of GRETINA (TEC $17,000,000). The GRETINA project was baselined with CD-2 approval in the fall of 2007. Subsequent reductions in the funding profile in the FY 2008 Appropriation put the TEC at risk and may lead to cost growth, dependent upon fluctuations in foreign exchange rates.
- Support is provided for groups at BNL, LANL, and LBNL to conclude the analysis of data and publication of results for the SNO experiment, and conduct R&D and scientific efforts directed at future high priority neutrino experiments.
- Support is provided to ORNL to continue to coordinate and play a leadership role in fabrication and development of the scientific program for the FNPB MIE at the SNS. The FNPB project is a beamline at the SNS that will deliver record peak currents of cold and ultra-cold neutrons for studying the fundamental properties of the neutron, leading to a refined characterization of the weak force. Fabrication began in FY 2004 and continues in FY 2009 with funding of $1,500,000 (TEC $9,200,000).
- FY 2009 support of $1,100,000 is provided to pursue the measurement of the electric dipole moment of the neutron (nEDM), a high discovery potential experiment at the FNPB (preliminary DOE TPC $17,600,000 - $19,000,000). The nEDM experiment is a joint DOE/NSF experiment. The measurement of a non-zero electric dipole moment of the neutron, or a stringent upper limit on its value, will significantly constrain extensions of the Standard Model. Reductions in the planned funding profile in the FY 2008 Appropriation for the nEDM experiment put the estimated TPC at risk and may lead to cost growth and schedule delays.
- Funding is increased within the Low Energy subprogram to support research efforts that are also relevant to the nuclear fuel cycle (+ $4,537,000). Additional funding is provided for this effort in the Nuclear Theory subprogram for Nuclear Data activities. This effort is carried out in collaboration with the Advanced Scientific Computing Research (ASCR) program and other DOE programs. A joint workshop was conducted in FY 2006 with ASCR to identify

	FY 2007	FY 2008	FY 2009
(dollars in thousands)			

the leading scientific issues for nuclear cross sections, nuclear data, and related computations.

- ► Funding of $2,000,000 is provided in FY 2009 to continue fabrication of the CUORE experiment (preliminary TPC $8,000,000 - $10,000,000) to search for neutrino-less double beta decay (DBD). This is a joint DOE/NSF project. R&D continues on additional technical approaches to DBD.

	FY 2007	FY 2008	FY 2009
▪ **Other Research**	**4,175**	**5,519**	**8,822**
• **Generic Rare Isotope Beam R&D**	**3,800**	**3,800**	—

In FY 2007 and FY 2008, funds were provided for R&D activities aimed at development of generic rare isotope beam capabilities. In FY 2009, these R&D activities become facility-specific and part of the Total Project Cost of the proposed facility for rare isotope beams.

	FY 2007	FY 2008	FY 2009
• **Rare Isotope Beam R&D and Conceptual Design**	—	—	**7,000**

Following a site selection planned in FY 2008, funds are provided in FY 2009 for R&D and to begin conceptual design activities aimed at development of a U.S. facility for rare isotope beams. This facility will enable world-leading research opportunities in nuclear structure, nuclear astrophysics, and fundamental studies, and complement the programs of high capability radioactive ion beam facilities elsewhere in the world.

	FY 2007	FY 2008	FY 2009
• **SBIR and Other**	**375**	**1,719**	**1,822**

In FY 2007, $1,344,000 was transferred to the SBIR program. This activity includes $1,344,000 for SBIR in FY 2008, and $1,426,000 for SBIR in FY 2009. Funding is also provided for other established obligations including the Lawrence and Fermi Awards, which provide annual monetary awards to honorees selected by the DOE for their outstanding contributions to science.

	FY 2007	FY 2008	FY 2009
Operations	**27,888**	**28,253**	**32,163**
▪ **User Facility Operations**	**24,603**	**24,903**	**28,331**

In FY 2009, support is provided to more effectively operate the two National User Facilities, the ATLAS at ANL ($13,740,000) and the HRIBF at ORNL ($14,591,000), for studies of nuclear reactions, structure, and astrophysics, and fundamental interactions at increased levels compared to FY 2008.

In FY 2009, funding supports accelerator operations at ATLAS providing increased beam hours compared to FY 2008 levels, and a full transition from 5 day a week operations to the more cost effective 7 day a week operations mode. AIP funding for upgrading the accelerator with a Californium Rare Ion Breeder Upgrade (CARIBU) project was reduced in the FY 2008 Appropriation and is restored in FY 2009. CARIBU will enhance the radioactive beam capabilities of ATLAS.

In FY 2009, funding supports accelerator operations at HRIBF at increased levels in comparison to the FY 2008 Appropriation. The facility begins to commission a second source and transport beamline (IRIS2) for radioactive ions, which will increase operations efficiency and reliability.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009

In FY 2008, these low energy facilities will carry out about 80 experiments involving over 600 U.S. and foreign researchers. The FY 2008 Appropriation provides support to almost maintain the level of operations achieved in FY 2007. Support in FY 2009 provides increased planned hours of operation with beam to more effectively operate the facilities as indicated below:

	FY 2007	FY 2008	FY 2009
ATLAS Hours of Operation with Beam			
Optimal Hours	7,000	6,600	6,600
Planned Operating Hours	4,736	5,200	5,900
Achieved Operating Hours	4,146	N/A	N/A
Unscheduled Downtime	6.2%	N/A	N/A
Number of Users[a]	200	400	370

	FY 2007	FY 2008	FY 2009
HRIBF Hours of Operation with Beam			
Optimal Hours	5,775	6,100	6,100
Planned Operating Hours	4,350	3,800	4,800
Achieved Operating Hours	4,986	N/A	N/A
Unscheduled Downtime	8.8%	N/A	N/A
Number of Users[b]	90	235	225

	FY 2007	FY 2008	FY 2009
▪ **Other Operations**	**3,285**	**3,350**	**3,832**

The 88-Inch Cyclotron has been jointly operated by the NP program and NRO and the USAF since FY 2004. The beams of the 88-Inch Cyclotron are used by NP supported researchers for a focused in-house program and for NRO and USAF to simulate cosmic ray damage to electronic components to be used in space. In FY 2009, the NRO and USAF will utilize the 88-Inch Cyclotron for approximately 2,000 hours for their testing program, and NP will utilize it for approximately 3,000 hours for the in-house nuclear physics research program. The NRO and USAF will provide a total of approximately $2,200,000 and NP will provide $3,674,000 for joint operations of the facility in FY 2009.

[a] Counting of users at the NP facilities has been improved to ensure consistent counting methodology from one facility to the next and to remove possible double counting. The more accurate count is reflected for FY 2008 and FY 2009.
[b] Counting of users at the NP facilities has been improved to ensure consistent counting methodology from one facility to the next and to remove possible double counting. The more accurate count is reflected for FY 2008 and FY 2009.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Funding is also provided for maintenance of the Oak Ridge Electron Accelerator (ORELA) for criticality measurements supported by DOE/NNSA.			
Total, Low Energy Nuclear Physics	**78,053**	**83,585**	**96,562**

Explanation of Funding Changes

	FY 2009 vs. FY 2008 ($000)
Research	
▪ **University Research**	
FY 2009 funding is increased compared to FY 2008, funding personnel at levels needed to support the national Nuclear Physics program. Research concentrates on high priority programs, operations of university accelerators, and non-accelerator initiatives.	+819
▪ **National Laboratory Research**	
• National Laboratory User Facility Research: FY 2009 funding is increased compared to FY 2008, funding personnel at levels needed to support the high priority research efforts and activities at the ATLAS and HRIBF.	+1,024
• Other National Laboratory Research: Funding is reduced for capital equipment (-$1,162,000) mostly as the result of planned funding profiles for ongoing fabrication of the GRETINA, FNPB, CUORE and nEDM MIEs. This decrease is offset by an increase for scientific/technical staff to support high priority research efforts including fundamental research with neutrons (+$5,083,000).	+3,921
Total, National Laboratory Research	**+4,945**
▪ **Other Research** The increase reflects the beginning of activities related to the proposed facility for rare isotope beams (+$7,000,000), which is offset by the completion of generic R&D for rare isotope beam capabilities (-$3,800,000). Required SBIR and other obligations increase by $103,000.	+3,303
Total, Research	**+9,067**

	FY 2009 vs. FY 2008 ($000)
Operations	
▪ User Facility Operations: Funding supports HRIBF (+$1,915,000) and ATLAS (+$517,000) at operating levels increased to that of the FY 2008 Appropriation to more effectively operate these two National User Facilities; capital equipment and AIP investments increase (+$996,000) as capital equipment funds that had been redirected to salaries in the FY 2008 Appropriation are restored and AIP projects are supported for the fabrication of a second source and transport beamline for radioactive ions at HRIBF, and to develop an ion source for unique capabilities for radioactive ions at ATLAS.	+3,428
▪ Other Operations: Maintains NP's share of the 88-Inch Cyclotron operations and provides needed funding for maintenance.	+482
Total, Operations	**+3,910**
Total Funding Change, Low Energy Nuclear Physics	**+12,977**

Nuclear Theory

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Nuclear Theory			
Theory Research			
University Research	13,524	13,930	15,299
National Laboratory Research	11,640	11,976	13,585
Scientific Discovery through Advanced Computing (SciDAC)	2,200	2,200	2,679
Total, Theory Research	27,364	28,106	31,563
Nuclear Data Activities	5,841	5,924	8,391
Total, Nuclear Theory	33,205	34,030	39,954

Description

Progress in nuclear physics, as in any science, depends critically on improvements in the theoretical techniques and on new insights that will lead to new models and theories that can be applied to interpret experimental data and predict new behavior. The Nuclear Theory subprogram supports fundamental research directed at answering the overarching questions that define all three of the frontiers identified by the nuclear science community—quantum chromodynamics, nuclei and nuclear astrophysics, and fundamental symmetries and neutrinos:

What are the phases of strongly interacting matter, and what roles do they play in the cosmos?

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?

What determines the key features of QCD, and what is their relation to the nature of gravity and spacetime?

and

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?

and

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 are present at the dawn of the universe, but disappeared from view as it evolved?

The research of this subprogram is conducted entirely by groups and individual researchers located at universities and DOE national laboratories. The researchers utilize the high performance computational facility at the National Energy Research Scientific Computing Center (NERSC) at the Lawrence Berkeley National Laboratory and other specialized computers at other institutions. This subprogram also sponsors the Institute for Nuclear Theory (INT), based at the University of Washington, Seattle, where visiting scientists focus on key frontier areas in nuclear physics, including those crucial to the success of existing and future experimental facilities and the education of postdoctoral researchers and graduate students. There is large participation in the INT by researchers from Europe and Japan and by researchers in overlapping fields such as astrophysics, atomic and molecular physics, condensed matter physics and particle physics.

The subprogram is responding to the need for large dedicated computational resources for Lattice Quantum Chromodynamics (LQCD) calculations that are critical for understanding the experimental results from RHIC and CEBAF. Together with the High Energy Physics (HEP) and Advanced Scientific Computing Research (ASCR) programs, an approximately 5 teraflop prototype computer was developed and implemented in FY 2005 using the custom QCD On-a-Chip (QCDOC) technology. In a joint effort with HEP, development of large-scale facilities began in FY 2006 and will be completed in FY 2009 to provide computing capabilities based on commodity cluster systems. By the end of FY 2008, it is anticipated that the joint HEP/NP Major IT initiative will be operating facilities with an aggregate capacity of 15.6 teraflop/s. The objective for FY 2009 is to acquire an additional 2.4 teraflop/s.

The program is enhanced through interactions with complementary programs overseas, efforts supported by the NSF, programs supported by the DOE HEP program and Japanese supported theoretical efforts related to RHIC at the RIKEN Center at Brookhaven National Laboratory. The Japan U.S. Theory Institute for Physics with Rare Isotope Nuclei (JUSTIPEN) was formed at RIKEN (in Wako, Japan) in FY 2006. JUSTIPEN's purview will be in the area of the physics of (or with) rare isotope nuclei, including nuclear structure and reaction theory, nuclear astrophysics, and tests of the Standard Model using rare isotope nuclei. U.S. participation in JUSTIPEN is in the form of travel grants and subsistence grants to individual theorists interested in collaborating with Japanese scientists.

Nuclear Theory subprogram activities are aimed at providing information services on critical nuclear data and have as a goal the compilation and dissemination of an accurate and complete nuclear data information base that is readily accessible and user oriented.

FY 2007 Accomplishments

Significant theoretical advances have been made in all of the three major frontiers of research in nuclear physics today. A few of the most recent accomplishments are:

- The transition from ordinary hadronic matter to the quark-gluon plasma (QGP) as well as properties of the high temperature phase is being studied in lattice QCD calculations. An international collaboration of theorists at Brookhaven National Laboratory, Columbia University, and Bielefeld University, Germany have performed a modern determination (using input quark masses near the physical values) of the transition temperature and find a new value that is about 10% higher than earlier estimates. These new results suggest that an intermediate regime between the QCD transition and freeze-out exists during which the system created in a heavy ion collision persists in a dense hadronic phase. The transition temperature project made intensive use of the two QCDOC computers managed at BNL for the RIKEN-Brookhaven-Research Center and for the Lattice QCD project of the HEP and NP programs.

- It has been speculated, since the 1950's, that the nucleon and its first excited state – Δ(1232) – are both composed of a core of some material that is enclosed in a cloud of mesons. With the advent of Quantum Chromodynamics (QCD), we now know that the core is composed of a complicated mix of quarks and gluons. This mélange can naturally emit and reabsorb mesons, so the old picture of the nucleon and Δ(1232) begins to appear very natural. The testing and verification of this picture is possible using modern electron scattering facilities via pion electroproduction reactions. Over the past ten years, such experiments have been performed at JLab, BNL-LEGS, MIT-Bates and Mainz, and a wealth of data has been accumulated. Working within the context of the recently established Excited Baryon Analysis Center (EBAC) at TJNAF, researchers completed an analysis of the data in 2006, using a dynamical model developed by researchers at Argonne National Laboratory and Osaka University. The results provide the long awaited and conclusive evidence that the early qualitative picture of the nucleon and Δ (1232) is correct; the meson cloud contribution is needed to describe the data at low momentum transfer. Another theoretical model of the quark and gluon core itself, also by TJNAF theorists, verified the need for the meson cloud contribution with similar attributes as that of the dynamical model.

- The auxiliary-field Monte Carlo (AFMC) method, long applied to condensed matter systems, was introduced to nuclear physics about 15 years ago to make predictions of the properties of heavier nuclei where shell model calculations were no longer possible because of the large many-body basis. The AFMC method, however, has been limited by the so-called "sign problem" (path integral of the shell model two-body interactions). Recently researchers at Lawrence Livermore National Laboratory have introduced a prescription to overcome the sign problem and tested it against the exact shell model. The success of these tests (nuclear level densities and ground state properties) indicates the hope of confidently extending AFMC to more massive nuclei (up to $A \approx 120$) and thus bringing the predictive power of the nuclear shell model to challenging problems of nuclear physics not confined to nuclear structure itself. For example, nuclear level densities play an important role in theoretical estimates of nuclear reaction rates needed in various applications including astrophysical nucleosynthesis processes like the *s*-, *r*-, and *rp*-process. In the search for physics beyond the Standard Model, the interpretation of future neutrino-less double beta decay experiments requires the value of the nuclear matrix element of the decay operator; a quantity whose present theoretical estimates differ by about a factor of ten for ^{76}Ge.

- In December 2006, the National Nuclear Data Center at Brookhaven National Laboratory released the next generation evaluated nuclear data library for nuclear science and technology, ENDF/B-VII.0; the major U.S. library dedicated to nuclear reactions. This event coincides with the renewed interest in the nuclear energy option (Advanced Fuel Cycles, Global Nuclear Energy Partnership, and Generation-IV Nuclear Energy Systems). The ENDF/B-VII.0 has been developed by the Cross Section Evaluation Working Group (CSEWG) with a significant contribution from the U.S. Nuclear Data program laboratories (LANL, BNL, NIST, and LLNL). It contains a host of advances over the previous library of computer codes and evaluated data including new methods for including the uncertainties and covariances needed by the physics community, the nuclear energy community and the Nation.

Detailed Justification

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Theory Research	**27,364**	**28,106**	**31,563**
▪ **University Research**	**13,524**	**13,930**	**15,299**

The research of about 145 university scientists and 105 graduate students is supported through 56 grants at 43 universities in 28 states and the District of Columbia. The range of topics studied is broad, constantly evolving, and each active area of experimental nuclear physics is supported by nuclear theory activities. Graduate student and postdoctoral support is a major element of this program. In FY 2009, funding supports a level of effort for theoretical efforts needed for interpretation of experimental results obtained at the NP facilities. The theoretical efforts are optimized to focus on the high priority activities that are aligned with SC Strategic Plan milestones.

The Institute for Nuclear Theory (INT) at the University of Washington hosts 3 programs per year where researchers from around the world attend to focus on specific topics or questions (annual budget approximately $2,000,000). These programs result in new ideas and approaches, the formation of collaborations to attack specific problems, and the opportunity for interactions of researchers from different fields of study. Often the key papers on the program subjects are either written during the INT programs or based on discussions that took place at the INT. For example, much of the early phenomenology of the Colored Glass Condensate (CGC) for RHIC collisions was developed at the INT. In particular, the prediction of particle suppression at forward rapidity originated at the INT, was subsequently verified experimentally, and remains the strongest evidence for the existence of CGC. The current focus of the nuclear structure community on mean field theory and the energy density functional can be traced back to programs at the INT.

▪ **National Laboratory Research**	**11,640**	**11,976**	**13,585**

Research programs are supported at seven national laboratories (ANL, BNL, LANL, LBNL, LLNL, ORNL, and TJNAF). In FY 2009, funding provides increased support for scientific staff in order to address theoretical issues important for advancing the national Nuclear Physics program. The nuclear theory research at a given laboratory provides support to the experimental programs at that laboratory, or takes advantage of some unique facilities or programs at that laboratory. The larger size and diversity of the national laboratory groups make them particularly good sites for the training of nuclear theory postdoctoral associates. Funding decisions are influenced by the results of periodic peer reviews of the national laboratory research efforts in the Nuclear Theory sub-program. In FY 2005, the reviewers evaluated each laboratory research group based on the significance of their accomplishments and future program, the scientific leadership, creativity and productivity of the personnel, and the overall cost-effectiveness of the group, which included support by the respective laboratory. The report findings included an adjectival rating along with an indication of the relative ranking of a particular laboratory group compared to the other groups. In response to the review, out-year funding guidance was provided to each group based on performance, issues and availability of funds. In addition, letters of intent were solicited from each laboratory group and subsequently support was provided in FY 2006 for the new Excited Baryon Analysis Center (EBAC) at Jefferson Laboratory. Following a recommendation of the NSAC Theory Review subcommittee in its report "A Vision for Nuclear Theory," support continues for investments in Lattice QCD computer capabilities in a joint effort with High Energy Physics.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
▪ **Scientific Discovery through Advanced Computing (SciDAC)**	**2,200**	**2,200**	**2,679**

Scientific Discovery through Advanced Computing (SciDAC) is an SC program to address major scientific challenges that require advances in scientific computing using terascale resources. Following the re-competition of SciDAC projects in FY 2006, the Nuclear Theory subprogram currently supports efforts in nuclear astrophysics, grid computing, Lattice Gauge QCD theory, and low energy nuclear structure and nuclear reaction theory. An effort on advanced accelerator design was added to the SciDAC portfolio in FY 2007. NP partners in various combinations with HEP, ASCR, NNSA, and NSF on these projects.

Nuclear Data Activities	**5,841**	**5,924**	**8,391**

The Nuclear Data program collects, evaluates, archives, and disseminates information on nuclear properties and reaction processes for the physics community and the Nation. The focal point for its national and international activities is the DOE-managed National Nuclear Data Center (NNDC) at Brookhaven National Laboratory. Funding in FY 2009 provides support for a viable effort in Nuclear Data activities. The NNDC relies on the U.S. Nuclear Data Network (USNDN), a network of DOE supported individual nuclear data professionals located in universities and national laboratories that perform assessment as well as developing modern network dissemination capabilities. The NNDC participates in the International Data Committee of the International Atomic Energy Agency (IAEA).

Funding is provided to increase research efforts that are relevant to nuclear fuel cycle, including covariant matrix studies, cross section evaluations, relevant computations, and other activities. Funding to support related efforts is provided in the Low Energy subprogram. This effort is carried out in collaboration with the ASCR program. Also a joint workshop was conducted in FY 2006 to identify the leading scientific issues.

Total, Nuclear Theory	**33,205**	**34,030**	**39,954**

Explanation of Funding Changes

	FY 2009 vs. FY 2008 ($000)
Theory Research	
▪ **University Research**	
FY 2009 provides increased support for personnel to focus on the theoretical understanding of the research that was identified in SC Strategic Plan Milestones and to implement recommendations from the recent NSAC Subcommittee on Nuclear Theory.	+1,369

	FY 2009 vs. FY 2008 ($000)
▪ **National Laboratory Research**	
FY 2009 funding provides increased support for theoretical efforts needed to achieve the scientific goals of the Nuclear Physics program, including the completion of the LQCD initiative with High Energy Physics.	+1,609
▪ **Scientific Discovery through Advanced Computing (SciDAC)**	
FY 2009 funding allows for continued support in the most promising areas for progress in nuclear physics with terascale computing capabilities.	+479
Total, Theory Research	**+3,457**
Nuclear Data Activities	
FY 2009 funding increases to support a viable effort in Nuclear Data related activities (+$401,000). Funding is provided for Nuclear Data activities, which are also related to advanced fuel cycles (+$2,066,000).	+2,467
Total Funding Change, Nuclear Theory	**+5,924**

Isotope Production and Applications

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Isotope Production and Applications[a]			
Isotope Production Infrastructure	—	—	16,720
Research Isotope Development and Production	—	—	3,090
Other Research	—	—	90
Total, Isotope Production and Applications	—[b]	—[b]	19,900

Description

The Isotope Production and Applications subprogram supports the production and processing of isotopes. One-of-a-kind facilities are maintained at the Oak Ridge, Brookhaven, and Los Alamos National Laboratories. These 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. Actual operations, production, research or other associated isotope activities are funded either by other DOE programs, by the private sector, or by other Federal agency users.

Starting in FY 2009, there is a new subprogram within the Nuclear Physics program entitled Isotope Production and Applications, which consists of the transferred Medical Isotopes Infrastructure program contained in Radiological Facilities program within the Office of Nuclear Energy (NE), as well as support for research isotope development and production. This FY 2009 Budget Request was generated by NE, prior to the transfer to NP. Upon appropriation, the NP Program will work with the community and other relevant federal agencies to define the resources needed to support a viable and robust Isotope Production program, and to identify and resolve issues that impede an adequate supply of stable and radioactive isotopes, with input from scientific advisory committees and the research community. In addition, NP will also consider the conclusions and recommendations from the jointly sponsored National Institute of Health and DOE study by the National Academy of Sciences entitled the *"State of the Science of Nuclear Medicine"* issued in September 2007.

The focus of the Isotope Production and Applications subprogram will be on supporting the research and development, and production of stable and radioactive isotopes, and making them more readily available to respond to the needs of the Nation. Support will be provided for the production of a broad suite of isotopes, important for applications in science, energy, medicine, and industry, and national security. A major objective of this program will be to improve the availability and reliability of research isotopes at

[a] All appropriations for the Isotope Production and Applications subprogram fund a payment into the Isotope Production and Distribution Funds as required by P.L. 101–101 and as modified by P.L. 103–316. Requested funding is required to maintain financial continuity of radioactive and stable isotope research, development, production, processing, distribution, and associated services to commercial and research customers. Funding will also be used to provide radioisotopes and enriched stable isotopes for research and development, medical diagnosis and therapy, isotope applications, and to support nuclear medicine research.
[b] Funding prior to FY 2009 is provided under the Nuclear Energy, Radiological Facilities Management program.

predictable prices needed for medical, national security, and industrial applications. A portfolio of research isotopes will be established with guidance from scientific advisory committees, in consultation with relevant federal agencies and the research community interested in using stable and radioactive isotopes. The NP program has the expertise and experience in operating facilities and developing technologies that are relevant to the production of stable and radioactive isotopes. The transfer of the national isotope production program into the NP program will optimize existing synergies within these two communities, and create new opportunities for collaboration that will benefit both programs and the productivity of the Isotope Production program.

The Isotope Production and Applications subprogram provides radioactive and stable isotope products and associated services to a wide and varied domestic and international market, supporting research by exploring the use of isotopes to advance medical technology. Ultimate applications of isotope products include medical research and health care, industrial research and manufacturing, education, and national defense. The subprogram supports development of new or improved isotope products and services that enable medical diagnoses and therapy and other applications that are in the national interest.

It is important to note that, unlike most Federal programs, the isotope program operates with a revolving fund. The Isotope Production and Applications subprogram fiscal year appropriation is deposited into the Isotope Production and Distribution Program Fund account as established by the 1990 Energy and Water Appropriations Act (Public Law 101-101), as modified by Public Law 103-316. The combination of the annual direct appropriation and revenues from isotope sales maintain financial viability of the Isotope Production and Applications subprogram. The appropriation is used to maintain and upgrade the infrastructure and to develop and produce research isotopes to meet the needs of the U.S. research community.

Detailed Justification

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Isotope Production Infrastructure	—	—	**16,720**
▪ **Oak Ridge National Laboratory (ORNL)**	—	—	**7,860**
• **Buildings 4501 and 7920 Hot Cells**	—	—	**3,800**

All isotope processing activities have been transferred from Building 3047 to Buildings 4501 and 7920. The Department will maintain these facilities in a safe and environmentally compliant condition for processing, packaging, and shipment of radioisotopes and other related services needed in medical diagnostic and therapeutic applications, homeland security applications, and other scientific research used by Federal and non-Federal entities. Activities include facility and shipping container maintenance, radiological monitoring, facility inspections, isotope inventory and shipment scheduling and delivery tracking. Isotope customers pay the cost of isotope processing in these facilities. Funding in FY 2009 is increased by $136,000 over the FY 2008 Appropriation of $3,664,000 within NE.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
• **Buildings 9204-3 and 5500 – Chemical and Materials Laboratories**	**—**	**—**	**3,764**

Maintain the two laboratories in a safe and environmentally compliant condition for the processing, packaging, and shipment of stable isotopes and other services needed in medical diagnostic and therapeutic applications and other scientific research used by Federal and non-Federal entities. Activities include facility maintenance and inspections and customer order and account tracking system maintenance (E-Government). Over the next several years, the Department will continue to phase out the Calutrons in Building 9204-3 at Y-12. Funding in FY 2009 continues at $3,764,000, the same as FY 2008 funding in NE.

• **Infrastructure Upgrades**	**—**	**—**	**296**

Funding will upgrade the alpha-emitting isotope processing capability to include new vacuum chambers and surface barrier detectors, dose calibrator, and installation of liquid nitrogen lines; upgrade the 30-year old control panel and provide for security and quality enhancements to 4501 hot cell to permit the processing of isotopes used in human clinical trials and biological research. This activity was not funded by NE in FY 2008.

▪ **Los Alamos National Laboratory (LANL)**	**—**	**—**	**4,640**
• **Isotope Production Facility/TA-48 Hot Cell, Building RC-1**	**—**	**—**	**3,650**

Maintain facilities in a safe and environmentally compliant condition for the production, processing, packaging, and shipment of radioisotopes and other services needed in medical diagnostic and therapeutic applications, and other scientific research used by Federal and non-Federal entities. Activities include maintenance, radiological monitoring, and facility inspections. Isotope customers will pay the full cost of isotope processing in these facilities. Funding in FY 2009 continues at $3,650,000, the same as FY 2008 funding in NE.

• **Infrastructure Upgrades**	**—**	**—**	**990**

Funding will include extension of the Isotope Production Facility truck bay and rail of the ten ton crane, thus enhancing radiological protection during cask loading; fabrication and installation of shielded detector aperture system on the hot cell; and rapid transfer of targets for efficient production of short lived isotopes. Also a new target station will be installed for target fabrication, target quality control and targetry development. This activity was not funded by NE in FY 2008.

▪ **Brookhaven National Laboratory (BNL)**	**—**	**—**	**3,470**
• **Brookhaven Linear Isotope Producer (BLIP) Building 931 and Hot Cell Building 801**	**—**	**—**	**3,200**

Maintain the BLIP Building 931 and Hot Cell Building 801 facilities in a safe, environmentally compliant condition and state of readiness for the production of radioisotopes and other services needed in medical diagnostic, therapeutic applications, and other scientific research used by Federal and non-Federal entities. Activities include maintenance, radiological monitoring, and

	FY 2007	FY 2008	FY 2009

facility inspections. Isotope customers will pay the full cost of isotope processing in this facility. Funding in FY 2009 continues at $3,200,000, the same as FY 2008 funding in NE..

	FY 2007	FY 2008	FY 2009
• **Infrastructure Upgrades**	—	—	**270**

Funding will provide for replacement of the acid fume scrubber system, installation of a crane/rail system for manipulator repairs in the hot cells, and upgrades to the BLIP beam line. This activity was not funded by NE in FY 2008.

	FY 2007	FY 2008	FY 2009
▪ **Other Activities**	—	—	**750**
• **Associated Nuclear Support**	—	—	**750**

This funding provides for requirements applicable to isotope producing sites. Such items include certification of isotope shipping casks, independent financial audits of the revolving fund, and other related expenses. Starting in FY 2009, limited investments will be made in university infrastructure that can achieve production of small quantities of medical research isotopes at lower cost than the national laboratories; this activity was not funded by NE in FY 2008.

	FY 2007	FY 2008	FY 2009
Research Isotope Development and Production	—	—	**3,090**

$3,090,000 is provided to support isotope production and research and development activities of commercially-unavailable research isotopes, in response to the needs of the scientific community and based upon peer review. This activity was not funded by NE in FY 2008.

	FY 2007	FY 2008	FY 2009
Other Research	—	—	**90**

In FY 2009, this activity includes funding for the Small Business Innovation Research (SBIR) program and the Small Business Technology Transfer (STTR) program. This activity was not funded by NE in FY 2008.

	FY 2007	FY 2008	FY 2009
Total, Isotope Production and Applications	—	—	**19,900**

Explanation of Funding Changes

	FY 2009 vs. FY 2008 ($000)
Isotope Production Infrastructure	
▪ **Oak Ridge National Laboratory (ORNL)**	
• **Buildings 4501 and 7920 Hot Cells**	
Funding in FY 2009 is increased by $136,000 over the FY 2008 funding of $3,664,000 in NE.	+3,800
• **Buildings 9204-3 and 5500 – Chemical and Materials Laboratories**	
Funding remains the same as FY 2008 funding in NE.	+3,764

	FY 2009 vs. FY 2008 ($000)
• **Infrastructure Upgrades**	
Funding will allow for infrastructure upgrades at Oak Ridge National Laboratory.	+296
▪ **Total, Oak Ridge National Laboratory**	**+7,860**
▪ **Los Alamos National Laboratory (LANL)**	
• **Isotope Production Facility/TA-48 Hot Cell, Building RC-1**	
Funding remains the same as FY 2008 funding in NE.	+3,650
• **Infrastructure Upgrades**	
Funding will allow for infrastructure upgrades mentioned above.	+990
▪ **Total, Los Alamos National Laboratory**	**+4,640**
▪ **Brookhaven National Laboratory (BNL)**	
• **Brookhaven Linear Isotope Producer (BLIP) Building 931 and Hot Cell Building 801**	
Funding remains the same as FY 2008 funding in NE.	+3,200
• **Infrastructure Upgrades**	
Funding will allow for infrastructure upgrades mentioned above.	+270
▪ **Total, Brookhaven National Laboratory (BNL)**	**+3,470**
▪ **Other Activities**	
• **Associated Nuclear Support**	
Funding in FY 2009 is increased by $200,000 over the FY 2008 funding in NE to allow for university investments such as improvements in target fabrication, modifications in target handling hardware and software, and changes to post-irradiation target processing to improve safety, efficiency and product yield.	+750
Total, Isotope Production Infrastructure	**+16,720**
Research Isotope Development and Production	
New FY 2009 funding reestablishes support for developing and producing medical and scientific research isotopes in short supply, as recommended by the isotope community and the National Academy of Sciences study on the *"State of the Science of Nuclear Medicine"* issued in September 2007.	+3,090

	FY 2009 vs. FY 2008 ($000)
Other Research	
This activity includes funding for SBIR ($80,000) and STTR ($10,000) associated with the increased funding for Research Isotope Development and Production.	+90
Total Funding Change, Isotope Production and Applications	**+19,900**

Construction

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Construction			
07-SC-02, Electron Beam Ion Source, BNL	5,000	4,162	2,438
06-SC-01, 12 GeV CEBAF Upgrade (PED/Construction), TJNAF	7,000	13,377	28,623
06-SC-02, Electron Beam Ion Source (PED), BNL	120	—	—
Total, Construction	12,120	17,539	31,061

Description

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

In FY 2008, funding for Project Engineering and Design (PED) of the 12 GeV CEBAF Upgrade was reduced as a result of the FY 2008 rescission. This reduction is restored in FY 2009 to maintain the TEC and project scope. Funds are also requested in FY 2009 to begin construction. The Upgrade project will enable scientists to address the mechanism that "confines" quarks together with a scientific portfolio that cannot be addressed at any other machine in the world. Critical Decision-2 (CD-2), Approve Performance Baseline was approved in November 2007.

The Nuclear Physics program provides funding for general plant projects (GPP) at TJNAF and general purpose equipment (GPE) at BNL to address laboratory infrastructure needs. Starting in FY 2009, funds that NP had provided for GPP at BNL are transferred to the Science Laboratories Infrastructure program. Facility capital equipment and accelerator improvement project (AIP) support is provided to the four NP National User Facilities (RHIC, TJNAF, HRIBF, and ATLAS) to develop new capabilities and address facility infrastructure needs. Nuclear Physics will meet the cost and schedule milestones for construction of facilities and fabrication of Major Items of Equipment (MIE) within 10% of baseline estimates.

Detailed Justification

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
07-SC-02, Electron Beam Ion Source, BNL	**5,000**	**4,162**	**2,438**

The Electron Beam Ion Source (EBIS) project, supported jointly by NP and NASA, will replace the high maintenance tandems as the RHIC pre-injector, leading to more cost effective operations and new research capabilities. The TEC is $13,700,000 and the TPC is $14,800,000; and NASA is contributing an additional $4,500,000 above the DOE TPC. EBIS received CD-2 and CD-3 approval in FY 2006. Funding was decreased from planned amounts in the FY 2007 and FY 2008 Appropriations. Restoration of those funds is requested in FY 2009 so that the project can be completed in FY 2010.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
06-SC-01, 12 GeV CEBAF Upgrade (PED/Construction), TJNAF	**7,000**	**13,377**	**28,623**

The baseline FY 2008 PED funding was reduced by $123,000 as a result of the FY 2008 rescission. This reduction is restored in FY 2009 to maintain the TEC and project scope. In FY 2009, funding is requested to begin construction of the 12 GeV CEBAF Upgrade (TEC $287,500,000). The upgrade was identified in the 2002 and 2007 NSAC Long-Range Plans as one of the highest priorities 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".

Critical Decision-2, Approve Performance Baseline, was approved in November 2007. The proposed cost and schedule profiles reflected in this FY 2009 budget request are consistent with the recommendations made by the DOE Office of Project Assessment Reviews performed in FY 2006 and FY 2007.

	FY 2007	FY 2008	FY 2009
06-SC-02, Electron Beam Ion Source (PED), BNL	**120**	**—**	**—**

PED funding was completed in FY 2007 (see 07-SC-02 above).

	FY 2007	FY 2008	FY 2009
Total, Construction	**12,120**	**17,539**	**31,061**

Explanation of Funding Changes

	FY 2009 vs. FY 2008 ($000)
07-SC-02, Electron Beam Ion Source, BNL	
Funds provide support in FY 2009 to complete the Electron Beam Ion Source (EBIS) that will replace the aging Tandem Van de Graaff as the heavy ion source for the RHIC complex.	-1,724
06-SC-01, 12 GeV CEBAF Upgrade (PED/Construction), TJNAF	
Support is provided to begin construction of the 12 GeV CEBAF Upgrade and the reduction in FY 2008 PED funding as a result of the FY 2008 rescission.	+15,246
Total Funding Change, Construction	**+13,522**

Capital Operating Expenses and Construction Summary

Capital Operating Expenses

(dollars in thousands)

	FY 2007	FY 2008	FY 2009
General Plant Projects	7,350	7,350	17,720
Accelerator Improvements Projects	5,196	4,821	6,705
Capital Equipment	26,925	27,593	34,960
Total, Capital Operating Expenses	39,471	39,764	59,385

Construction Projects

(dollars in thousands)

	Other Project Costs	Total Estimated Cost (TEC)	Prior Year Appro-priations	FY 2007	FY 2008	FY 2009	Unappro-priated Balance
07-SC-02, Electron Beam Ion Source, BNL	1,100	13,700	—	5,000	4,162[a]	2,438	—
06-SC-01, 12 GeV CEBAF Upgrade (PED/Construction), TJNAF	22,500	287,500[b]	500	7,000	13,377	28,623	238,000
06-SC-02, Electron Beam Ion Source (PED), BNL	—	2,100[c]	1,980	120	—	—	—
Total, Construction				12,120	17,539	31,061	

Major Items of Equipment (TEC $2 million or greater)

(dollars in thousands)

	Total Project Cost (TPC)	Other Project Costs	Total Estimated Cost (TEC)	Prior Year Appro-priations	FY 2007	FY 2008	FY 2009	Completion Date
STAR Time-of-Flight, BNL[d]	4,800	—	-4,800	2,400	2,400	—	—	FY 2009
GRETINA Gamma-Ray Detector, LBNL	18,800[e]	1,800	17,000[e]	6,500	3,900	3,900	2,000	FY 2011[e]

[a] Funding was decreased from planned amounts in the 2007 and FY 2008 Appropriations. Restoration of those funds are requested in 2009 so that the project can be completed in FY 2010.
[b] Critical Decision-2, Approve Performance Baseline, was approved in November 2007.
[c] The TEC for the EBIS PED (06-SC-02) is included in the total EBIS TEC reflected.
[d] This is a joint U.S./Chinese project and is on track for project completion in FY 2009.
[e] This project has CD-2 approval. Reductions in the planned funding profile as a result of the FY 2008 Appropriation put the established TPC and TEC at risk. The project will have to be re-baselined and the impact on cost and schedule evaluated.

(dollars in thousands)

	Total Project Cost (TPC)	Other Project Costs	Total Estimated Cost (TEC)	Prior Year Appro-priations	FY 2007	FY 2008	FY 2009	Completion Date
Fundamental Neutron Physics Beamline, ORNL	9,288	88	9,200	4,100	1,500	1,500	1,500	FY 2010
Heavy Ion LHC Experiments, LBNL	13,000-16,000[a]	TBD[a]	TBD[a]	—	1,000	2,000	4,000	FY 2012
PHENIX Silicon Vertex Tracker, BNL)[b]	4,700	—	4,700	—	1,251	2,000	1,200	FY 2010
Neutron Electric Dipole Moment (nEDM), LANL	17,600-19,000[c]	TBD[c]	TBD[c]	—`	770	2,177[c]	1,100	FY 2015
PHENIX Forward Vertex Detector, BNL	4,850[d]	TBD	4,850[d]	—	—	500	2,400	FY 2011[d]
PHENIX Nose Cone Calorimeter, BNL	4,500-4,700[e]	TBD	4,500-4,700[e]	—	—	200	1,200	FY 2012[e]
Cryogenic Underground Observatory for Rare Events (CUORE), LBNL	8,000-10,000[f]	TBD	TBD	—	—	500	2,000	FY 2012
Total, Major Items of Equipment					10,821	12,777	15,400	

[a] CD-1 was approved in December 2006 with a preliminary TPC range of $13,000,000–$16,000,000. The TPC is preliminary and the TPC/TEC/OPC will be baselined at CD-2, planned for 2Q 2008.
[b] This is a joint U.S./Japanese project.
[c] CD-1 was approved in February 2006 with a preliminary TPC range of $17,600,000–$19,000,000. The TPC is preliminary and the TPC/TEC/OPC will be baselined at CD-2 in 2008. Support was reduced from planned funding in the FY 2008 Appropriation, placing cost and schedule estimates for this project at risk.
[d] The TEC and TPC were baselined at a Technical, Cost, Schedule and Management Review. However, funding was reduced relative to the baselined profile with the FY 2008 Appropriation, placing the TPC and TEC at risk. Impacts to cost and schedule are being evaluated.
[e] The TEC and TPC are preliminary and will be baselined at a Technical, Cost, Schedule and Management Review. Funding was reduced in the FY 2008 Appropriation relative to planned amounts, placing cost and schedule estimates at risk for this project.
[f] CD-0 for multiple candidate double beta decay experiments was approved in November 2005 and CUORE represents one of the candidate experiments, with a preliminary TPC range of $8,000,000–$10,000,000. NSF will also make a modest contribution to this Italian/U.S. project. R&D efforts continue on a detector utilizing a different technology.