Nuclear Physics

Funding Profile by Subprogram

(dollars in thousands)

	FY 2003 Comparable Appropriation	FY 2004 Original Appropriation	FY 2004 Adjustments	FY 2004 Comparable Appropriation	FY 2005 Request
Nuclear Physics					
Medium Energy Nuclear Physics	116,164	124,198	-731[a]	123,467	125,775
Heavy Ion Nuclear Physics	159,611	167,805	-989[a]	166,816	173,600
Low Energy Nuclear Physics	67,587	71,789	-424[a]	71,365	72,805
Nuclear Theory	27,293	28,138	-163[a]	27,975	28,860
Subtotal, Nuclear Physics	370,655	391,930	-2,307[a]	389,623	401,040
Use of Prior Year Balances	0	-826	0	-826	0
Total, Nuclear Physics	370,655[bc]	391,104	-2,307[a]	388,797	401,040

Public Law Authorizations:

Public Law 95-91, “Department of Energy Organization Act”

Public Law 103-62, “Government Performance and Results Act of 1993”

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 develop the scientific knowledge, technologies and trained manpower that are 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.

Benefits

The Office of Science’s Nuclear Physics program will substantially advance our understanding of nuclear matter and the early universe. It will help the United States maintain a leading role in nuclear physics research, which has been central to the development of various technologies, including nuclear energy, nuclear medicine, and the nuclear stockpile. Highly trained manpower in fundamental nuclear

[a] Excludes a rescission in accordance with the Consolidated Appropriations Act, 2004, as reported in conference report H.Rpt. 108-401, dated November 25, 2003.

[b] Excludes $8,416,000 which was transferred to the SBIR program and $505,000 which was transferred to the STTR program.

[c] Excludes $2,483,381 rescission in accordance with the Consolidated Appropriations Resolution, FY 2003.

physics is another important result of the program. This valuable human resource is essential for many applied fields, such as nuclear medicine, space exploration, and national security.

Strategic and Program Goals

The Department's Strategic Plan identifies four strategic goals (one each for defense, energy, science, and environmental aspects of the mission plus seven general goals that tie to the strategic goals. The NP program supports the following goals:

Science Strategic Goal
General Goal 5, World-Class Scientific Research Capacity: Provide world-class scientific research capacity needed to ensure the success of Department missions in national and energy security, to advance the frontiers of knowledge in physical sciences and areas of biological, medical, environmental, and computational sciences, and to provide world-class facilities for the Nation's science enterprise.

The NP program has one program goal which contributes to General Goal 5 in the "goal cascade":

Program Goal 05.20.00.00 - Explore Nuclear Matter, from the Quarks to the Stars — Understand the evolution and structure of nuclear matter, from the smallest building blocks, quarks and gluons, to the 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 Program Goal 05.20.00.00 Explore Nuclear Matter, from the Quarks to the Stars

The Nuclear Physics subprograms (Medium Energy, Low Energy, Heavy Ion and Theory) contribute to Program Goal 05.20.00.00 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 program builds and supports world-leading scientific facilities and state-of-the-art instruments necessary to carry out its basic research agenda. Scientific discoveries at the frontiers of Nuclear Physics further the nation's energy-related research capacity, which in turn, provides for the nation's security, economic growth and opportunities, and improved quality of life. In developing strategies to pursue these exciting research opportunities, the Nuclear Physics program is guided by the long range planning report prepared by its primary advisory panel: *Nuclear Science Advisory Committee (NSAC) - Opportunities in Nuclear Science* (2002), and by the program's cognizance of opportunities expressed elsewhere; e.g., *Connecting Quarks with the Cosmos* (2003), a report prepared by the National Research Council and sponsored by DOE, NSF, and NASA.
The Medium Energy subprogram will contribute to Program Goal 05.20.00.00 by investigating the quark and gluon substructure inside the nucleon. Although protons and neutrons can be separately observed, their quark constituents cannot be, because they are permanently confined inside the nucleons. Measurements are carried out primarily using electron beams at the Thomas Jefferson National Accelerator Facility (TJNAF), using polarized proton collisions at the Relativistic Heavy Ion Collider (RHIC) and with electron beams at the MIT/Bates Linear Accelerator Center. MIT/Bates operations will continue for three months in FY 2005, ensuring that the BLAST detector research program is completed to provide information complimentary to that obtained at TJNAF on the quark and gluon substructure of the nucleon. The following indicator establishes a specific long-term goal in World-Class Scientific Research Capacity that the Nuclear Physics program is committed to, and progress can be measured against:

- making precision measurements of fundamental properties of the proton, neutron, and simple nuclei for comparison with theoretical calculations to provide a quantitative understanding of their quark substructure.

The Heavy Ion subprogram will contribute to Program Goal 05.20.00.00 by searching for the quark-gluon plasma 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 heated sufficiently, quarks will become de-confined: 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. The following indicator establishes a specific long-term goal in World-Class Scientific Research Capacity that the Nuclear Physics program is committed to, and progress can be measured against:

- searching for, and characterizing the properties of, the quark-gluon plasma by recreating brief, tiny samples of hot, dense nuclear matter.

The Low Energy subprogram will contribute to Program Goal 05.20.00.00 by investigating nuclei at the limits of stability, nuclear astrophysics and the nature of neutrinos. The coming decade in nuclear physics may reveal new 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. Neutrinos are mysterious particles that permeate the universe and hardly interact with matter, yet play a key role in the explosion of stars. Recent experiments have shown that a neutrino oscillates among all its three types as it travels through space. This remarkable metamorphosis can only happen if neutrinos, long thought to have no mass at all, actually do have tiny masses. Measurements of nuclear structure and nuclear reactions are carried out primarily at the Argonne Tandem Linac Accelerator System (ATLAS) and the Holifield Radioactive Ion Beam Facility (HRIBF). The following indicators establish specific long-term goals in World-Class Scientific Research Capacity that the Nuclear Physics 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 Theory subprogram will contribute to Program Goal 05.20.00.00 by providing the theoretical underpinning needed to support the interpretation of a wide range of data obtained from all the other Nuclear Physics subprograms, with the ultimate aim of advancing knowledge and providing insights into the most promising avenues for future research. An over-arching theme of this subprogram is an understanding of the mechanism of quark confinement and de-confinement—while it is qualitatively 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 that dwarf current capabilities are being developed to tackle challenging calculations of sub-atomic structure, such as those of lattice gauge QCD. The Theory subprogram also supports an effort in nuclear data compilation and evaluation that serves a broad community of users as well as the nuclear physics community.

Annual Performance Results and Targets

FY 2000 Results	FY 2001 Results	FY 2002 Results	FY 2003 Results	FY 2004 Targets	FY 2005 Targets
Program Goal 05.20.00.00 – Explore Nuclear Matter, from Quarks to the Starts					
	Maintained and operated Nuclear Physics scientific user facilities so that the unscheduled operational downtime was 15%, on average, of total scheduled operating time. [Met Goal]	Maintained and operated Nuclear Physics scientific user facilities so the unscheduled operational downtime was 11%, on average, of total scheduled operating time. [Met Goal]	Maintained and operated Nuclear Physics scientific user facilities so the unscheduled operational downtime was 12%, on average, of total scheduled operating time. [Met Goal]	Average achieved operation time of the scientific user facilities as a percentage of the total scheduled annual operation time will be greater than 80%.	Average achieved operation time of the scientific user facilities as a percentage of the total scheduled annual operation time will be greater than 80%.
	Met the cost and schedule milestones for construction of facilities and Major Items of Equipment within 10% of baseline estimates. Completed on schedule the Analysis System for Relativistic Heavy Ion Collider (RHIC) Detectors and RHIC Silicon Vertex Detector. [Met Goal]		Met the cost and schedule milestones for the construction of facilities and Major Items of Equipment within 10% of baseline estimates; completed on schedule the Solenoidal Tracker at RHIC (STAR) Electro-Magnetic Calorimeter (EMCAL). [Met Goal]		
Medium Energy Nuclear Physics					
	As elements of the electron beam program, (a) completed fabrication of the BLAST detector at MIT/Bates in accordance with project milestones, and (b) conducted precise studies of nucleon structure, including studies of the proton's internal charge distribution and role of Quantum Chromodynamics (QCD) in nuclear structure by delivering high intensity (140 micro amps), highly polarized (75%) electron beams with Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (TJNAF). [Met Goal]	As elements of the electron beam program, (a) completed commissioning of the BLAST detector at MIT/Bates and initiated first measurements, and (b) completed fabrication, installation and commissioning of the G0 detector, a joint NSF-DOE project at TJNAF. [Mixed Results]	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]		

FY 2000 Results	FY 2001 Results	FY 2002 Results	FY 2003 Results	FY 2004 Targets	FY 2005 Targets
				At Thomas Jefferson National Accelerator Facility perform experiments and record the weighted average of approximately 2.4 billion events in Hall A, 7.2 billion events in Hall B, and 2.1 billion events in Hall C, weighted by the relative event rates, where approximately means within 20% of the expected baseline.	At Thomas Jefferson National Accelerator Facility perform experiments and record the weighted average of approximately 2.9 billion events in Hall A, 9.6 billion events in Hall B, and 2.8 billion events in Hall C, weighted by the relative event rates, where approximately means within 20% of the expected baseline.
		Commissioned polarized protons at RHIC. [Met Goal]	Collected first data with polarized protons with the RHIC STAR, PHENIX and pp2pp detectors. [Met Goal]		
Heavy Ion Nuclear Physics					
Advanced knowledge from experiments at the Relativistic Heavy Ion Collider (RHIC) to see possible evidence of the predicted quark-gluon plasma (a high-temperature, high-density state of nuclear matter that may have existed a millionth of a second after the "Big Bang"). [Met Goal]	Produced first heavy-ion collisions at the Relativistic Heavy Ion Collider (RHIC – construction completed FY 1999) at 10% of its design luminosity, as planned, with four experimental detectors. Published first results of heavy-ion collisions. [Met Goal]	Completed first round of experiments at RHIC at full energy; achieved the full design luminosity (collision rate) of 2 x 10^{26} cm^{-2} s^{-1} for heavy ions. [Met Goal]	Initiated first round of experiments with collisions with other ions to compare to results of gold-gold collisions. [Met Goal]	At the Relativistic Heavy Ion Collider, perform experiments with approximately the weighted average of 0.9 billion heavy-ion collision events sampled for the PHENIX detector and 40 million heavy-ion collision events recorded for the STAR detector, weighted by the relative event rates, where approximately means within 30% of the expected baseline.	At the Relativistic Heavy Ion Collider, perform experiments with approximately the weighted average of 1.8 billion heavy-ion collision events sampled for the PHENIX detector and 40 million heavy-ion collision events recorded for the STAR detector, weighted by the relative event rates, where approximately means within 30% of the expected baseline.
	Continued major accelerator improvement projects at RHIC in order to improve machine reliability and efficiency. [Met Goal]	Completed Helium Storage addition and liquid nitrogen standby cooling system at RHIC leading to better cost effectiveness ($0.5M savings) and operational efficiency (10% increase). [Mixed results] Met the cost and schedule milestones for the PHENIX Muon Arm Instrumentation (Major Item of Equipment) within 10% of baseline estimates. [Met Goal]	Upgraded the RHIC cryogenics system by replacing turbine oil skids and removing seal gas compressor, eliminating a single point failure. [Met Goal]		

FY 2000 Results	FY 2001 Results	FY 2002 Results	FY 2003 Results	FY 2004 Targets	FY 2005 Targets
Low Energy Nuclear Physics					
				Perform experiments and record the weighted average of approximately 25 billion events at the Argonne Tandem Linac Accelerator System (ATLAS) facility and 5.3 billion events at the Holifield Radioactive Ion Beam (HRIBF) facility, weighted by the relative event rates, where approximately means within 20% of the expected baseline.	Perform experiments and record the weighted average of approximately 25 billion events at the Argonne Tandem Linac Accelerator System (ATLAS) facility and 5.3 billion events at the Holifield Radioactive Ion Beam (HRIBF) facility, weighted by the relative event rates, where approximately means within 20% of the expected baseline.
	Produced first results on the solar neutrino flux with the Sudbury Neutrino Observatory (SNO). SNO measures properties of solar neutrinos. [Met Goal]	Collected the first data from neutral current interactions from the Sudbury Neutrino Observatory (SNO). [Met Goal]	Collected the first data from the Kamioka Large Anti-Neutrino Detector (KamLAND), a joint U.S.-Japan experiment measuring neutrinos produced in nuclear reactors. [Met Goal]		
	Tested low-energy prototype of Rare Isotope Accelerator (RIA) fast catcher and tested low-beta accelerator cavities. [Met Goal]	Constructed a prototype high energy, high power gas catcher for the possible Rare Isotope Accelerator (RIA). [Met Goal]	Delivered the prototype high energy, high power gas catcher to the GSI facility in Germany and prepared it for testing. Completed tests of prototype targets for RIA. Complete prototype Electron Cyclotron Resonance ion source and fabricated prototypes of the high-beta superconducting radio frequency (RF) cavities for RIA. [Met Goal]		

Means and Strategies

The Nuclear Physics program will use various means and strategies to achieve its program goals. However, various external factors may impact the ability to achieve these goals.

The Nuclear Physics program will support 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. The program also builds and supports 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.

External factors that affect the programs and performance include: (1) changing mission needs as described by the DOE and SC mission statements and strategic plans; (2) evolving scientific opportunities, which sometimes emerge in a way that revolutionizes disciplines; (3) results of external program reviews and international benchmarking activities of entire fields or subfields, such as those performed by the National Academy of Sciences; (4) unanticipated failures, for example, in critical components of scientific user facilities, that cannot be mitigated in a timely manner; and (5) strategic and programmatic decisions made by other Federal agencies and by international entities.

The Nuclear Physics program is closely coordinated with the research activities of the National Science Foundation (NSF). The major scientific facilities required by NSF supported scientists are usually the DOE facilities. NSF often jointly supports the fabrication of major research equipment at DOE user facilities. DOE and NSF jointly charter the Nuclear Science Advisory Committee (NSAC).

Scientists supported by the Nuclear Physics program collaborate with researchers from many countries. Large numbers of foreign scientists, who provide monetary and equipment support, heavily utilize all of the Nuclear Physics user facilities, especially RHIC at BNL and CEBAF at TJNAF. The program also supports some collaborative work at foreign accelerator facilities. 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, and industrial processes. In particular, nuclear reaction data are an important resource for these programs. NP user facilities are utilized by other Office of Science programs (e.g., High Energy Physics and Basic Energy Sciences), other DOE Offices (e.g., National Nuclear Security Administration and Nuclear Energy), other Federal agencies (e.g., National Aeronautics and Space Administration) and industry to carry out important studies of the effects of particle beams (radiation) in a variety of materials and biological systems.

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. Quarterly, semiannual, 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 implemented a tool to evaluate selected programs. PART was developed by 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 Nuclear Physics (NP) program has incorporated feedback from OMB into the FY 2005 Budget Request and has taken, or will take, the necessary steps to continue to improve performance.

In the PART review, OMB gave the Nuclear Physics (HEP) program a high score of 85% overall which corresponds to 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. Although NP is establishing a Committee of Visitors (COV), to provide outside expert validation of the program's merit-based review processes for impact on quality, relevance, and performance, this committee has not yet met. Once the COV issues a report, NP will develop an action plan to respond to the findings and recommendations within 30 days. The assessment found that NP has developed a limited number of adequate performance measures and has already engaged its advisory committee in developing research milestones for the long-term performance goals. However, OMB noted concerns regarding the collection and reporting of performance data. To address these concerns, NP will work to improve performance reporting by grantees and contractors, will include the long term research goals in grant solicitations, and will work with the CFO to improve NP sections of the Department's performance documents. NP's role in providing scientific research facilities is strongly supported by the Administration. Funding is provided in FY 2005 to operate the program's five facilities at 88 percent of maximum capacity. NP will also ensure that a thorough, independent scientific assessment of the proposed Rare Isotope Accelerator is carried out by October 2005.

Funding by General and Program Goal

(dollars in thousands)

	FY 2003	FY 2004	FY 2005	$ Change	% Change
General Goal 5, World-Class Scientific Research Capacity					
Program Goal 05.20.00.00 Explore Nuclear Matter in All its Forms					
Medium Energy Nuclear Physics	116,164	123,467	125,775	+2,308	+1.9%
Heavy Ion Nuclear Physics	159,611	166,816	173,600	+6,784	+4.1%
Low Energy Nuclear Physics	67,587	71,365	72,805	+1,440	+2.0%
Nuclear Theory	27,293	27,975	28,860	+885	+3.2%
Total Program Goal 05.20.00.00 Explore Nuclear Matter in All its Forms	370,655	389,623	401,040	+11,417	+2.9%
Use of Prior Year Balances	0	-826	0	+826	+100.0%
Total, Nuclear Physics	370,655	388,797	401,040	+12,243	+3.1%

Overview

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. Great benefit, especially to medicine, emerged from these efforts. But today, nuclear science is much more than this. Today, its reach extends from the quarks and gluons that form the substructure of the once-elementary protons and neutrons, 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 questions as stated recently by the Nuclear Science Advisory Committee (NSAC) in the ***Opportunities in Nuclear Science: A Long-Range Plan for the Next Decade***.

- *What is the structure of the nucleon?* Protons and neutrons are the building blocks of nuclei and neutron stars. But these nucleons are themselves composite objects having a rich internal structure. Connecting the observed properties of the nucleons with an underlying theoretical framework, known as quantum chromodynamics (QCD), is one of the central goals of modern nuclear physics.
- *What is the structure of nucleonic matter?* Nuclear physics strives to explain the properties of nuclei and of nuclear matter. The coming decade will focus especially on unstable nuclei, where we expect to find new phenomena and new structure unlike anything known from the stable nuclei of the world around us. With new theoretical tools, we hope to build a bridge between the fundamental theory of strong interactions and the quantitative description of nuclear many-body phenomena, including the new and exotic properties we expect in unstable nuclei and in neutron stars.
- *What are the properties of hot nuclear matter?* The quarks and gluons that compose each proton and neutron are normally confined within the nucleon. However, QCD predicts that, if an entire nucleus is heated sufficiently, individual nucleons will lose their identities, the quarks and gluons will become "deconfined," and the system will behave as a plasma of quarks and gluons. With the Relativistic Heavy Ion Collider (RHIC), the field's newest accelerator, nuclear physicists are now hunting for this new state of matter.

Other major questions identified by NSAC, of equal importance for nuclear physics as those above, overlap with major questions that drive the fields of astrophysics and particle physics. These are:

- *What is the nuclear microphysics of the universe?* A great many important problems in astrophysics—the origin of the elements; the structure and cooling of neutron stars; the origin, propagation, and interactions of the highest-energy cosmic rays; the mechanism of core-collapse supernovae and the associated neutrino physics; galactic and extragalactic gamma-ray sources—involve fundamental nuclear physics issues. The partnership between nuclear physics and astrophysics will become ever more crucial in the coming decade, as data from astronomy's "great observatories" extend our knowledge of the cosmos.
- *What is to be the new Standard Model?* The resolution of the solar and atmospheric neutrino puzzles by the Sudbury Neutrino Observatory (SNO) and the SuperKamiokande Detector may require the addition of supersymmetry to the Standard Model. Precision nuclear physics experiments deep underground and at low energies are proving to be an essential complement to searches for new physics in high-energy accelerator experiments.

How We Work

The Nuclear Physics program uses a variety of mechanisms for conducting, coordinating, and funding nuclear physics research. The program is responsible for planning and prioritizing all aspects of supported research, conducting ongoing assessments to ensure a comprehensive and balanced portfolio, regularly seeking advice from stakeholders, supporting core university and national laboratory programs, and maintaining a strong infrastructure to support nuclear physics research.

Advisory and Consultative Activities

To ensure that resources are allocated to the most scientifically promising research, the Department of Energy and its national user facilities actively seek external input using a variety of advisory bodies. The Nuclear Physics research program needs to produce the scientific knowledge, technologies and trained manpower that underpin the Department's missions in national security, energy, and environmental quality.

The ***Nuclear Science Advisory Committee*** (NSAC) provides advice to the Department of Energy and the National Science Foundation on a continuing basis regarding the direction and management of the national basic nuclear sciences research program. In FY 2003, the DOE Nuclear Physics program provided about 90% of the federal support for fundamental nuclear physics research in the nation. The National Science Foundation (NSF) provided most of the remaining support. NSAC regularly conducts reviews of university and national laboratory facilities to assess their scientific productivity, evaluates major components of the Division's research program, and evaluates the scientific case for new facilities. One of the most important functions of NSAC is development of long-range plans that express community-wide priorities for the upcoming decade of nuclear physics research.

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 lab 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 manpower requirements. The PAC also provides recommendations for proposals to be approved, conditionally approved, deferred, or rejected.

Facility Operations Reviews

In FY 2002 the Nuclear Physics program conducted operations reviews of its two largest national user facilities: the Relativistic Heavy Ion Collider (RHIC) and Continuous Electron Beam Accelerator Facility (CEBAF). Conducted by the Office of Science's Construction Management Support Division, these reviews enlisted experts from DOE National Laboratories and NSF-supported university nuclear physics facilities to evaluate present performance and costs of operations. In 2003 the Office conducted operations reviews of the Holifield Radioactive Ion Beam Facility (HRIBF) and the Argonne Tandem Linac Accelerator System (ATLAS) facility, using such external experts. Annual reviews of the RHIC and CEBAF programs with external reviewers are also conducted to assess the performance and scientific productivity of the facilities.

Program Reviews

NSAC, on a rotating schedule, reviews the major elements of the nuclear physics program. These reviews examine scientific progress in each program element against the previous long-range plan, assess the scientific opportunities, and recommend reordering of priorities based upon existing budget profiles. In 1998, the Medium Energy subprogram was reviewed. In 2001, the Low Energy subprogram was reviewed. A review of the Theory subprogram was completed in November, 2003. Quality and productivity of university grants are peer reviewed on an approximately three-year basis and laboratory groups performing research will be peer reviewed on an approximately four-year basis. The first review of laboratory research groups occurred for the Heavy Ion subprogram in January, 2004.

Planning and Priority Setting

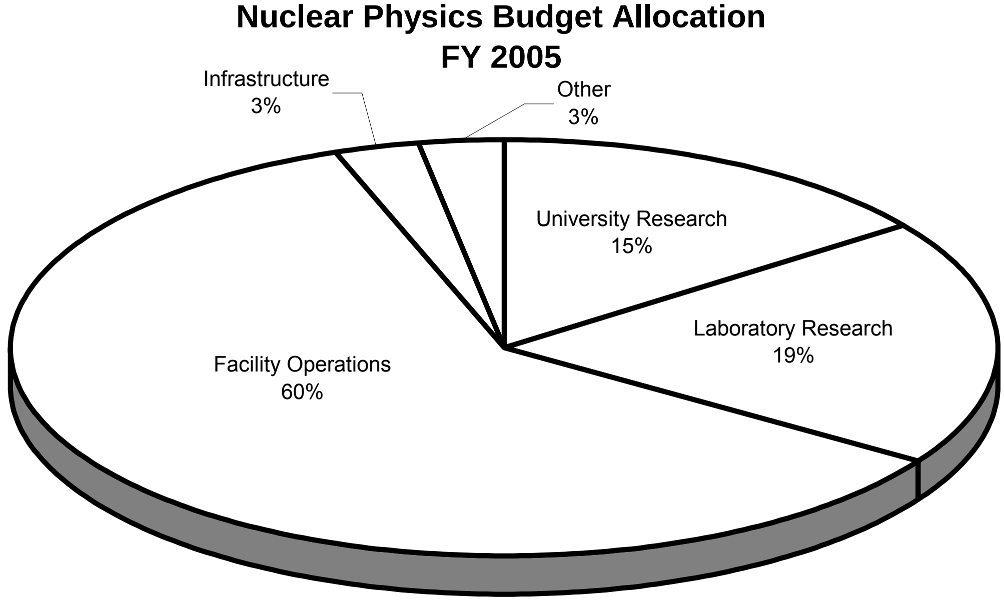
One of the most important activities of NSAC is the development of long-range plans that serve as a framework for the coordinated advancement of the field for the coming decade. These plans are undertaken every 5-6 years to review the scientific opportunities in the field, perform retrospective assessments of the major accomplishments by the field, and set priorities for the future. NSAC recommended as its highest priority the effective utilization of its existing facilities, especially the recently completed facilities, to extract the science for which they were built. This includes adequate support for facility operations and for university and laboratory research efforts. Priority was also given to making investments for capabilities needed to mount a forefront program in the future. Priority within the recent budgets has been given to implementing these recommendations by making tough programmatic decisions. In the FY 2005 budget, funding supports increased utilization of the large major nuclear physics scientific user facilities CEBAF and RHIC. In FY 2004 the 88-Inch Cyclotron at Lawrence Berkeley National Laboratory transitions from a nuclear physics user facility to a facility providing 2,000 hours for testing electronic components for radiation “hardness” to cosmic rays with support from the National Reconnaissance Office and the Air Force, and for a small in-house research program. The support for reduced operations for nuclear physics will allow enhanced support for the remaining Low Energy user facilities and to make investments in instruments and to enhance capabilities. At the end of the first quarter of FY 2005 operations will be terminated at the MIT/Bates Linear Accelerator Center with completion of the research program using the Bates Large Acceptance Spectrometer Toroid (BLAST) detector. Theory and experimental research efforts are supported to collect and analyze data at the operating facilities and to interpret results. The NSAC Long Range Plan identified the proposed Rare Isotope Accelerator (RIA) as the highest priority for major new construction: the FY 2005 budget requests continued support for RIA R&D. Furthermore, the NSAC Long Range Plan recommended an upgrade of TJNAF from 6 to 12 GeV and R&D and conceptual design activities for this upgrade are supported.

Committee of Visitors

A Committee of Visitors was appointed under the guidance of the Nuclear Science Advisory Committee to review the management practices of the Nuclear Physics program. In particular they examined the decision process for awarding grants and for determining priorities of funding among the various activities within the Nuclear Physics program.

How We Spend Our Budget

The Nuclear Physics budget has three major components: research, facility operations and experimental support, and construction and laboratory infrastructure support. The FY 2005 budget request is focused on optimizing the scientific productivity within the resources available. Research support, including capital equipment and R&D activities, is almost constant compared to FY 2004. Support for facility operations is increased ~5% in FY 2005 from FY 2004, allowing the achievement of 85% and 92% utilization of the TJNAF and RHIC facilities, respectively. Despite the closure of the MIT/Bates facility, there will be about the same number of beam hours for research compared to FY 2004. Modest R&D and other investments are made.



Research

One-third of the program's funding was provided to scientists at universities and laboratories to conceive and carry out the research. The DOE Nuclear Physics program involves over 1900 researchers and students at over 100 U.S. academic, federal and private sector institutions. The program funds research activities at over 85 academic institutions located in 35 states and at 7 DOE Laboratories in 6 states. Funding for university and national laboratory research (excluding capital equipment and proposed RIA R&D) is increased ~3.5% compared to FY 2004, resulting in about constant manpower. National laboratory research scientists work together with the experimental collaborations to collect and analyze data as well as support and maintain the detectors. The laboratories provide state-of-the-art resources for detector and accelerator R&D for future upgrades and new facilities. The division of support between national laboratories and universities is adjusted to maximize scientific productivity.

- ***University Research***: University researchers play a critical role in the nation's research effort and in the training of graduate students. During FY 2003, the DOE Nuclear Physics program supported approximately two-thirds of the nation's university researchers and graduate students doing fundamental nuclear physics research. Among the 85 academic institutions DOE supports researchers in five university laboratories with local accelerators (Texas A&M Cyclotron Laboratory, Triangle Universities Nuclear Laboratory (TUNL) at Duke University, MIT Laboratory for Nuclear Science, University of Washington, and Yale University). DOE also supports the Institute for Nuclear Theory at the University of Washington. Typically about 80 Ph.D. degrees are granted annually to students for research supported by the program. One-half of those who received nuclear science Ph.D.'s between 1980 and 1994 are pursuing careers outside universities or national labs in such diverse areas as nuclear medicine, medical physics, space exploration, and national security.

  The university grants program is proposal driven. The Nuclear Physics program funds the best and brightest of those ideas submitted in response to grant solicitation notices (see ***http://www.sc.doe.gov/ production/grants/grants.html***). Proposals are reviewed by external scientific peers and competitively awarded according to the guidelines published in 10 CFR 605.

- ***National Laboratory Research***: The Nuclear Physics program supports National Laboratory-based research groups at Argonne, Brookhaven, Thomas Jefferson, Los Alamos, Lawrence Berkeley, Lawrence Livermore, and Oak Ridge National Laboratories. The directions of laboratory research programs are driven by the needs of the Department and are highly tailored to the major scientific facilities at the laboratories. Laboratory researchers collaborating with academic users of the facilities are important for developing and maintaining the large experimental detectors and computing facilities for data analysis. At the weapons laboratories, Nuclear Physics program funding plays an important role in supporting basic research that can improve the applied programs, such as proton radiography, neutron-capture reaction rates, properties of radioactive nuclei, etc.

  The Nuclear Physics program funds field work proposals from the National Laboratories. Performance of the laboratory groups is reviewed every year to examine the quality of their research and identify needed changes, corrective actions or redirection of effort. Individual laboratory groups have special capabilities or access to laboratory resources that can be profitably utilized in the development of the scientific program.

Nuclear physics has made important contributions to our knowledge about the natural universe 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.

The DOE Nuclear Physics program focuses its scientific thrusts along the high priority nuclear science questions identified by NSAC. To most effectively address these topics, the Nuclear Physics program is structured into four subprograms: the Medium Energy Nuclear Physics subprogram seeks to understand the structure of the nucleon; the Heavy Ion Nuclear Physics subprogram studies the properties of hot nuclear matter; the Low Energy Nuclear Physics subprogram focuses on the structure of nucleonic matter, the nuclear microphysics of the universe, and addresses the possibility of new physics beyond the Standard Model; the Nuclear Theory subprogram provides the fundamental theories, models and computational techniques to address these science topics.

Significant Program Shifts

In the FY 2005 budget request the scientific scope of the nation's nuclear physics program is maintained. The FY 2005 budget request terminates operations of the MIT/Bates facility at the end of the first quarter of FY 2005. This follows the transitions of the LBNL 88-Inch Cyclotron in FY 2004 from a user facility to a dedicated in-house facility. This will allow resources to better utilize and increase science productivity of the remaining user facilities (BNL/RHIC, TJNAF/CEBAF, ANL/ATLAS, and ORNL/HRIBF) with operations at these facilities at ~87% of maximal utilization. The research programs at these major user facilities are integrated partnerships between DOE scientific laboratories and the university community, and the planned experimental research activities are considered essential for scientific productivity of the facilities. Funding for university and national laboratory research is maintained approximately constant compared to FY 2004. Funding for capital equipment will address opportunities identified in the recently completed 2002 NSAC Long Range Plan, and R&D activities for the proposed RIA are maintained. Increased funding from FY 2004 is provided for R&D activities associated with the upgrade from 6 to 12 GeV at TJNAF.

Scientific Discovery through Advanced Computing

The Scientific Discovery through Advanced Computing (SciDAC) activity is a set of coordinated investments across all Office of Science mission areas with the goal to achieve breakthrough scientific advances through computer simulation that were impossible using theoretical or laboratory studies alone. The power of computers and networks is increasing exponentially. By exploiting advances in computing and information technologies as tools for discovery, SciDAC encourages and enables a new model of multi-discipline collaboration among the scientific disciplines, computer scientists and mathematicians. The product of this collaborative approach is a new generation of scientific simulation codes that can fully exploit terascale computing and networking resources. The program will bring simulation to a parity level with experiment and theory in the scientific research enterprise as demonstrated by major advances in climate prediction, plasma physics, particle physics, astrophysics and computational chemistry.

The Nuclear Physics program funds SciDAC programs in the areas of theoretical physics (National Computational Infrastructure for Lattice Gauge Theory), astrophysics (Shedding New Light on Exploding Stars: TeraScale Simulations of Neutrino-Driven Supernovae and their Nucleosynthesis - TSI), and grid technology (Particle Physics Data Grid Collaborative Pilot) that support the scientific goals of the Nuclear Physics subprograms. Each of these projects is not only at the cutting-edge of science and technology, but collectively these projects are supplying innovative new ideas to other disciplines and industry. The principal goal of TSI is to understand the mechanism responsible for the explosions of massive stars–arguably, the dominant source of most elements in the Periodic Table between oxygen and iron. Recently, new three-dimensional hydrodynamics simulations reveal a particular type of supernova shock wave instability that could provide the first explanation of the polarization of the light emitted from a supernova. Simulations of the r-process have also led to a surprising observation: nucleosynthesis can occur in very different environments than previously thought. An example of a technical accomplishment is the development of algorithms to solve algebraic equations for multidimensional radiation transport on terascale computers. Without these algorithms, the simulation of neutrino transport in stars would not be possible. The National Computational Infrastructure for Lattice Gauge Theory has as an aim to make precision numerical calculations of Quantum ChromoDynamics (QCD) in order to determine the structure and interactions of hadrons and the properties of nuclear matter under extreme conditions. (This initiative provides results complementary to a similar initiative by the High Energy Physics program.) Two unique computational hardware approaches are being pursued: one using specially designed systems-on-a-chip that leverages IBM proprietary core technology, the other using commodity general-purpose computing systems. Under the SciDAC Program, Applications Program Interface (QCD API) software has been designed to provide a unified programming environment to achieve high efficiency for running lattice gauge calculations on multi-terascale computer architectures targeted for future deployment. The Particle Data Grid project has allowed Nuclear Physics experiments to tackle the task of replicating thousands of files. Members of the Solenoidal Tracker at RHIC (STAR) collaboration and the Scientific Data Management group at Lawrence Berkeley National Laboratory have collaborated on deploying Hierarchical Resource Managers to automate data transport between the RHIC Computing Facility (RCF) storage system at Brookhaven National Laboratory and the storage system at the National Energy Research Scientific Computing Center (NERSC) at LBNL. In tests, rates of up to 8 MB/sec for the wide-area-network stage have been achieved, with rates of 3-4 TB/week reached during the 2003 data taking run for STAR at RHIC.

Scientific Facilities Utilization

The Nuclear Physics request for FY 2005 supports the Department's scientific user facilities. In FY 2003 Nuclear Physics operated six National User Facilities, which provide research time for scientists in universities and other Federal laboratories. In FY 2004 the program supports operations at:

- The Relativistic Heavy Ion Collider (RHIC) complex at Brookhaven National Laboratory;
- The Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility;
- The Bates Linear Accelerator Center at Massachusetts Institute of Technology;
- The Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory; and
- The Argonne Tandem Linac Accelerator System (ATLAS) at Argonne National Laboratory.

These facilities provide beams for research for a user community of about 2,290 scientists. The FY 2005 Budget Request will support operations of five facilities (MIT/Bates for only one-quarter year) that will provide ~21,450 hours of beams for research, ~1.5% increase from the anticipated beam hours in FY 2004.

Nuclear Physics will maintain and operate its major scientific user facilities so that the unscheduled operational downtime will be kept to less than 20%, on average, of total scheduled operating time.

	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005 Request
Number of Facilities	7	7	6	5	5
Maximum Hours	31,600	31,600	32,275	27,675	24,300
Planned Operating Hours...........	20,285	17,510	23,570	21,145	21,450
Achieved Operating Hours.........	24,575	26,750	28,150	–	–
Unscheduled Downtime – Major user facilities	18%	13%	12%	–	–
Number of Users*......................	3,020	2,440	2,355	2,290	2,325

* Due to use of multiple facilities some users may be multiply counted.

In FY 2003, increased efficiency in operations of the TJNAF facility and the change from 5 to 7-days per week operation for much of the year at the HRIBF and ATLAS facilities resulted in actual operating hours that exceeded what was planned.

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. Earned-value tracking is not maintained for MIE projects under $20,000,000; however, quarterly progress reviews and annual peer review are used to help ensure that projects remain on track.

High Energy Density Physics

The high energy density environment at the core of stars and especially inside the core of collapsing and then exploding supernovae is the cauldron in which we believe all the heavier chemical elements are formed. Such an environment is necessary in order for nuclear reactions to proceed in rapid succession, with radioactive products able to participate in further reactions before they decay. Such conditions are needed for the nucleosynthesis of the elements. Experiments at the Holifield Radioactive Ion Beam

Facility explore this process with radioactive isotope beams in the lighter elements. The proposed Rare Isotope Accelerator (RIA) would provide the world's most powerful facility for such measurements, extending capability for these measurements into the heavier isotopes and to the very limits of nuclear stability.

The beginning of the universe created nuclear matter in its most extreme energy density. A new form of matter, the quark-gluon plasma, composed of deconfined quarks and gluons, is predicted to be this initial state, and experiments at the Relativistic Heavy Ion Collider (RHIC) are searching to find and characterize this new state. A luminosity upgrade at RHIC would permit measurements of the earliest highest energy-density stage in the formation and development of the quark-gluon plasma, whose study is facilitated by measurements with rare-particle probes.

The High Energy Density Physics activities support research and development (R&D) for the proposed RIA and for electron beam cooling at the Relativistic Heavy Ion Collider (RHIC). The R&D for RIA is focused on developing and testing prototype accelerator components to yield design improvements that could reduce project cost and schedule and cost risk to the project. Pre-conceptual design activities are also supported. The R&D activities for electron beam cooling at RHIC also consist of developing and testing prototype components. The electron cooling would produce more focused, or brighter, beams, in the two RHIC rings. These, in turn, could produce an anticipated factor of 10 increase in the luminosity, or collision rate, at the crossing areas. This increase would allow the development of a physics program using rare particle probes.

Construction and Infrastructure

Funding for capital equipment in FY 2005 is reduced by ~2% compared to FY 2004. The Nuclear Physics program, as part of its responsibilities as the landlord for Brookhaven National Laboratory and Thomas Jefferson National Accelerator Facility (TJNAF), provides funding for general plant projects (GPP) to both sites and general purpose equipment (GPE) to BNL only. Funding for GPP is increased by ~8.5% in FY 2005 compared to FY 2004 to address the backlog of needed infrastructure improvements.

Workforce Development

The Nuclear Physics program supports development of the Research and Development (R&D) workforce through support of undergraduate researchers, graduate students working toward a doctoral degree, and postdoctoral associates developing their research and management skills. The R&D workforce developed under this program provides new scientific talent in areas of fundamental research. It also provides talent for a wide variety of technical, medical, security and industrial areas that require the finely-honed thinking and problem-solving abilities and the computing and technical skills developed through an education and experience in a fundamental research field. Scientists trained as Nuclear Physicists can be found in such diverse areas as nuclear medicine, medical physics, space exploration, and national security. The Outstanding Junior Investigator (OJI) program, initiated in FY 2000, through ~5 new awards each year, has been very successful in identifying, recognizing, and supporting promising young faculty. About 865 postdoctoral research associates and graduate students supported by the Nuclear Physics program in FY 2003 were involved in a large variety of experimental and theoretical research projects. Over one fifth of these researchers are involved in theoretical research. Those involved in experimental research utilize a number of scientific facilities supported by the DOE, NSF, and foreign countries. The majority of the experimental postdoctoral associates and graduate students (~80%) conducted their research at the Nuclear Physics user facilities. Details of the DOE nuclear physics human capital are given below. In FY 2003 there were about 274 faculty researchers supported at the universities (~1.5 per grant), with an average award of ~$200,000 per faculty researcher. Almost all grants have a duration of three years.

	FY 2001	FY 2002	FY 2003	FY 2004, est.	FY 2005, est.
# University Grants*	180	181	183	185	185
Average size (excl. CE)	$310,000	$306,000	$304,000	$306,000	$314,000
# Lab groups	28	28	28	28	28
# Permanent Ph.D.'s	683	702	727	730	730
# Postdocs	362	364	410	410	410
# Graduate students	408	442	457	460	460
# Ph.D.'s awarded	67	100	79	80	80

*Tasks in multitask grants to university laboratories are counted separately.

Medium Energy Nuclear Physics

Funding Schedule by Activity

	(dollars in thousands)				
	FY 2003	FY 2004	FY 2005	$ Change	% Change
Medium Energy Nuclear Physics					
Research					
University Research	15,183	15,409	15,618	+209	+1.4%
National Laboratory Research	14,741	15,223	16,034	+811	+5.3%
Other Research	418	5,647	5,411	-236	-4.2%
Subtotal, Research	30,342	36,279	37,063	+784	+2.2%
Operations					
TJNAF Operations	72,635	74,693	79,212	+4,519	+6.1%
Bates Operations	13,169	12,495	9,500	-2,995	-24.0%
Other Operations	18	0	0	0	0.0%
Subtotal, Operations	85,822	87,188	88,712	+1,524	+1.7%
Total, Medium Energy Nuclear Physics	116,164	123,467	125,775	+2,308	+1.9%

Description

The Medium Energy Nuclear Physics subprogram supports fundamental research directed primarily at answering the first of the five broad questions listed in the 2002 Nuclear Science Advisory Committee Long Range Plan:

What is the structure of the nucleon? A quantitative understanding of the internal structure of the nucleons (protons and neutrons) requires a description of their observed properties in terms of the underlying quarks and gluons of Quantum Chromo-Dynamics (QCD), the theory of 'strong' interactions. Furthermore, this understanding would allow the nuclear binding force to be described in terms of the QCD interactions among the quarks.

Benefits

The Medium Energy subprogram seeks to advance our knowledge of the internal structure of protons and neutrons, the basic constituents of all nuclear matter, by providing precision experimental information concerning the quarks and gluons that form the protons and neutrons. This program, in coordination with the Theory subprogram seeks to provide a quantitative description of these particles in terms of the fundamental theory of the strong interaction, Quantum Chromo-Dynamics. This work provides a basis for our description of matter in terms of its fundamental constituents and strengthens scientists' ability to explore how matter will behave under conditions that cannot be duplicated by man. To accomplish this task, the Medium Energy program operates the Thomas Jefferson National Accelerator Facility, a unique, world-class facility, funds research at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory, and supports university researchers to carry out the necessary experiments at these facilities. These research activities contribute to the training of the next generation of scientists and engineers that contribute to the Department's nuclear and energy missions.

Supporting Information

To achieve the experimental description, the Medium Energy program supports different approaches that focus on:

(1) determining the distribution of up, down, and strange quarks in the nucleons,

(2) determining dynamic degrees of freedom of the quarks by measuring the excited states of hadrons (any composite particle made of quarks, such as nucleons),

(3) measuring the effects of the quark and gluon polarizations within the nucleon,

(4) determining the role of the "sea" of virtual quarks and gluons, which also contributes to the properties of protons and neutrons, and

(5) measuring the properties of simple, few-nucleon systems, with the aim to describe them in terms of their fundamental components.

Most of this work is done at this subprogram's primary research facility, the Thomas Jefferson National Accelerator Facility (TJNAF), but the program also has a major research effort at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory. Individual experiments are supported at the National Synchrotron Light Source at Brookhaven, the High Intensity Gamma Source at Triangle University Nuclear Laboratory, Fermilab, and at several facilities in Europe. All these facilities produce beams of sufficient energy (small enough wavelength) to probe at a scale within the size of a nucleon.

The operation of the national user facility, TJNAF, supported by Medium Energy Nuclear Physics, serves a nationwide community of about 300 Department of Energy and about 300 National Science Foundation supported scientists and students from over 140 American institutions and involves about 300 scientists per year from 19 foreign countries. Many of these scientists are from the European Center for Nuclear Research (CERN) member states. At TJNAF, the National Science Foundation (NSF) has made a major contribution to new experimental apparatus in support of the large number of NSF users. Foreign collaborators have also made a significant investment in experimental equipment. Allocation of beam time at TJNAF is based on guidance from Program Advisory Committees that review and evaluate proposed experiments regarding their merit and scientific priority.

Accomplishments

The DOE Nuclear Physics program has made important discoveries in the past decade. The assembly of a large set of precision nucleon-nucleon scattering data, for example, has provided critical input for theoretical models that now produce a significantly more quantitative description of nuclei, making possible the development of a "Standard Model for Nuclei." The past decade has seen a growing interest by the field to understand nucleons in terms of the quarks and gluons of QCD. Advances in both theory and experiment have spurred this interest. The recent long-range plan singled out three significant achievements of the Medium Energy program related to the important central question of the structure of the nucleon:

- The combined discovery that the spins of the quarks alone account for only one third of the proton's overall spin and the observed increasing density of gluons inside the proton with increasing beam resolving power has increased the importance of the role of gluons in understanding nucleon structure.
- The discovery of a significant imbalance between antiquarks of different types inside the proton suggests that fleeting particles composed of quark-antiquark pairs called pions play as important a role inside the nucleon (via the "sea" of virtual quarks) as they do in theories of the nuclear force.

These discoveries have been further extended by these recent highlights:

- *Evidence for the existence of a new five-quark state of matter:* Data from TJNAF indicates the existence of a new kind of matter that contains five quarks rather than the two or three quarks that make up all matter presently observed. Identification of this particle along with the observation of additional particles of similar five-quark structure would provide vital information on how quarks and gluons interact to form nuclear matter.
- *Providing a link between the Bjorken and the Gerasimov-Drell-Hearn (GDH) Sum Rules:* These two sum rules are well defined "benchmarks" for the nucleon's spin structure: the GDH sum rule, which applies at long distance scales that are not directly calculable in Quantum Chromo-Dynamics (QCD), and the Bjorken sum rule, which applies in the very small distance scale where perturbative QCD is known to work. New data from TJNAF show how the nucleon's spin structure transitions between these two extremes, providing essential information for developing an understanding of how the nucleon total spin evolves from the underlying quark and gluon structure. Such data are vital to eventually developing a quantitative understanding of the nucleon based on QCD.
- *The first exclusive measurement of Deeply Virtual Compton Scattering (DVCS) from the Proton:* These results from Hall B at TJNAF provide strong support for the interpretation of this class of reactions within the framework of the Generalized Parton Distributions, theoretical functions which provide a means to determine the quark wave functions inside the nucleon.
- *Role of the "sea quarks" in the structure of the nucleon:* The deformation from a spherical shape of the first excited state of the nucleon was measured at Thomas Jefferson National Accelerator Facility. New data revealing the spatial character of the this state are in agreement with the first full lattice QCD calculation of the transition amplitudes, and indicate an oblate shape resulting from the sea of virtual quark-antiquark pairs inside the nucleon.
- *New results from SLAC have determined the value of the weak mixing angle that is expected at lower energies:* A fundamental tenant of the Standard Model of particle physics predicts that the Weinberg or 'weak mixing' angle, a parameter that determines the strength of the weak interaction, should change as particle interactions occur at lower energies. The new SLAC results are consistent with the Standard Model prediction.

Facility and Technical Accomplishments:

- *The BLAST Detector at the MIT/Bates facility begins operations*: The Bates Large Acceptance Spectrometer Toroid (BLAST) experimental program at Bates began taking data in FY 2003 to obtain unique information on proton and neutron structure.
- *The G0 Detector is complete:* At the Thomas Jefferson National Accelerator Facility, the research program using the G0 detector to measure the strangeness content of the proton over a wide range of momentum transfer was initiated in FY 2003.
- *The MiniBooNE detector fabrication is completed and operations begin:* This jointly supported high-energy and nuclear physics experiment at Fermilab began in late FY 2002 to look for the disapperance of muon neutrinos in an attempt to confirm the earlier result of the Los Alamos Liquid Scintillator Neutrino Detector (LSND) experiment's observation of the disappearance of muon anti-neutrinos. With the observation of electron neutrino oscillations by the SNO experiment, this experiment becomes important for determining whether or not 'sterile' or non-interacting neutrinos exist. First results are expected in FY 2005.

Detailed Justification

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005
Research	**30,342**	**36,279**	**37,063**
▪ **University Research**	**15,183**	**15,409**	**15,618**

These activities comprise a broad program of research, and include support of about 165 scientists and 105 graduate students at 34 universities in 17 states and the District of Columbia. These research efforts utilize not only each of the accelerator facilities supported under the Medium Energy program, but also other U.S. and foreign accelerator laboratories. *Support for university research increases by ~1.5%.*

• **Bates Research**	**2,238**	**2,400**	**2,300**

MIT scientists along with other university researchers are completing the Bates Large Acceptance Spectrometer Toroid (BLAST) program of research started in FY 2003 on the structure of the nucleon and the nature of the nucleon-nucleon force. Support for analysis of data will continue after data taking is completed in FY 2005.

• **Other University Research**	**12,945**	**13,009**	**13,318**

Most of the university research supports the activities associated with our main facilities at MIT/Bates, TJNAF, and RHIC. At TJNAF the experiments are largely focused on the study of nucleon structure and its internal dynamics. Hall A will continue its measurements of the neutron electric form factor and is expected to complete installation of the new high resolution hypernuclear spectrometer which will begin a program to study hypernuclear states (quantum states in which a nucleon is replaced by a baryon containing a strange quark) in light to medium-heavy nuclei. Hall B is expected to carry out its first broad range Deeply Virtual Compton Scattering (DVCS) experiment using the CLAS detector to test the new Generalized Parton Distribution functions calculated for the nucleon's structure. In Hall C, the G0 experiment is expected to complete the first phase of its experimental program started in FY 2003.

A number of university groups are collaborating in experiments using the new BLAST detector and the South Hall Ring at the MIT/Bates Linear Accelerator Center, for which operations are planned to terminate at the end of the first quarter of FY 2005. Support is provided for data analysis from BLAST precision polarization measurements of the proton and nuclear structure measurements on light nuclei.

University scientists and National Laboratory collaborators will continue to develop the RHIC Spin program at Brookhaven National Laboratory. This program is expected to provide critical information on the contribution of gluons to the nucleon's intrinsic spin. Complementary research efforts include the HERMES (HERa MEasurements with Spin) experiment at the DESY laboratory in Hamburg, Germany, the Crystal Ball detector at the Mainz, Germany, electron accelerator, and the precision experiments in weak decay at the Paul Scherrer Institute, Switzerland.

	FY 2003	FY 2004	FY 2005
	(dollars in thousands)		
▪ **National Laboratory Research**	**14,741**	**15,223**	**16,034**

Included are: (1) the research supported at the Thomas Jefferson National Accelerator Facility (TJNAF), that houses the world's most powerful high intensity continuous wave electron accelerator and (2) research efforts at Argonne, Brookhaven, and Los Alamos National Laboratories. The National Laboratory groups carry out research at various world facilities as well as at their home institutions.

	FY 2003	FY 2004	FY 2005
• **TJNAF Research**	**5,085**	**5,184**	**5,405**

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 experimental support and operate the detectors for safe and effective utilization by the user community. TJNAF scientists participate in the laboratory's research program. One of the priorities in FY 2005 will be the G0 experiment that is being supported in cooperation with the National Science Foundation. This detector will determine the electromagnetic contribution of the strange quark to the nucleon for a range of different resolutions. A follow-up experiment, Q-weak, is being developed to make a precision measurement of the weak charge of the proton.

	FY 2003	FY 2004	FY 2005
• **Other National Laboratory Research**	**9,656**	**10,039**	**10,629**

Support for research activities at accelerator and non-accelerator facilities at National Laboratories is increased by ~6% to provide constant effort relative to FY 2004. These activities include:

- ► Argonne National Laboratory scientists will pursue research programs at TJNAF and at the DESY Laboratory in Germany. The theme running through this entire effort is the search for a detailed understanding of the internal quark-gluon structure of the nucleon. The ANL program at DESY is expected to be phased out in FY 2005. ANL scientists have also made important advances in a new laser atom-trapping technique Atom Trap Trace Analysis (ATTA) to be used in measurements of rare isotopes for precision studies of nuclear structure.
- ► At Brookhaven National Laboratory, the Medium Energy Research group plays a lead role in the "RHIC Spin" research program. This is the set of experiments at RHIC that use colliding polarized proton beams to investigate the spin content of the nucleon and, in particular, the role of gluons.
- ► Also at Brookhaven, Laser Electron Gamma Source (LEGS) scientists are operating a new spectrometer and a recently developed polarized "ice" target for a program of spin physics at low energies, to measure the structure of the nucleon. This unique facility produces polarized gamma-rays by back scattering laser light from the circulating electron beam at the National Synchrotron Light Source (NSLS).

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005

- At Los Alamos National Laboratory, scientists and collaborators are participating in a next-generation neutrino oscillation experiment that builds on the experience of the Liquid Scintillator Neutrino Detector (LSND) experiment at Los Alamos, which detected a signal consistent with the existence of neutrino oscillations. This experiment, the Mini Booster Neutrino Experiment (MiniBooNE), uses neutrinos generated from the Fermi National Accelerator Laboratory Booster proton beam; data collection began in FY 2002. Initial results are expected in FY 2005.

  Los Alamos scientists also are involved in experiments at Fermilab and at RHIC (RHIC Spin) that will probe the structure of the virtual "sea" of quarks in the nucleon and the gluonic contribution to its spin, respectively. The Los Alamos group has also been instrumental in providing major components of the PHENIX detector at RHIC that are crucial in carrying out the RHIC Spin program of research.

▪ **Other Research**	**418**	**5,647**	**5,411**

In FY 2003 $4,260,000 was transferred to the SBIR program and $505,000 was transferred to the STTR program. This section includes $3,770,000 for SBIR and $1,049,000 for STTR in FY 2004 and $3,711,000 for SBIR and $1,084,000 for STTR in FY 2005 and other established obligations that the Medium Energy Nuclear Physics subprogram must meet.

Operations	**85,822**	**87,188**	**88,712**
▪ **TJNAF Operations**	**72,635**	**74,693**	**79,212**

Included is the funding that supports: (1) operation of the Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility (TJNAF), and (2) major manpower, equipment, and staging support for the assembly and dismantling of complex experiments.

• **TJNAF Accelerator Operations**	**46,620**	**48,542**	**52,284**

Accelerator operations in FY 2005 support a 4,985 hour running schedule, 92% utilization of the facility. At this level of funding the accelerator provides beams of differing energies and currents simultaneously to all three experimental halls.

	(hours of operation with beam)		
	FY 2003	FY 2004	FY 2005
TJNAF	5,400	3,715	4,985

Funding of $1,500,000 is provided for R&D and possible conceptual design activities for the proposed upgrade of CEBAF to 12 GeV. The upgrade is recommended as one of the highest priorities for Nuclear Physics in the 2002 NSAC Long Range Plan for Nuclear Science. There is an increase in accelerator improvement project (AIP) funds of $100,000 to $1,200,000 and an additional amount of $340,000 is provided for GPP funding above the FY 2004 level in order to address a backlog of needed infrastructure improvements at the laboratory. Recent investments in AIP projects have improved the reliability of CEBAF resulting in a decrease in

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005

unscheduled downtime from 17.8% in FY 2002 to 14.7% in FY 2003, a significant improvement. Further improvement is anticipated with an ongoing reliability improvement campaign.

• **TJNAF Experimental Support**	**26,015**	**26,151**	**26,928**

These funds provide for the scientific and technical manpower, 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. In FY 2005 funding for experimental support is increased by ~3%.

Capital equipment funds ($6,100,000) are used towards assembly and installation of ancillary equipment items such as polarized targets for experimental Halls A, B, and C; spectrometer systems; the completion of a major upgrade of the data reduction system to handle massive amounts of raw data; and the continuation of the fabrication of second generation experiments. The Q-weak detector system is being developed, as a follow-up to the G0 experiment, to perform a precision measurement of the weak charge of the proton.

▪ **Bates Operations**	**13,169**	**12,495**	**9,500**

MIT/Bates Linear Accelerator Center is provided funding for operation during the first quarter of FY 2005 to complete the BLAST research program followed by phase-out activities of the facility. These phaseout activities will include final calibration activities and initiation of decontamination and decommissioning (D&D).

	(hours of operation with beam)		
	FY 2003	FY 2004	FY 2005
Bates	3,920	4,000	1,625

Operating funds will provide for 1,625 hours of operation of the BLAST detector in early FY 2005, followed by termination of the Bates research program. Although the BLAST detector was completed on schedule, the experimental program also requires a polarized gas target. Due to technical difficulties a longer than anticipated commissioning of this target resulted in a delay in the beginning of the data collection program until the fourth quarter of FY 2003. As a result, completion of the planned experimental program by the end of FY 2004 will not be possible. The funds provided will allow a successful completion of the program and realize the scientific return on the sizeable investment in both hardware and manpower in fabricating the BLAST detector.

▪ **Other Operations**	**18**	**0**	**0**

No funds are provided for other operations in FY 2005.

Total, Medium Energy Nuclear Physics	**116,164**	**123,467**	**125,775**

Explanation of Funding Changes

	FY 2005 vs. FY 2004 ($000)
Research	
▪ **University Research**	
• Funding supports the continuation of the MIT/Bates research effort focused on analysis of BLAST data. Support for Bates research staff is then phased out.	-100
• The research support at Other Universities increases by ~2.5% relative to FY 2004. Support is focused on the TJNAF and RHIC spin-physics research programs.	+309
Total, University Research	+209
▪ **National Laboratory Research**	
• Funding for capital equipment increases by $329,000 from FY 2004, of which $200,000 will provide funding for developing an experiment to measure the electric dipole moment of Radium-225 using the Atom Trap Trace Analysis (ATTA) technique at ANL. Funding for research support increases by ~3% ($482,000), providing approximately constant effort.	+811
▪ **Other Research**	
• Estimated SBIR/STTR and other obligations decrease.	-236
Total Research	+784
Operations	
▪ **TJNAF Operations**	
• TJNAF Accelerator Operations: Accelerator operating funds are increased by ~7.5% relative to FY 2004, providing a 4,985 hour running schedule, 92% utilization of the accelerator, and support for R&D and possible conceptual design activities for the proposed 12 GeV upgrade. Included is funding for AIP/GPP ($2,000,000) that is increased by $440,000 compared to FY 2004 to address the backlog in accelerator/physical infrastructure.	+3,742
• TJNAF Experimental Support: The increase of 3% ($722,000) for Experimental Support relative to FY 2004 supports the increased running schedule. Overall capital equipment funding ($6,100,000) is increased by $55,000 compared to FY 2004.	+777
Total, TJNAF Operations	+4,519

	FY 2005 vs. FY 2004 ($000)
▪ **Bates Operations**	
• The funding for Bates operations is decreased from FY 2004 with the termination of operations of the Bates facility at the end of the first quarter of FY 2005. Funds are provided for phaseout and decontamination and decommissioning activities and transitioning of staff.	-2,995
Total Operations	+1,524
Total Funding Change, Medium Energy Nuclear Physics	+2,308

Heavy Ion Nuclear Physics

Funding Schedule by Activity

(dollars in thousands)

	FY 2003	FY 2004	FY 2005	$ Change	% Change
Heavy Ion Nuclear Physics					
Research					
University Research	12,173	12,325	12,848	+523	+4.2%
National Laboratory Research	18,054	18,374	16,826	-1,548	-8.4%
Other Research	0	4,242	3,958	-284	-6.7%
Subtotal, Research	30,227	34,941	33,632	-1,309	-3.7%
Operations					
RHIC Operations	118,849	120,047	129,201	+9,154	+7.6%
Other Operations	10,535	11,828	10,767	-1,061	-9.0%
Subtotal, Operations	129,384	131,875	139,968	+8,093	+6.1%
Total, Heavy Ion Nuclear Physics	159,611	166,816	173,600	+6,784	+4.1%

Description

The Heavy Ion Nuclear Physics subprogram supports research directed at answering one of the central questions of nuclear science identified in the Nuclear Science Advisory Committee (NSAC) 2002 Long Range Plan:

(1) *What are the properties of hot nuclear matter?* At normal temperatures and densities, nuclear matter contains individual protons and neutrons (nucleons), within which the quarks and gluons are confined. At extremely high temperatures, however, such as those that existed in the early universe immediately after the "Big Bang," the quarks and gluons become deconfined and form a quark-gluon plasma. It is the purpose of this research program to recreate extremely small and brief samples of this phase of matter in the laboratory by colliding heavy nuclei at relativistic energies. The distributions and properties of particles emerging from these collisions are studied for the predicted signatures of the quark-gluon plasma to establish its existence and further characterize its properties experimentally. At much lower temperatures, nuclear matter passes through another phase transition from a Fermi liquid to a Fermi gas of free roaming nucleons; understanding this phase transition is also a goal of the subprogram.

Benefits

The Heavy Ion Nuclear Physics subprogram supports all elements of the Nuclear Physics mission by engaging in fundamental experimental research directed at acquiring new knowledge on the novel properties and the phases of hot, high energy density nuclear matter such as existed in the early universe; by developing and operating the world-class facility, the Relativistic Heavy Ion Collider (RHIC), at which most of the world's research in relativistic heavy ion nuclear physics is performed; by supporting research and development of the next generation particle detectors, advanced accelerator technologies, such as electron beam cooling, state-of-the-art electronics, software and computing, and by training manpower that is needed by the Nation's diverse high-skills industries and academic institutions.

Supporting Information

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 Bevalac (LBNL) accelerator found the first direct evidence that nuclear matter can be compressed to high temperature and density using accelerated beams. This observation led to the studies of hot and extremely dense hadronic matter created in heavy-ion collisions with gold beams at the Alternating Gradient Synchrotron (BNL) 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—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 10 times higher than those available at any other facility in the world. While the RHIC facility puts heavy ion research at the highest energy frontier, it is also the only facility in the world that provides collisions of polarized protons with polarized protons. This unique capability will allow 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 National Superconducting Cyclotron Laboratory (NSF funded) at Michigan State University, at Texas A&M University, and at foreign laboratories.

The construction of RHIC was completed in August 1999 and three successful running periods have been completed: Run 1 in FY 2000 with gold beams; Run 2, which spanned the end of FY 2001 and the beginning of FY 2002, with gold beams and commissioning of polarized protons; and Run 3 in FY 2003, with deuteron-gold collisions and the first physics results with polarized proton collisions. This facility is utilized by over 1,100 DOE, NSF and foreign agency supported researchers. Capital equipment and accelerator improvement project (AIP) funds are provided for additions, modifications and improvements to various accelerator components and systems that comprise the RHIC complex and ancillary experimental facilities, in order to maintain safety, improve the reliability and efficiency of operations, and provide new experimental capabilities. Beam time at the RHIC facility is allocated with guidance from a Program Advisory Committee, consisting of distinguished scientists that review and evaluate experiments regarding their merits and scientific priority. An annual review of the effectiveness of RHIC operations and its research program is conducted by the program office and its recommendations are used to improve RHIC operations.

Accomplishments

The recent NSAC long-range plan identified several recent discoveries that support the goals of the Heavy Ion program:

- Production of small regions of space with energy densities more than twenty times that of atomic nuclei. Matter under these extreme conditions may well be in the quark-gluon plasma phase.
- Observation of a strong "flow" of matter in relativistic heavy-ion collisions, indicating that the initial kinetic energy of the beams is rapidly converted to heating the nuclear matter created in the collision zone, putting it under immense internal pressure.
- Observation of a deficit of high transverse-energy particles in relation to proton-proton collisions. This result indicates that high-energy particles suffer energy losses much larger than those expected for the partons (making up the particles) passing through normal nuclear matter – hinting at the formation of the plasma phase in the collision.

- Measurements of anti-matter to matter ratio. Since the number of anti-baryons (anti-matter) is almost equal to the number of baryons (matter), it is concluded that the collision zone immediately after the collision consists of almost pure energy, from which particle-antiparticle pairs are produced.

These discoveries have been extended by the wealth of exciting new results reported from the second RHIC running period in FY 2002 with gold-gold collisions. The third running period, in FY 2003, successfully collided deuterons (d) with gold (Au) nuclei—another landmark technical accomplishment — allowing scientists to report preliminary, but tantalizing results of central importance to the whole RHIC program. Some of the highlights from the Au-Au and d-Au programs are:

- *First measurements of Jet-like behavior:* Measurements of a spray of highly energetic particles emitted back-to-back ("jets") have been measured with Au-Au collisions; separated from a background of thousands of other particles using correlation techniques. Because "jet" phenomena occur at very early times, they are harbingers of the environment in which they are born. In peripheral or glancing collisions, two back-to-back jets are observed, but in the most violent head-on or "central" collisions one jet is "lost" or "quenched." One explanation presumes that dual jets are, in fact, created near the surface of the hot, dense collision zone where one of the jets plows into an unusually opaque form of matter while the other jet escapes unimpeded in the opposite "matter-free" direction. Data from observing deuteron on gold collisions, in which neither heating nor compression of nuclear matter is expected, show that both jets are present.
- *Hadron suppression:* The hadron suppression effect in Au-Au collisions and the disappearance of back-to-back 'jets' are positively correlated.
- *Reconstruction of multiply strange hadrons:* Yields of kaons, phi mesons, and lambda, cascade and omega baryons containing one to three strange quarks have been measured, the amount of strangeness affecting the particle lifetime. Each particle is emitted during a different "window" of time; thus, by comparing rates for the different species, the evolution of the hot matter collision zone can be studied.
- *Kaon and lambda elliptic flow show scaling behavior:* Measurement of elliptic flow (a parameter based on azimuthal anisotropy of particle emission) of neutral kaons and lambda particles show evidence of collective scaling behavior derived from the hypothesis of partonic (quark) coalescence in the early stages of the collisions.
- *Hydrodynamic expansion:* Elliptical flow measurements for different particle species exhibit a hierarchy of strength which monotonically decreases with increasing mass of the particle. This behavior is observed below particle momentum ~ 2 GeV/c, indicating that a high degree of local thermal equilibrium is achieved, a requirement for a "plasma" state to be observed.

Facility and Technical Accomplishments:

- *RHIC obtains first collisions of deuterons with gold nuclei:* In FY 2003, RHIC successfully collided deuterons (d) with gold (Au) nuclei (a landmark achievement producing the world's first colliding accelerated beams of asymmetric nuclei) at full beam energies of 100 GeV per nucleon, with final typical peak and average luminosities (collision rate) reaching 130% and 150% of the d on Au program goals, respectively. This third period of operation (Run 3) supported a very successful experimental research program with several papers already being submitted for publication.
- *RHIC provides polarized protons from two colliding beams:* After the d-Au running, the RHIC was commissioned (involving a very complex sequence of adjustments) to deliver polarized proton beams for the second part of the Run 3 research program in FY 2003. RHIC successfully accelerated polarized protons in the two RHIC rings with about 37% polarization at beam energies of 100 GeV,

representing a 25% improvement over the polarization value attained in the previous year. Both the STAR and PHENIX collaborations expect to collect sufficient data for a first publication on gluon polarization inside the proton.

- *Spin Rotators at RHIC become operational:* A system of complex magnets, called "Helical Spin Rotators" (also referred to as "Siberian Snakes") were successfully deployed at RHIC in FY 2003 that allow the direction of the polarization of the circulating protons to be rotated from being perpendicular to its direction of motion (transverse polarization) to point along its path of motion (longitudinal polarization). This "tour de force" of magnetic engineering allows RHIC to deliver highly versatile beams of polarized protons with which scientists can probe the spin structure of the nucleon.
- *RHIC detector enhancements remain on cost and schedule:* In FY 2003, the Electromagnetic Calorimeter (EMCAL) of STAR was completed on schedule and within its estimated cost.

The Heavy Ion Nuclear Physics subprogram also provides general purpose equipment (GPE), general plant project (GPP), and other funding as part of Nuclear Physics' stewardship responsibilities for this laboratory. These funds are for general purpose equipment, minor new capital construction, alterations and additions, improvements to land, buildings, and utility systems, and other normal operations that are needed for effective laboratory operations.

Detailed Justification

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005
Research..	**30,227**	**34,941**	**33,632**
▪ **University Research**...	**12,173**	**12,325**	**12,848**

Support is provided for the research of about 135 scientists and 85 graduate students at 26 universities in 18 states. Support for university research is increased by ~4% ($523,000) compared with FY 2004.

- Researchers using relativistic heavy ion beams are focused on the study of the production and properties of hot, dense nuclear matter at experiments at RHIC, where an entirely new regime of nuclear matter might be created for the first time. The university groups provide core manpower for the operation of the RHIC detectors, data analysis and publication of results.
- Researchers using primarily the NSF supported National Superconducting Cyclotron Laboratory at Michigan State University, at the DOE supported Texas A&M University, and at foreign facilities in France and Italy, investigate nuclear reactions at intermediate energies, with the aim of studying the fragmentation of nuclei and the flow of nuclear matter in violent collisions.
- A limited effort in R&D and computer simulations directed at the relativistic heavy-ion program at the Large Hadron Collider at CERN is supported.

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005
▪ **National Laboratory Research**	**18,054**	**18,374**	**16,826**

Support is provided for scientists at five National Laboratories (BNL, LBNL, LANL, LLNL and ORNL). These scientists provide essential manpower for the operations of the RHIC detectors: analyzing data and publishing scientific results; conducting R&D of innovative detector designs, integrated electronics designs for high bandwidth data acquisition systems and software technologies; as well as planning for future experiments. Also, BNL, LBNL, and LLNL provide substantial computing infrastructure for terabyte-scale data analysis and state-of-the-art facilities for detector and instrument development. Support is provided for computer simulations of expected experimental behavior for a proposed relativistic heavy-ion program at the Large Hadron Collider at CERN that will begin data taking in 2008.

• **BNL RHIC Research**	**8,506**	**7,991**	**6,496**

BNL scientists play a major role in planning and carrying out research with the four detectors (STAR, PHENIX, BRAHMS and PHOBOS) at RHIC and have major responsibilities for maintaining, improving and developing this instrumentation for use by the user community. In FY 2005 funding for capital equipment decreases by $1,760,000, with the completion of the STAR Electromagnetic Calorimeter Enhancement MIE project, while support for manpower increases by ~4.5% ($265,000). The initial survey work with gold ions at the full energy will be substantially complete by FY 2004 and measurements of the yields of rarer signals, such as the expected J/ψ suppression due to its breakup by the quark-gluon plasma, will dominate the experimental program. By the end of FY 2004, the initial RHIC detector enhancement projects will be completed and ready for investigations of the “rarer” signals during the next experimental running period at RHIC. Research, development, and design for detector upgrades is being performed by scientists from BNL, and other national laboratories, and universities, to add or enhance measurement capabilities that will allow the extraction of a broader variety of rare, but detectable signals that could become measurable at high RHIC luminosity:

- The STAR Time-of-Flight (TOF) outer barrel detector, based on Multi-gap Resistive Plate Chamber (MRPC) technology developed at CERN for the ALICE experiment, at the Large Hadron Collider, will extend particle identification of the particles tracked in the existing Time Projection Chamber (TPC) to much higher transverse momentum (up to 10 GeV/c) and provide electron tagging capability. Excellent results (timing resolution) have been obtained from a prototype unit (covering 1/60 of the barrel circumference) from the FY 2003 d-Au run.
- The PHENIX spectrometer-matched micro vertex detector, based on barrels and disks of silicon strip and pixel technologies, will provide D- and B-meson reconstruction capability to directly probe the production of charm and bottom quark production at RHIC.

• **Other National Laboratory Research**	**9,548**	**10,383**	**10,330**

Researchers at LANL, LBNL, LLNL, and ORNL provide leadership in the commissioning of the PHENIX muon arms and the STAR electromagnetic calorimeter, as well as playing leadership roles in the research utilizing these detectors. At LBNL, a large scale computational system, PDSF (Parallel Distributed Systems Facility), is a major resource used for the analysis of RHIC data, in alliance with the National Energy Research Scientific Computing Center (NERSC). At LLNL substantial computing resources are made available for the PHENIX data analysis.

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005

Compared to FY 2004 there is a decrease in capital equipment funding of $844,000 to $275,000. Support for research manpower increases by ~8.5% ($791,000) to correct for erosion in effort in recent years, needed with the increase in utilization of RHIC.

	FY 2003	FY 2004	FY 2005
▪ **Other Research**	**0**	**4,242**	**3,958**

In FY 2003 $3,285,000 was transferred to the SBIR program. This section includes $3,879,000 for SBIR in FY 2004 and $3,958,000 for SBIR in FY 2005.

	FY 2003	FY 2004	FY 2005
Operations	**129,384**	**131,875**	**139,968**
▪ **RHIC Operations**	**118,849**	**120,047**	**129,201**

The Relativistic Heavy Ion Collider (RHIC) is a unique world-class scientific research facility that achieved first collisions in 2000. Its colliding beams of relativistic heavy ions allow scientists an unprecedented opportunity to explore and understand the nature of hot, dense matter and to recreate conditions under which nuclear matter dissolves into its primeval form – the quark-gluon plasma. The first two initial survey runs (Run 1 in 2000 and Run 2 in 2001-2002) have already produced 42 refereed journal papers, creating an enormous interest in the scientific community. Run 3 in FY 2003 marked another milestone of technical accomplishment with the realization of the world's first relativistic collisions of 100 GeV per nucleon deuterons (d) and gold nuclei (Au) in the intersection regions of the two RHIC rings. Analysis of the d-Au research program is well underway providing exciting new insights into understanding the properties of exotic nuclear matter. During the later part of Run 3, RHIC successfully operated with 100 GeV polarized protons and successfully demonstrated the functionality of the Spin Rotator Helical Magnet system which manipulates the spin direction of the circulating protons. Initial measurements for the RHIC spin-physics research program were completed. The RHIC facility, the first collider using two intense ion beams since the CERN Intersecting Storage Ring (ISR) of the 1970's, is providing critical new information in the development of accelerator technology that will be directly useful in the operation of the Large Hadron Collider at CERN that will begin operation in 2008.

	FY 2003	FY 2004	FY 2005
• **RHIC Accelerator Operations**	**88,400**	**89,685**	**96,824**

Support is provided for the operation, maintenance, improvement and enhancement of the RHIC accelerator complex. This includes the Tandem, Booster and AGS accelerators that together serve as the injector for RHIC. FY 2005 funding will support 3,840 hours of operations, a 16% increase in hours from FY 2004, and 85% utilization of the collider. This funding also supports $1,000,000 for R&D activities towards increasing luminosity of the collider. Capital equipment is maintained at $1,200,000 compared to FY 2004 and accelerator improvement (AIP) funding is increased by $200,000 to $3,100,000. These funds allow needed improvements to be made and allow the replacement of legacy systems such as the AGS main magnet power supply, in order to sustain reliability, increase efficiency and maintain safety of RHIC operations, as well as to provide funds for the design efforts for the Electron Beam Ion Source (EBIS) that will provide a more efficient ion source than the present Tandem Van de Graaff.

	FY 2003	FY 2004	FY 2005
	(dollars in thousands)		

RHIC Operations

	(hours of operation with beam)		
	FY 2003	FY 2004	FY 2005
RHIC	3,440	3,300	3,840

	FY 2003	FY 2004	FY 2005
• **RHIC Experimental Support**	**30,449**	**30,362**	**32,377**

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 (STAR, PHENIX, BRAHMS and PHOBOS) reached their initial planned potential by FY 2003. About 1,100 scientists and students from 82 institutions and 19 countries participate in the RHIC research program. These four detectors (described in the Site Descriptions) provide complementary measurements, but with some overlap in order to cross-calibrate the measurements. In FY 2005, funding for capital equipment is increased by $350,000 to $4,525,000 compared with FY 2004, to provide increased support for upgrades to the RHIC computing facility and minor upgrades to the four detectors.

	FY 2003	FY 2004	FY 2005
▪ **Other Operations**	**10,535**	**11,828**	**10,767**

As steward for Brookhaven National Laboratory (BNL), the Nuclear Physics program provides general plant project (GPP), general purpose equipment (GPE) and other funding for minor new construction, other capital alterations and additions, and for buildings and utility system, for needed laboratory equipment and other expenses. Funding of this type is essential for maintaining the productivity and usefulness of Department-owned facilities and for meeting its requirement for safe and reliable facilities operation. In FY 2005 funding for GPP is increased by ~3.5% ($213,000) to $6,357,000 and GPE is increased by $26,000 to $4,410,000, relative to FY 2004. Funding of other operations decreases by $1,300,000 to $0.

	FY 2003	FY 2004	FY 2005
Total, Heavy Ion Nuclear Physics	**159,611**	**166,816**	**173,600**

Explanation of Funding Changes

	FY 2005 vs. FY 2004 ($000)

Research

▪ **University Research**

• FY 2005 funding for grants for University Research increases by ~4%, providing increased travel funds needed for the increased running of the research program at RHIC.	+523

	FY 2005 vs. FY 2004 ($000)
▪ **National Laboratory Research**	
• BNL RHIC Research: Research support for manpower is increased by ~4.5% ($265,000) from FY 2004. Funding for capital equipment is decreased by $1,760,000, because of the completion of the STAR Electromagnetic Calorimeter Enhancement project.	- 1,495
• Other National Laboratory Research: Support for research operations is increased by ~8.5% ($791,000) compared to FY 2004, to correct for erosion in effort in recent years. Funding for capital equipment decreases by $844,000 to $275,000, compared to FY 2004.	-53
Total, National Laboratory Research	-1,548
▪ **Other Research**	
• Estimated SBIR and other obligations decrease.	-284
Total, Research	-1,309
Operations	
▪ **RHIC Operations**	
• Collider Complex Operations: A ~8% increase in operating funds compared with FY 2004 brings operations to 85% utilization. This includes a $200,000 increase in accelerator improvement project (AIP) funds to $3,100,000 and $1,000,000 is provided for R&D activities towards increased luminosity of the collider.	+7,139
• Experimental Support: A ~6.5% increase in funding for experimental manpower and materials support compared with FY 2004 provides for running at 85% utilization. An increase of $350,000 in capital equipment funds provides for support of the RHIC Computing Facility and the detectors.	+2,015
Total, RHIC Operations	+9,154
▪ **Other Operations**	
• FY 2005 funding for general plant projects at Brookhaven National Laboratory is increased by ~3.5% ($213,000) to $6,357,000, compared with FY 2004, to address the backlog of needed infrastructure improvements. Funding for general purpose equipment at Brookhaven National Laboratory is increased by $26,000 compared with FY 2004. Other operations decrease by $1,300,000.	-1,061
Total, Operations	+8,093
Total Funding Change, Heavy Ion Nuclear Physics	+6,784

Low Energy Nuclear Physics

Funding Schedule by Activity

	(dollars in thousands)				
	FY 2003	FY 2004	FY 2005	$ Change	% Change
Low Energy Nuclear Physics					
Research					
University Research	17,070	18,212	18,642	+430	+2.4%
National Laboratory Research	20,297	22,172	24,775	+2,603	+11.7%
Other Research	3,910	7,963	5,738	-2,225	-27.9%
Subtotal Research	41,277	48,347	49,155	+808	+1.7%
Operations	26,310	23,018	23,650	+632	+2.7%
Total, Low Energy Nuclear Physics	67,587	71,365	72,805	+1,440	+2.0%

Description

The Low Energy Nuclear Physics subprogram supports research directed at understanding three of the central questions of nuclear science identified in the NSAC 2002 Long Range Plan:

(1) *What is the structure of nucleonic matter?* The forefront of nuclear structure research lies in studies of nuclei at the limits of energy, deformation, angular momentum, and isotopic stability. The properties of nuclei at these extremes are not known and such knowledge is needed to test and drive improvement in nuclear models and theories about the nuclear many-body system.

(2) *What is the nuclear microphysics of the universe?* Knowledge of the detailed nuclear structure, nuclear reaction rates, half-lives of specific nuclei, and the limits of nuclear existence at both the proton and neutron drip lines is crucial for understanding the nuclear astrophysics processes responsible for the production of the chemical elements in the universe, and the explosive dynamics of supernovae.

(3) *Is there new physics beyond the Standard Model*? Studies of fundamental interactions and symmetries, including those of neutrino oscillations, are indicating that our current Standard Model is incomplete, opening up possibilities for new discoveries by precision experiments.

Benefits

The Low Energy subprogram supports the mission of the Nuclear Physics program by fostering fundamental research for the purpose of obtaining new insight into the structure of nucleonic matter, the nuclear microphysics of the universe, and fundamental tests for new physics. This subprogram supports a broad range of experiments at two national user facilities, the Holifield Radioactive Ion Beam Facility and the Argonne Tandem Linac Accelerator System, four university-based accelerators, and non-accelerator based facilities such as the Sudbury Neutrino Observatory in Canada and KamLAND in Japan. The development of advanced accelerator technologies is also supported including the proposed new Rare Isotope Accelerator (RIA) facility which would allow scientists to expand their knowledge of the origin of the elements. The Low Energy subprogram is an important source of trained manpower which contributes to a wide variety of nuclear technologies, national security, and environmental quality programs of interest to the DOE.

Supporting Information

Progress in both nuclear structure and astrophysics studies depend upon the availability of exotic beams, or beams of short-lived nuclei, to produce and study nuclei that lie in unstudied regions of the nuclear chart and are involved in important astrophysics processes. While the U.S. today has facilities with limited capabilities for these studies, it was already noted in the NSAC 1996 Long Range Plan for Nuclear Science that a facility with next generation capabilities for short-lived radioactive beams will be needed in the future for the U.S. to maintain a leadership role. In FY 1999, a NSAC Taskforce established the optimal technical option for such a facility, the Rare Isotope Accelerator (RIA) facility. The NSAC 2002 Long Range Plan identified RIA as the highest Nuclear Physics priority for a major new construction project. Starting in FY 2000, R&D activities have been supported in preparation for a possible request for approval for construction. Continued funding for these pre-conceptual design and R&D activities is provided in FY 2005.

The research of this subprogram is generally conducted using beams provided by accelerator facilities either operated by this subprogram or by other domestic or foreign facilities. In FY 2005 the Low Energy Nuclear Physics subprogram supports the operation of two national user facilities: the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory and the Argonne Tandem Linac Accelerator System (ATLAS) facility at Argonne National Laboratory. The 88-Inch Cyclotron (LBNL) transitions in FY 2004 from a user facility to a facility for tests of electronic circuit components for radiation "hardness" to cosmic rays and a small in-house research program. These facilities are utilized by DOE-, NSF-, and foreign-supported researchers. The allocation of beamtime is made with the guidance of Program Advisory Committees, consisting of distinguished scientists, who review and evaluate proposed experiments regarding their merit and scientific priority. Capital equipment funds are provided for detector systems, for data acquisition and analysis systems, and for accelerator instrumentation for effective utilization of all the national accelerator facilities operated by this subprogram. Accelerator improvement project (AIP) funds are provided for additions, modifications, and improvements to the research accelerators and ancillary equipment facilities to maintain and improve the reliability and efficiency of operations, and to provide new accelerator capabilities. 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), University of Washington, and Yale University. 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.

The Low Energy subprogram also supports studies of fundamental interactions and symmetries in selected nuclei: "laboratories" that allow exquisite 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, for example the ultra-cold neutron trap at the Los Alamos Neutron Science Center (LANSCE) at Los Alamos National Laboratory. Other experiments in Low Energy nuclear physics do not require the use of accelerators: the Sudbury Neutrino Observatory (SNO) detector is studying the production rate and properties of solar neutrinos, while the Kamioka Large Anti-Neutrino Detector (KamLAND) is studying the properties of anti-neutrinos produced by nuclear power reactors.

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. In 1997, the HRIBF facility became operational and is now producing over 100 proton-rich and neutron-rich radioactive beams. Research at these three facilities has explored nuclei at the extremes of nuclear spin, deformation, stability, and excitation energy. 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 neutrino physics, following the pioneering work on solar neutrinos with radiochemical experiments, the SNO experiment, conceived in the late 1980's to search for neutrino flavor oscillations, was designed and built in the 1990's. In 2001, SNO reported its first physics results, which together with other experimental results, made a persuasive case for neutrino oscillations among their different types (or "flavors") and thus showed that neutrinos have mass. These results have been confirmed by new measurements reported in 2002 from SNO that are sensitive to the different types of neutrinos, and from the first KamLAND results with reactor produced anti-neutrinos. These results have stimulated an increasing interest in non-accelerator experiments, particularly those that study neutrino properties. Both SNO and KamLAND continue to operate to extend and refine measurements of neutrino oscillation parameters.

Accomplishments

The NSAC 2002 Long Range Plan identified significant achievements of the Low Energy subprogram that are related to the important central questions about nuclear structure, nuclear astrophysics, and fundamental interactions and symmetries:

- Studies of nuclei at extreme conditions are pointing to alterations of the nuclear shell structure, the ability of heavy nuclei to sustain rapid rotation demonstrating unexpected stability, and evidence for phase transitional behavior between spherical and deformed nuclei.
- Nuclear measurements of very neutron-rich, unstable nuclei, combined with new computational techniques, are leading to a better identification of the r-process site or sites for nucleosynthesis in stars and to quantitative models for the production of heavy elements.
- Measurements of solar neutrinos have indicated that neutrinos change their identity on the way to earth, implying that they have mass, and providing a key to the fundamental structure of the forces of nature.

The basic knowledge and understanding in these areas have been further extended by these recent highlights:

- *Kamioka Large Anti-Neutrino Detector (KamLAND) first results:* This joint Japanese/U.S. detector project, which utilizes neutrinos from distant reactors, was completed in FY 2002. The collaboration reported the first physics result in December 2002 on neutrino oscillations, the ability of neutrinos of one type to change to another type. This first result favors the so-called Large Mixing Angle solution, one of the solutions found possible by solar neutrino experiments. KamLAND will operate for additional years to reduce the measurement uncertainty and extend the result. U.S. participation in KamLAND is supported jointly with the High Energy Physics program.
- *Measurement of masses important in nuclear astrophysics processes:* The Canadian Penning Trap (CPT) located at the ATLAS facility at ANL has been used for accurate measurement of the masses of ^{64}Ge and ^{68}Se, two important nuclei on the rp-process pathway to production of heavy proton-rich nuclei in stars. The CPT has also been utilized to measure the masses of twenty neutron-rich nuclei

in the A = 140 region extending toward the region where the r-process occurs in stellar explosions. The masses of many of these nuclei are found to deviate from those calculated using common nuclear models.

- *Measurement of the E2 transition rate for ^{132}Sn*: Researchers at ORNL have utilized intense, pure beams of ^{132}Sn to perform Coulomb excitation experiments to study the electric quadrupole (E2) transition rate in that nucleus, which has closed shells of both protons and neutrons, and thus has extra binding and is more stable against excitation. Normally, the E2 transition rate in such nuclei is lower than that of neighboring nuclei; unexpectedly, the E2 transition rate for ^{132}Sn is higher than that of its close neighbors. Current nuclear structure models may have to be extended to accommodate this result.

Facility and Technical Accomplishments:

- *On the possibility of stimulated emission from the ^{178}Hf Isomer:* Quantities of long-lived nuclear isomers such as ^{178}Hf^{m} could serve as energy storage media. Researchers at ANL and LLNL have investigated the claim that low energy X-rays can stimulate emission from the ^{178}Hf isomer, releasing the energy on demand. The ANL/LLNL results do not support that claim, and the upper limit the team establishes for any release is compatible with known nuclear processes.
- *The Gammasphere spectrometer moved to ATLAS for a second science campaign there:* Gammasphere, the premier gamma-ray spectrometer in the world, has completed its most recent science campaign at LBNL, and has been moved to ANL to begin its second research campaign at ANL. Gammasphere has moved approximately every two years to address compelling research opportunities. The Gammasphere research program at ATLAS will include forefront topics in nuclear structure, nuclear astrophysics, and fundamental interactions.
- *Elementally pure neutron rich beams at the HRIBF:* At the Holifield Radioactive Ion Beam Facility at ORNL, an important parameter is isotopic purity of rare beams for research. Rare isotope beams usually contain mixtures of several isotopes, but a new technique of adding sulfur to the production target utilizes in-target chemistry to produce pure tin (Sn) and germanium (Ge) beams. These pure beams are being used to expand nuclear structure and astrophysics studies to new neutron rich species.

Detailed Justification

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005
Research	**41,277**	**48,347**	**49,155**
▪ **University Research**	**17,070**	**18,212**	**18,642**

Support is provided for the research of about 120 scientists and 90 graduate students at 29 universities in 21 states. 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. FY 2005 funding for operation of university accelerator facilities, for equipment and for researchers and students is increased ~2.5% compared to FY 2004, maintaining approximately constant effort. Research activities include:

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005

- Research programs conducted using the low energy heavy-ion beams and specialized instrumentation at the national laboratory user facilities supported by this subprogram (the ANL-ATLAS and ORNL-HRIBF facilities). The effort at the user facilities involves about two-thirds of the university scientists supported by this subprogram.
- Accelerator operations at four universities: the University of Washington, the Triangle Universities Nuclear Laboratory (TUNL) facility at Duke University, Texas A&M University (TAMU) and at Yale University. Each of these small university facilities has a well-defined and unique physics program, providing light and heavy ion beams, specialized instrumentation and opportunities for long-term measurements that complement the capabilities of the National Laboratory user facilities. Equipment funds are provided for new instruments and capabilities, including an energy and intensity upgrade to the High Intensity Gamma-ray Source (HIγS) facility at TUNL.
- Involvement in other accelerator and non-accelerator experiments directed at fundamental measurements, such as measurements of solar neutrino rates and the neutrino mass at the Sudbury Neutrino Observatory (SNO) in Canada. The U.S. effort with the Kamioka Large Anti-Neutrino Detector (KamLAND) in Japan is being supported jointly with the High Energy Physics program.

▪ **National Laboratory Research**	**20,297**	**22,172**	**24,775**

Support is provided for the research programs of scientists at six National Laboratories (ANL, BNL, LBNL, LANL, LLNL and ORNL).

• **National Laboratory User Facility Research**..	**14,352**	**13,447**	**14,351**

Scientists at ANL, LBNL, and ORNL have major responsibilities for maintaining, improving and developing instrumentation for research by the user communities at the user facilities, as well as playing important roles in carrying out research that addresses the program's priorities. In FY 2005 funding is increased by ~6% for manpower compared with FY 2004, to correct for erosion in manpower in recent years. Support is provided for the following research activities:

- ► 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 half-lives, 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 has been built, and is being utilized in an experimental program in nuclear astrophysics.

	(dollars in thousands)	
FY 2003	FY 2004	FY 2005

- 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 to study nuclei at the extremes of excitation energy, angular momentum, deformation and isotope stability. Studies are undertaken with the Advanced Penning Trap, the successor to the Canadian Penning Trap, to measure atomic masses with high precision and search for effects in beta decay outside the standard decay model.
- At LBNL the research focuses on the completion of data analysis from the research program at the 88-Inch Cyclotron and the use of this DOE user facility to study nuclei at high angular momentum and deformation. Development of test modules, electronics, and data analysis algorithms of a high-sensitivity gamma-ray tracking detector, GRETINA, is continuing.

	FY 2003	FY 2004	FY 2005
• **Other National Laboratory Research**	**5,945**	**8,725**	**10,424**

Scientists at BNL, LBNL, LLNL, LANL and ORNL play important roles in a number of high-priority accelerator- and non-accelerator-based experiments directed towards fundamental questions. FY 2005 funding for manpower increases from FY 2004 for low energy accelerator R&D activities and retaining critical manpower at LBNL. Capital equipment investments increase from FY 2004 by $1,819,000 to $5,106,000. These activities include:

- The Sudbury Neutrino Observatory (SNO) experiment in Canada. The SNO detector, jointly built by Canada, England and the U.S., addresses the question of whether the observed reduced rate of solar neutrinos reaching the earth results from unexpected properties of the sun, or whether it results from a fundamental property of neutrinos–namely that neutrinos produced in the sun change their nature (that is, oscillate to a new neutrino type) during the time it takes them to reach the earth. This latter explanation would imply that the neutrinos have mass. In FY 2001 and 2002, the first results from SNO with the heavy water detector were reported, indicating strong evidence for neutrino oscillations. Results from the second phase measurements of neutrino types to which the solar neutrinos have been transformed were reported in FY 2003. In FY 2003, the third phase of SNO began; it will provide additional detail and confirmatory information on neutrino oscillations. Results from this phase are expected to be reported in FY 2005-2006.
- The KamLAND experiment in Japan will measure the rate and properties of anti-neutrinos produced by several distant nuclear power reactors to study neutrino "oscillations." KamLAND has the advantage of comparing the measured fluxes to known sources. Commissioning of the KamLAND detector began in FY 2002, with data collection continuing through FY 2005. The U.S. participation in KamLAND is supported jointly with the High Energy Physics program.

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005

- ► Neutron beams at the LANSCE facility at LANL are "cooled" to very low energies for new cold and ultra-cold neutron experiments, which will allow very precise measurements of fundamental neutron properties. Commissioning of neutron experiments with these beams begins in FY 2004. Funds ($1,200,000) are provided in FY 2005 to continue development of a beamline for neutron studies at the Spallation Neutron Source (SNS) (a Major Item of Equipment). Also, development and design of an experiment to search with high precision for the electric dipole moment of the neutron is supported.
- ► The Gamma-Ray Energy-Tracking In-beam Nuclear Array (GRETINA), for which fabrication began in FY 2004, is especially important for the study of the nuclear decay and structure of exotic nuclei in fast fragmentation beams, and a smaller version of the proposed GRETA detector for the Rare Isotope Accelerator. The improved position resolution and higher efficiency for high-energy gamma rays compared with presently available gamma-ray detector arrays will allow this new detector system to utilize fragmented nuclear beams to open up a new frontier for understanding exotic nuclei that may exist in stars and supernovae, but live only briefly (fractions of a second). In FY 2005 funding of $2,500,000 is provided to continue fabrication of GRETINA (a Major Item of Equipment).
- ► The Fundamental Neutron Physics Beamline MIE at the Spallation Neutron Source will allow measurements of the fundamental properties of the neutron. Fabrication began in FY 2004 and continues in FY 2005 with funding of $1,200,000.

▪ **Other Research**..	**3,910**	**7,963**	**5,738**
• **RIA R&D Activities**.....................................	**3,910**	**5,965**	**4,000**

Funds are provided for R&D and pre-conceptual design activities directed at the development of an advanced proposed Rare Isotope Accelerator (RIA) facility. A next-generation facility for beams of short-lived, radioactive nuclei for nuclear structure, reaction and astrophysics studies is identified in the NSAC 2002 Long Range Plan as a compelling scientific opportunity and as the highest priority for new construction. The RIA concept emerged from the 1999 NSAC Taskforce study involving international experts as a new paradigm for producing intense beams of very short-lived nuclei. This facility would position the U.S. to play a leadership role in an area of study with the potential for new discoveries about basic properties of nuclei and to significantly advance our understanding of astrophysical phenomena. Funding for FY 2005 is increased by $500,000 compared to the FY 2004 Presidential Request, supporting some needed R&D activities in critical accelerator components and possibly Conceptual Design Report (CDR) activities.

• **SBIR and Other**..	**0**	**1,998**	**1,738**

In FY 2003 $871,000 was transferred to the SBIR program. This section includes $1,092,000 for SBIR in FY 2004 and $1,363,000 for SBIR in FY 2005 and other established obligations. The Lawrence and Fermi Awards, funded under this line, provide annual monetary awards to honorees selected by the Department of Energy for their outstanding contributions to science.

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005
Operations	**26,310**	**23,018**	**23,650**
▪ **User Facility Operations**	**26,010**	**22,868**	**23,500**

Support is provided for the operation of two National User Facilities, the Argonne Tandem Linac Accelerator System (ATLAS) at ANL and the Holifield Radioactive Ion Beam Facility (HRIBF) at ORNL, for studies of nuclear reactions, structure and fundamental interactions, with operations at 86% of full utilization.

HRIBF has coupled the existing cyclotron and tandem accelerator to develop a focused radioactive-ion beam program. Both proton-rich and neutron-rich beams are provided to spectrometer systems such as CHARMS, designed for nuclear structure studies, and the Daresbury Recoil Separator and the Silicon Detector Array for nuclear astrophysics studies. In FY 2005 accelerator improvement project funding is provided ($1,400,000) to continue fabrication of a platform for development and testing targets and ion sources.

ATLAS provides stable heavy-ion beams and selected radioactive-ion beams for research. Experiments utilize ion traps, the Fragment Mass Analyzer, and advanced detectors to study the structure of nuclei at the limits of stability, and fundamental and decay properties of nuclei. In FY 2005 accelerator improvement project funding is directed towards upgrading the accelerator to increase the radioactive beam capabilities of ATLAS

Operations at the 88-Inch Cyclotron are transitioning in FY 2004 to provide resources to optimize the utilization and science productivity of the remaining user facilities and to be consistent with the recommendations of the NSAC Low Energy Program Review in 2001. In late FY 2003 the National Reconnaissance Office and the Air Force determined that operation of the 88-Inch Cyclotron was essential for production of heavy-ion beams that could be used to simulate cosmic ray damage to electronic components that would be used in space. In this way circuits could be tested to determine if they were appropriately “hardened” to radiation in space. A Memorandum of Understanding has been developed in which these offices will provide a total of $2,000,000 annually to maintain operations for 2,000 hours of operation of the Cyclotron for these tests in FY 2004 and FY 2005. They will decide in late FY 2004 if they wish to continue this arrangement beyond FY 2005. If this funding is not continued, the operations will terminate. Funding of $3,000,000 is provided in FY 2005 for a small in-house program of testing of ion sources for RIA R&D and for a limited scientific program in nuclear science studies using local LBNL and University of California (Berkeley) researchers and the unique capabilities of the LBNL complex.

Included in the funding are capital equipment and accelerator improvement project funds provided to each of the operating facilities for the enhancement of the accelerator systems and experimental equipment. In FY 2005 these low energy facilities will carry out about 95 experiments involving over 360 U.S. and foreign researchers. Planned hours of operation with beam are indicated below:

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005

	(hours of operation with beam)		
	FY 2003	FY 2004	FY 2005
ATLAS	6,220	6,350	6,650
HRIBF	4,725	3,780	4,350
88-Inch Cyclotron*	4,445	0	0
Total Beam Hours for Low Energy Facilities	15,390	10,130	11,000

* Operations as a user facility is terminated in FY 2004 as the facility transitions to a dedicated facility for the testing of electronic circuit components for use in space (using funding from other agencies) and a small in-house nuclear physics research program.

	FY 2003	FY 2004	FY 2005
▪ **Other Operations**	**300**	**150**	**150**

Funding is provided for maintenance of the Oak Ridge Electron Accelerator (ORELA) for criticality measurements supported by DOE/NNSA.

	FY 2003	FY 2004	FY 2005
Total, Low Energy Nuclear Physics	**67,587**	**71,365**	**72,805**

Explanation of Funding Changes

	FY 2005 vs. FY 2004 ($000)
Research	
▪ **University Research**	
• FY 2005 funding for researchers and students and capital equipment is increased ~2.5% compared to FY 2004	+430
▪ **National Laboratory Research**	
• National User Facilities Research: FY 2005 funding provides an increase of +6.5% for research efforts and activities at the user facilities. This increase will help correct erosion of manpower in recent years.	+904
• Other National Laboratory Research: Research funding decreases by $120,000 in FY 2005 compared with FY 2004. Equipment funds are increased by $1,819,000 to address scientific opportunities identified in the NSAC 2002 Long Range Plan for Nuclear Science, such as the Fundamental Neutron Physics Beamline at the Spallation Neutron Source and the fabrication of the GRETINA gamma-ray tracking detector	+1,699
Total, National Laboratory Research	+2,603

	FY 2005 vs. FY 2004 ($000)
▪ **Other Research**	
• RIA R&D funding is decreased from $5,965,000 to $4,000,000.	-1,965
• Estimated SBIR and other obligations decrease	-260
Total, Other Research	-2,225
Total Research	+808
Operations	
▪ In FY 2005 operating funds are increased by ~5% ($832,000) compared to FY 2004 for ATLAS and HRIBF operations to provide an estimated 11,000 hours of beam time. Funding for capital equipment and accelerator improvement projects decreases by $200,000 compared to FY 2004.	+632
Total Funding Change, Low Energy Nuclear Physics	+1,440

Nuclear Theory

Funding Schedule by Activity

	(dollars in thousands)				
	FY 2003	FY 2004	FY 2005	$ Change	% Change
Nuclear Theory					
Theory Research					
University Research	11,644	11,888	12,204	+316	+2.7%
National Laboratory Research	8,516	8,962	9,192	+230	+2.6%
Scientific Computing (SciDAC)[a]	1,980	1,988	2,000	+12	+0.6%
Subtotal Theory Research	22,140	22,838	23,396	+558	+2.4%
Nuclear Data Activities	5,153	5,137	5,464	+327	+6.4%
Total, Nuclear Theory	27,293	27,975	28,860	+885	+3.2%

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 research directed at understanding the five central questions identified in the NSAC 2002 Long Range Plan:

(1) *What is the structure of the nucleon?* Protons and neutrons are the basic components of all observable matter in the universe that are themselves made-up of lightweight, point-like particles, called quarks and gluons. The fundamental theory governing the dynamics of quarks and gluons is known as Quantum Chromodynamics (QCD). A key goal of modern theoretical nuclear physics is to comprehend the intricate structure and properties of the nucleon and ultimately nuclei, in terms of the interactions between the quarks, gluons and the extraordinarily complex vacuum.

(2) *What is the structure of nucleonic matter?* Nuclear theorists strive to understand the diverse structure and remarkable properties of the nucleus. With the possibility of obtaining new experimental results for unstable nuclei from studies with radioactive beams, theorists will be able to probe nuclei at limits of high excitation energy, deformation, and isotopic stability. Ultimately, this major frontier of research will permit the development of a "comprehensive model" for nuclei that is applicable across the entire periodic table.

(3) *What are the properties of hot nuclear matter?* The properties of hot, dense nuclear matter, is the central topic of research at the new Relativistic Heavy Ion Collider (RHIC) facility. Lattice QCD theory predicts that the physical vacuum "melts" at extremely high temperatures and the underlying symmetries of QCD are restored. Under these conditions, normal nuclear matter should transform into a plasma of nearly massless quarks and gluons – a new form of matter that is believed to have pervaded the primordial universe a few microseconds after the Big Bang. Theoretical research provides the framework for interpreting the experimental measurements for evidence of the quark-

[a] In FY 2003 funding for the NP portion of the SciDAC program was distributed between University ($1,026,843) and National Laboratory Research ($953,157).

gluon plasma and other new phenomena. A key goal of the theoretical program is to establish knowledge of the QCD phase diagram of bulk nuclear matter.

(4) *What is the microphysics of the universe?* The theory subprogram attempts to understand the nuclear microphysics of the universe that involve fundamental nuclear physics processes, such as the origin of elements; the structure and cooling of neutron stars; the properties of neutrinos from the sun and the mechanism of core-collapse supernovae.

(5) Is there new physics beyond the Standard Model? The search for a single framework describing all known forces of nature – the so-called 'Standard Model' represents a formidable challenge. The current version of the Standard Model has been tested with impressive precision in experiments with atoms, in various nuclear experiments testing Standard Model symmetries, and in high-energy experiments. However, despite its successes, recent experimental observations of neutrino behavior and studies of fundamental symmetries present some conceptual difficulties that lead physicists to believe a more fundamental theory must exist.

Benefits

The Theory subprogram cuts across all components of the Nuclear Physics mission to foster fundamental research in nuclear physics that will provide new insights and advance our knowledge on the nature of matter and energy. The theory groups and individual researchers at universities and DOE national laboratories strive to improve the theoretical techniques and gain new insights used to interpret data gathered by Nuclear Physics supported user facilities and the non-accelerator based experimental programs. By doing so, they not only advance our scientific knowledge and technologies, especially in the area of large scale computing, but serve to train the manpower needed for this research and indeed for an increasingly technological society. The mission of the nuclear data program, included within the theory subprogram, is also directly supportive of the Department of Energy's missions for nuclear-related national security, energy, and environmental quality.

Supporting Information

The research of this program 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 sponsors the national Institute for Nuclear Theory (INT), based at the University of Washington, in Seattle, Washington, 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.

The program is enhanced through interactions with complementary programs overseas, with efforts supported by the National Science Foundation, with programs supported by the High Energy Physics program and with the Japanese supported theoretical efforts related to RHIC at the RIKEN Center at Brookhaven National Laboratory. Many foreign theorists participate on advisory groups as peer reviewers. 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.

Included in the theory subprogram are the activities that 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.

Progress in Nuclear Theory is reviewed as a component in reviews of the three other major program components of the Nuclear Physics program.

Accomplishments

The 2002 Long Range Plan highlights many significant theoretical advances in all of the five major frontiers of research in nuclear physics today. A few of the most recent accomplishments are:

- *Studies of hadronic structure on the lattice:* Recent lattice calculations, which solve the equations of Quantum Chromodynamics (QCD) numerically on a granular space-time "lattice", appear to give clear answers to some very old questions about the hadron structure studied experimentally at TJNAF and other laboratories. Researchers report this year the first observation of the Roper resonance on the lattice and conclude that the Roper is a radially excited nucleon with 3 valence quarks and not a Λ-K bound state, thus settling (if confirmed) a thirty year controversy in the literature. They also have found the Λ(1405) has a quark structure and is not therefore a hadron bound state. They confirm on the lattice the experimental pattern of positive and negative parity excited states in N, Δ, and Λ, a result which has profound implications for the interpretation of the quark-quark hyperfine interaction.
- *Ab initio calculations of light nuclei:* Green's Function Monte Carlo (GFMC) methods allow one to reliably calculate the properties of light nuclei (up to ten nucleons) with nucleon-nucleon (NN) interactions which describe NN data very precisely and include three-nucleon (NNN) interactions needed to describe three-body nuclei correctly. With this tool, researchers have attacked a basic question that involves an entire nucleus: Why are there no stable 5- or 8-body nuclei? Lacking these nuclei, the "Big Bang" created nothing heavier than lithium, and therefore the Sun has shone long enough for humans to evolve. The answer is the presence of the tensor force, which is similar to the force felt by two magnets side by side, in the NN interaction. Remove this force and these nuclei become stable in the calculations. Another program of ab initio calculations, under the label of No-Core Shell Model, has calculated properties of nuclei with up to twelve bodies. It does not have quite the accuracy of GFMC, but treats a greater variety of NN and NNN interactions such as those emerging effective field theory interactions closely related to QCD. The applications of these calculations, so far, have been aimed at Standard Model tests. These calculations include neutrino-nucleus scattering needed for experimental studies of neutrino oscillations and superallowed beta decay of light nuclei which provide an excellent laboratory for precise tests of the properties of the electroweak interaction.
- *Indicators of quark-gluon plasma formation:* Over twenty years ago it was suggested that fast partons (quarks and gluons) traveling through a quark-gluon plasma (QGP) might lose a large amount of energy by elastic scattering with the plasma constituents, resulting in the suppression of jets from the interior of the collision fireball in relativistic heavy ion collisions. Such a suppression of energetic particles has recently been observed in central gold-gold collisions at RHIC. The far-side partners of the observed jets are completely suppressed in central gold-gold collisions. This observation can be quantitatively described by a quantum chromodynamic (QCD) calculation. Together this confrontation of theory and experiment can provide key information on the properties of dense matter produced at RHIC.
- *Origin of elements:* Spectacular core-collapse supernovae explosions represent the violent end of a massive star's life, and create and disperse many elements – but the explosion mechanism remains elusive. Theoretical nuclear astrophysics, coupled with results from a variety of nuclear physics measurements, represents the foundation of an emerging generation of sophisticated, computationally intensive models of astrophysical phenomena. For example, nuclear theorists working under the DOE Scientific Discovery through Advanced Computing (SciDAC) program on

simulations of exploding stars are continuing to make rapid progress on many fronts. Neutrino transport is now being utilized in one-dimensional (spherical) models of stars. Recent progress has also been made in calculating electron-capture rates crucial to the understanding of stellar collapse. Multi-dimensional stellar models are now able to explore effects such as convection induced by neutrino heating. These new computational tools could also be applied to other fields of research.

In the past five years, the availability of enormous computing power has allowed theorists to make spectacular progress on problems that were previously thought intractable. It is now possible to simulate complex nuclear physics processes at extreme length scales ranging from astrophysical objects, to nuclei, to the quark structure of matter. The development of the Green's Function Monte Carlo Technique and the No-Core Shell Model as solutions to the nuclear many-body system for small numbers of nucleons, and the Monte Carlo Shell Model of nuclei are state-of-the-art computational methods that could provide a framework for a "Standard Nuclear Model" in the near future. In the last few years, large-scale parallel processor machines have been exploited to simulate QCD problems on a space-time lattice.

Detailed Justification

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005
Theory Research	**22,140**	**22,838**	**23,396**
▪ **University Research**	**11,644**	**11,888**	**12,204**

The research of about 170 university scientists and 95 graduate students is supported through 58 grants at 46 universities in 26 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. *Funding is increased by ~2.5% ($316,000) compared with FY 2004, providing almost constant effort.*

The Institute for Nuclear Theory (INT) at the University of Washington hosts three programs per year where researchers from around the world attend to focus on specific topics or questions. 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. For example, recent programs have resulted in a new research effort that fuses modern shell model technology with effective field theory to potentially provide a tractable, rigorous solution for low-energy properties of nuclei.

▪ **National Laboratory Research**	**8,516**	**8,962**	**9,192**

Research programs are supported at six National Laboratories (ANL, BNL, LANL, LBNL, ORNL and TJNAF). Funding is increased by ~2.5% ($230,000) compared with FY 2004 to maintain national laboratory theoretical efforts at the FY 2004 level.

- The range of topics in these programs is broad, and each of the active areas of experimental nuclear physics is supported by at least some of these nuclear theory activities.
- In all cases, 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.

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005

- The larger size and diversity of the National Laboratory groups make them particularly good sites for the training of nuclear theory postdocs.

▪ **Scientific Computing**	**1,980**	**1,988**	**2,000**

Scientific Discovery through Advanced Computing (SciDAC) is an Office of Science program to address major scientific challenges that require advances in scientific computing using terascale resources. A SciDAC planning effort managed by the High Energy and Nuclear Physics (HENP) programs identified the most compelling opportunities for advancements and for coordinated efforts in these two scientific fields by the application of terascale computing resources. This effort resulted in the identification of two such challenge areas within the domain of theoretical nuclear physics, and in FY 2001 several major multi-institutional grants in high-priority topical areas were awarded through this program for the first time. One topical area is Lattice QCD. The scientific goal is to solve Quantum Chromodynamics (QCD), the fundamental theory of the strong interaction, on a 'lattice' of space-time points using advanced numerical methods. This is an extremely active area of inquiry world-wide, with major ongoing efforts in Europe and Japan. Of particular relevance to nuclear physics are the activities focused on solving QCD in two domains: the structure of the proton and neutron and their excited states at TJNAF and elsewhere, and the quark-gluon plasma that is anticipated to be produced at RHIC. A second topical area is Theoretical Nuclear Astrophysics, particularly focusing on supernova phenomena. Two types of supernova explosions are being modeled: Type Ia explodes because of nuclear reaction processes; types II, Ib, and Ic, are thought to explode through core collapse, fueled by neutrino energy transport. These problems are intrinsically multidisciplinary, involving nuclear physics, general relativity, neutrino science, hydrodynamics and transport theory, and advanced computing techniques. This is an ideal challenge to push the frontiers of advanced computing.

Nuclear Data	**5,153**	**5,137**	**5,464**

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 is increased by ~6.5% ($327,000) to enhance efforts in this critical activity, helping to correct some of the erosion in effort in recent years. New scientists need to take on compilation and evaluation roles in the U.S. Nuclear Data program. This is a critical issue, with over 50% of the compilers and evaluators over 60 years old, retired and working part time.

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 who perform data assessment as well as developing modern network dissemination capabilities.

The NNDC participates in the International Data Committee of the International Atomic Energy Agency (IAEA).

Total, Nuclear Theory	**27,293**	**27,975**	**28,860**

Explanation of Funding Changes

	FY 2005 vs. FY 2004 ($000)
University Research	
▪ FY 2005 funding is increased ~2.5% compared to FY 2004 and will be focused on priority research that was identified in the 2002 NSAC Long Range Plan for Nuclear Science and to implement recommendations from the recent NSAC Subcommittee on Nuclear Theory	+316
National Laboratory Research	
▪ FY 2005 funding is increased ~2.5% compared to FY 2004, with efforts directed toward higher priority research as identified in the 2002 NSAC Long Range Plan and to implement recommendations from the recent NSAC Subcommittee on Nuclear Theory	+230
Scientific Computing	
▪ FY 2005 funding is increased by ~0.5% compared to FY 2004	+12
Nuclear Data	
▪ FY 2005 funding is increased ~6.5% compared to FY 2004 to enhance efforts to effectively disseminate nuclear data needed for basic and applied research	+327
Total Funding Change, Nuclear Theory	+885

Capital Operating Expenses & Construction Summary

Capital Operating Expenses

(dollars in thousands)

	FY 2003	FY 2004	FY 2005	$ Change	% Change
General Plant Projects	6,876	6,604	7,157	+553	+8.4%
Accelerator Improvement Projects	6,745	6,400	6,100	-300	-4.7%
Capital Equipment	27,718	27,046	26,492	-554	-2.0%
Total, Capital Operating Expenses	41,339	40,050	39,749	-301	-0.8%

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

(dollars in thousands)

	Total Estimated Cost (TEC)	Prior Year Approp-riations	FY 2003	FY 2004	FY 2005 Request	Accept-ance Date
STAR EM Calorimeter	8,600	8,297	303	0	0	FY 2003
STAR EM Calorimeter Enhancement[a]	4,830	0	2,750	2,080	0	FY 2005
GRETINA gamma-ray detector	15,000	0	0	1,000	2,500	FY 2010
Fundamental Neutron Physics Beamline at Spallation Neutron Source[b]	9,200	0	0	1,000	1,200	FY 2010
Total, Major Items of Equipment		8,297	3,053	4,080	3,700	

[a] The TEC has increased by $130,000 and the completion date has slipped by one quarter due to impact from a late start as a result of the FY 2003 continuing resolution.

[b] The TEC and funding profile were refined in the conceptual design effort. Increased funding from $500,000 to $1,000,000 in FY 2004 will reduce schedule and cost risk. The TEC has decreased by $600,000 to $9,200,000.