Nuclear Physics

Program 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 DOE'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 NP mission areas under the mandate provided in Public Law 95-91 that established the Department.

Strategic Objectives

SC2: By 2015, describe the properties of the nucleon and light nuclei in terms of the properties and interactions of the underlying quarks and gluons; by 2010, establish whether a quark-gluon plasma can be created in the laboratory and, if so, characterize its properties; by 2020, characterize the structure and reactions of nuclei at the limits of stability and develop the theoretical models to describe their properties, and characterize using experiments in the laboratory the nuclear processes within stars and supernovae that are needed to provide an understanding of nucleosynthesis.

SC7: Provide major advanced scientific user facilities where scientific excellence is validated by external review; average operational downtime does not exceed 10% of schedule; construction and upgrades are within 10% of schedule and budget; and facility technology research and development programs meet their goals.

Progress toward accomplishing these Strategic Objectives will be measured by Program Strategic Performance Goals, Indicators and Annual Targets, as follows:

Program Strategic Performance Goals

SC2-1: Determine the structure of nucleons in terms of bound states of quarks and gluons. Measure the effects of this structure on the properties of atomic nuclei. (Medium Energy Nuclear Physics and Nuclear Theory subprograms)

Performance Indicators

Results of external and internal reviews of quality, relevance and leadership of research activities and facility operations; number of significant scientific discoveries.

Performance Standards

As discussed in Corporate Context/Executive Summary.

Annual Performance Results and Targets

FY 2001 Results	FY 2002 Targets	FY 2003 Targets
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 QCD in nuclear structure by delivering high intensity (140 microamps), highly polarized (75%) electron beams with CEBAF at TJNAF. (SC4-1) [Met goal]	As elements of the electron beam program, (a) complete commissioning of the BLAST detector at MIT/Bates and initiate first measurements and (b) complete fabrication, installation and commissioning of the G0 detector, a joint NSF-DOE project, at TJNAF. (SC2-1)	As elements of the electron beam program, (a) complete first experiments with the BLAST detector at MIT/Bates, studying the structure of nucleons and few body nuclei and (b) map out the strange quark contribution to nucleon structure using the G0 detector, utilizing the high intensity polarized electron beam developed at TJNAF. (SC2-1)
	Commission polarized protons at RHIC. (SC2-1)	Collect first data with polarized protons with the RHIC STAR, PHENIX and pp2pp detectors. (SC2-1)

SC2-2: Determine the behavior and properties of hot, dense nuclear matter as a function of temperature and density. Discover and characterize the quark-gluon plasma. (Heavy Ion Nuclear Physics and Nuclear Theory subprograms)

Performance Indicators

Results of external and internal reviews of quality, relevance and leadership of research activities and facility operations; number of significant scientific discoveries.

Performance Standards

As discussed in Corporate Context/Executive Summary.

Annual Performance Results and Targets

FY 2001 Results	FY 2002 Targets	FY 2003 Targets
Produced first heavy-ion collisions at the Relativistic Heavy Ion Collider (RHIC - construction completed FY1999) at 10% of its design luminosity, as planned, with four experimental detectors. Published first results of heavy-ion collisions. [Met Goal]	Complete first round of experiments at RHIC at full energy; achieve the full design luminosity (collision rate) of 2 x 10^{26} cm^{-2} s^{-1} for heavy ions. (SC2-2)	Initiate first round of experiments with collisions with other ions to compare to results of gold-gold collisions. (SC2-2)
Continued major accelerator improvement projects at RHIC in order to improve machine reliability and efficiency. [Met Goal]	Complete Helium Storage addition and liquid nitrogen standby cooling system at RHIC leading to better cost effectiveness ($0.5M savings) and operational efficiency (10% increase). (S2-2/SC7-2)	Upgrade the RHIC cryogenics system by replacing turbine oil skids and removing seal gas compressor, eliminating a single point failure. (S2-2/SC7-2)

SC2-3: Determine the low energy properties of nuclei, particularly at their limits of stability. Use these properties to understand energy generation and the origin of the elements in stars, and the fundamental symmetries of the "Standard Model" of elementary particle physics. (Low Energy Nuclear Physics and Nuclear Theory subprograms)

Performance Indicators

Results of external and internal reviews of quality, relevance and leadership of research activities and facility operations; number of significant scientific discoveries.

Performance Standards

As discussed in Corporate Context/Executive Summary.

Annual Performance Results and Targets

FY 2001 Results	FY 2002 Targets	FY 2003 Targets
Produced first results on the solar neutrino flux with the Sudbury Neutrino Observatory (SNO). SNO measures properties of solar neutrinos. [Met Goal]	Collect the first data from neutral current interactions from SNO. (SC2-3)	Collect the first data from KamLAND, a joint U.S.-Japan experiment measuring neutrinos produced in nuclear reactors. (SC2-3)
Tested low-energy prototype of RIA fast catcher and tested low-beta accelerator cavities. [Met Goal]	Construct a prototype high energy, high power gas catcher for RIA. (SC2-3)	Complete testing the prototype high energy, high power gas catcher, and prototype targets for RIA. Complete prototype ECR ion source and work on the development of the high-beta superconducting RF cavities for RIA. (SC2-3)

SC7-2: Manage all NP facility operations and construction to the highest standards of overall performance, using merit evaluation with independent peer review. (Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, and Low Energy Nuclear Physics subprograms)

Performance Indicators

Percent on time/on budget; percent unscheduled downtime.

Performance Standards

As discussed in Corporate Context/Executive Summary.

Annual Performance Results and Targets

FY 2001 Results	FY 2002 Targets	FY 2003 Targets
Maintained and operated NP scientific user facilities so that the unscheduled operational downtime was 15%, on average, of total scheduled operating time. [Met Goal]	Maintain and operate NP scientific user facilities so that the unscheduled operational downtime will be kept to less than 20%, on average, of total scheduled operating time. (SC7-2)	Maintain and operate NP scientific user facilities so that the unscheduled operational downtime will be kept to less than 20%, on average, of total scheduled operating time. (SC7-2)
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 RHIC Detectors and RHIC Silicon Vertex Detector. [Met Goal]	Meet the cost and schedule milestones for construction of facilities and Major Items of Equipment within 10% of baseline estimates. Complete the PHENIX Muon Arm Instrumentation. (SC7-2)	Meet the cost and schedule milestones for construction of facilities and Major Items of Equipment within 10% of baseline estimates. Complete the RHIC STAR EMCAL. (SC7-2)

Significant Accomplishments and Program Shifts

In FY 2001, the DOE Nuclear Physics (NP) program was the major sponsor of fundamental nuclear physics research in the nation, providing about 90% of the federal support, with the National Science Foundation (NSF) providing most of the remaining support.

Over one-third of the program's funding was provided to scientists at universities and laboratories to conceive and carry out the research. The DOE NP 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. University researchers play a critical role in the nation's research effort and in the training of graduate students. About two-thirds of the nation's university researchers and graduate students doing fundamental nuclear physics research in FY 2001 were supported by the DOE Nuclear Physics program. Typically about 90 Ph.D. degrees are granted annually to students for research supported by the program. State-of-the-art facilities to address forefront physics are essential for the U.S. to maintain its world leadership role in nuclear physics research. They are necessary not only to make progress in our understanding of fundamental nuclear physics, but also to provide scientific opportunities for discovery that generate the interest and excitement to attract the brightest, most talented students.

The DOE Nuclear Physics program has made important discoveries in the past decade of great relevance to the field and DOE science missions. The assembly of a large set of precision nucleon-nucleon scattering data has provided critical input for theoretical models that now produce a significantly more quantitative description of nuclei, now 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. This interest has been spurred by advances in both theory and experiment. The discoveries in the late eighties that the quarks carried only 1/3 of the nucleon spin instead of all of it and that the velocity distributions of quarks in iron nuclei were different from those in deuterium raised interest in studying the roles of gluons and the nuclear medium in nucleon structure. This was the first clear evidence of nuclear medium effects at the quark level. The start of the Continuous Electron Beam Accelerator Facility (CEBAF) in 1995 at the Thomas Jefferson National Accelerator Facility, using a new superconducting radio-frequency (SRF) technology, provided a unique high-energy, high-intensity polarized electron beam, the "world's finest electron microscope," to perform detailed measurements of the structure of the nucleon and of light nuclei. This has led to the use of SRF for powerful new light and particle sources, worldwide, such as the Spallation Neutron Source. Recent results from CEBAF are revealing evidence of the transition from hadronic to quark degrees of freedom.

In the Heavy Ion program, after decades of search and study, the elusive transition of nuclear matter from a liquid to a gaseous phase was observed in the late 1990's. At much higher energies, the study of hot and extremely dense hadronic matter became possible with the advent of gold beams at the Alternating Gradient Synchrotron in 1992 and lead beams at the CERN SPS in 1994, where the U.S. played a substantial role in major experiments. The "fireball" systems formed in these collisions equilibrated rapidly and at a high temperature and density, producing conditions that indicated that the new phase of nuclear matter, the predicted quark-gluon plasma, would likely be formed at the even higher energies that would be available with the Relativistic Heavy Ion Collider at Brookhaven National Laboratory. First gold-gold collisions were observed at RHIC in 2000. With this new facility, the U.S. is leading the world effort in creating and characterizing the quark-gluon plasma, a new form of matter that is thought to have existed shortly after the "Big Bang."

The Low Energy subprogram embraces studies of nuclear structure and nuclear astrophysics, as well as related work in fundamental interactions and neutrino physics. The 1990's began with an effervescent research effort at the 88" 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 in solar neutrinos with radiochemical experiments, the SNO experiment was conceived in the late 1980's to search for neutrino flavor oscillations due to their having mass, and designed and built it in the 1990's. In 2001, SNO reported its first physics results, which, together with other experimental results, make a persuasive case for neutrino oscillations and that neutrinos have mass.

It has been known for a long time that nuclear structure cannot be explained fully using only two-body (nucleon-nucleon) interactions. The first fully converged calculations of the properties of the tri-nucleon (^{3}H and ^{3}He) ground states were completed in 1991. The description of the three-body system is one of the most fundamental problems of nuclear physics and had been studied for decades before this result. Recently, the origin of many collective modes of motion in even-even nuclei was explained by the interacting boson model, which makes use of the symmetry properties of valence neutron-proton pairs. In a series of papers published between 1989 and 1995, a new method for understanding the quark structure of matter via QCD was developed by focusing on systems in which one of the quarks is very heavy. This technique has led to a significant advance for using QCD to describe hadron structure. 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, nuclei, to the quark structure of matter. The development of the Green's Function Monte Carlo Technique, as a solution to the nuclear many-body system, 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.

Recent accomplishments are detailed below.

SCIENCE ACCOMPLISHMENTS

Medium Energy Nuclear Physics

- *Role of the Strange Quark in the Structure of the Proton:* The SAMPLE experiment at Bates and the HAPPEX experiment in Hall A at TJNAF have provided information on the contribution of strange quarks to the electromagnetic form factors of the proton. The SAMPLE experiment was completed in FY 2001 and provided the first direct information on how different quark flavors in the quark "sea" contribute to the proton's magnetic moment. The HAPPEX experiment measured these form factors in a different kinematic regime than the SAMPLE experiment. Both found, quite unexpectedly, that the strange quarks play a small role in contributing to the electromagnetic form factors.
- *New Measurements of the Deuteron Provide Information on the Role of QCD in Nuclear Structure:* The deuteron is the simplest nucleus that can be formed, a bound proton and neutron. New measurements of deuteron structure functions at TJNAF allow scientists to study how well conventional nuclear models compare with calculations done by the full theory of Quantum Chromodynamics (QCD). Such measurements provide scientists with guidance on how to mathematically "connect" high-energy QCD calculations to low energy systems in which QCD cannot be calculated exactly.
- *New Precision Measurement of G_E^p / G_M^p Yields Surprising Results:* A recent experiment which measures the ratio of the proton's internal charge distribution to its magnetic (or current) distribution indicates that this ratio significantly decreases from unity as one probes as a function of increasing spatial resolution. This was unexpected since the charge distribution and current distributions are related and the ratio was expected to remain near unity. This experiment used a new technique that capitalizes on the high intensity polarized beam that is unique to TJNAF. The measurement is very important for understanding the internal quark structure of the proton and will constrain quark models of the proton that try to predict this effect. New measurements are planned which will go to even higher resolution to determine if the trend continues or reverses.
- *Recent Results on Flavor Asymmetry in the Nucleon's Quark "Sea:"* Recent publications of work done at Fermilab and the HERMES experiment at DESY in Germany clearly show a strong asymmetry in the number of "down" antiquarks compared to "up" antiquarks in the nucleon's "sea" of virtual quarks. The asymmetry varies significantly with the degree of momentum transferred to the struck quark in the "sea". This "sea" of virtual quarks and gluons is believed to play a significant role in the properties of the nucleon. Many theoretical models have been proposed to explain this asymmetry. Most of these models indicate that the asymmetry can be explained by the existence of virtual mesons in the nucleon. These results have distinct implications for the spin and flavor structure of hadrons that can be tested in future experiments.
- *Precision Measurements of an Excited State of the Nucleon Yield Information on its Dynamic Structure:* Recently published data from Hall B at TJNAF report on a resonance, an excited state of the nucleon, that has unusual properties which makes it possible that it is not a standard three-quark excited state of the nucleon. These new data will provide strong constraints on theoretical models that attempt to explain the resonance's properties.
- *First Determination of the Shrinkage of a Nucleus Due to the Presence of Strange Quarks:* Recent measurements by the HyperBall detector using the Alternating Gradient Synchrotron at Brookhaven National Laboratory have measured a 20% shrinkage in the nuclear radius of ^{7}Li when a neutron is changed into a Lamda (Λ) particle by exchanging a "down" quark with a "strange" quark, which is much heavier. While the shrinkage was expected, the magnitude of the effect was surprising. The precision of the measurement makes it possible to study the effect of this heavier quark in the

nuclear environment, giving us information on both the strange quark and the binding forces inside the nucleus.

- *Development of a New Isotope-Counting Technique with Potential for Important Applications:* A new precision technique for Atom Trap Trace Analysis (ATTA) to identify and count extremely rare isotopes has been developed at Argonne National Laboratory. The technique allows one to make precision measurements of the charge radius of several helium isotopes for fundamental tests of nuclear models and to measure the solar neutrino flux integrated over several million years as a test of the solar model prediction for neutrino production in the sun. The latter is an important test for understanding the low solar neutrino flux problem. This technique also potentially has broad new practical applications, such as dating ground water and polar ice for environmental and geologic studies, dating bones for archeological purposes, and, in medicine, monitoring bone loss in humans.

Heavy Ion Nuclear Physics

- *First Relativistic Heavy Ion Collider Results:* First RHIC measurements indicate that the energy density – a measure of the energy deposited in the collision region by the colliding nuclei – is the highest ever achieved in a laboratory, at least 70% higher than in similar experiments at CERN, and sufficient to create the long sought quark-gluon plasma (QGP), believed to be the state of matter of the universe shortly after the "Big Bang." Several papers reporting results have already been published and many others are expected to follow shortly. Discussion of these results dominated the premier international conference of this field - Quark Matter 2001.
- *3D Imaging:* Collisions between heavy ions create a brief microcosm of strongly interacting subatomic particles termed a "fireball". Using a correlation technique called HBT (Hanbury Brown Twiss) first applied to determine stellar sizes, physicists have measured the volume of the fireball created in the collisions at RHIC to be about as large as that of a gold nucleus. Two-particle correlations can be used to map out the time profile of hadron emission from the hot, dense matter.
- *Expansion of the Fireball:* In the most violent collisions at RHIC, over 5000 subatomic particles emanate from the fireball. By measuring their energies, scientists have determined that the fireball expands rapidly with a velocity approaching 2/3 the speed of light. This is evidence of the extremely rapid thermalization of the incident energy and its conversion into heating up the fireball.
- *Elliptic Flow:* The fireball emits particles asymmetrically in space. This information suggests the fireball geometry has an 'almond' shape – a result that has intrigued the scientific community. One theoretical model suggests this shape occurs as a consequence of pressure generated by an early fluid-like expansion of the quark-gluon plasma – a plasma of nearly massless quarks and gluons.
- *Abundance of Anti-matter:* Scientists have analyzed the constituents of the fireball and have found the ratio of baryonic matter and anti-matter to be nearly 0.8 (i.e., almost equal amounts of each). An equal mixture of matter and anti-matter is thought to have existed in the primitive universe. The RHIC observation is a preliminary indication that favorable conditions exist for QGP formation.
- *Jet Quenching:* A very energetic quark and anti-quark pair may decay into many subatomic particles focused in a narrow cone called a jet. First results suggest these 'hard scattered' pairs are created in a fireball with a high energy density. Jets lose energy as they travel through a QGP and, in turn, fewer subatomic particles are found with high energies. The preliminary RHIC data provide tantalizing hints of a suppression of high momentum subatomic particles. This quenching effect is not observed in lower energy collisions.

Low Energy Nuclear Physics

- *First Solar Neutrino Physics Results from SNO:* The first phase of data taking with the SNO solar neutrino experiment has been completed and the first published results report that neutrino oscillations, not lower than expected neutrino production by the sun, are the reason for deficits in solar neutrinos detected on earth. The SNO experiment is unique among solar neutrino experiments in that in its second experimental phase now underway it can also measure the appearance of non-electron neutrino flavors into which the solar electron neutrinos oscillate. If neutrinos oscillate, as first SNO results indicate, they must have a non-zero mass. These results will have profound implications for the present understanding of the Standard Model of fundamental particles and interactions.

- *Measurement of the ^{44}Ti(α,p) Reaction Cross Section:* At ATLAS (ANL) the cross section for the ^{44}Ti (α,p) reaction has been measured experimentally for the first time using a beam of radioactive ^{44}Ti; this cross section has been determined to be significantly larger than previously estimated. ^{44}Ti can be used to identify and study supernovae remnants in the nearby cosmos because it has a half-life of 60 years and emits high-energy gamma rays. The use of the measured cross section for the ^{44}Ti (α,p) reaction in supernova explosion calculations results in lower residual ^{44}Ti in a supernova remnant, since this reaction process is a principal cause of ^{44}Ti destruction in these explosions. As the residual ^{44}Ti is less than previously assumed, this means that supernovae remnants studied by orbiting gamma-ray spectrometers are closer that previously believed.

- *First Identification Of The Di-Proton Decay Mode:* Decay of a nucleus by simultaneous emission of two protons has been identified for the first time by researchers at the ORNL HRIBF. The decaying nucleus, ^{18}Ne, was produced using a radioactive ^{17}F beam reacting with a hydrogen target. Future measurements will be undertaken to determine if the two protons are correlated (i.e., briefly interacting as a pair of protons) or uncorrelated (i.e., moving independently in the nucleus before decay). These data will provide information on the structure of nuclei near the proton dripline.

- *Characterization of the Superdeformed Band in ^{36}Ar:* The lifetimes of superdeformed states in the light Z = N nucleus ^{36}Ar have been measured with Gammasphere using beams provided by the ANL ATLAS facility. This information can be used to understand the microscopic origin of collective nuclear rotations. Superdeformed states occur in rapidly rotating nuclei that are oblong shaped with axes having ratios of about 2:1. Most of these are heavy nuclei where protons and neutrons are treated collectively by theoretical models. Since ^{36}Ar has comparatively few protons and neutrons, it may be possible to calculate the detailed properties of these states with the nuclear shell model that describes nuclei in terms of individual protons and neutrons.

- *First Evidence of Freeze-Out Effects in the S-Process:* At ORNL the resonance analysis of ^{192,194,195,196}Pt(n,γ) data from the Oak Ridge Electron Linac Accelerator (ORELA), and the study of the slow neutron capture process (s-process) branching at ^{192}Ir, have resulted in first evidence of long-sought freeze-out effects during s-process nucleosynthesis in a certain class of stars. These freeze-out effects involve the time dependence of the mean neutron density and temperature in the star as the capture process proceeds, thus providing details on stellar dynamics.

- *Observation and Characterization of Chiral Symmetry in Nuclei*: Scientists at several universities, including Yale University and the University of Tennessee, have identified twin bands of nuclear levels interpreted as resulting from chiral (mirror) symmetry. Although this symmetry in nuclei has been predicted theoretically it had never been experimentally observed. The existence of chiral symmetry requires specific conditions, including a deformed nucleus with an odd neutron and an odd proton. The spin vectors of the nuclear core, the odd neutron and the odd proton point in three mutually perpendicular directions, forming either a right-handed or left-handed coordinate system and giving rise to the twin band structure.

Nuclear Theory

- *Advances in Neutron Star Science:* A number of theoretical nuclear astrophysicists have focused their recent efforts on understanding the characteristics of neutron stars. Increasingly realistic calculations are testing assertions that there may be condensation of kaons in these giant 'nuclei' and that there may be quasi-crystalline structure within them. Input to these studies includes both the fundamental understanding of particle interactions folded into massive numerical simulations, and experimental observations. The mass accretion properties of these stars have been deduced through study of 'X-ray bursters' that has shed light on both their equation of state and their rotational properties. The sudden spin-up behavior of pulsars known as 'glitches' has also been analyzed to yield an important new constraint on the mass-radius relationship for neutron stars that does not depend on their equation of state.
- *Quark Structure of the Deuteron:* New calculations have successfully explained the breakup of the deuteron into a proton and neutron by photons at high energies in terms of a single quark-level process. This is an important step toward understanding the quark and gluon degrees of freedom in nuclei, since deuterium is the simplest stable nucleus with more than a single nucleon. Previous theoretical attempts had successfully described the angular distributions of the emitted protons and neutrons fairly well, but predicted the basic probability of the breakup to occur to be 100 times too small. The new theory describes the data on average with better than 20% accuracy using only a single process; several further improvements are possible.
- *Thermalization in Ultra Relativistic Heavy Ion Collisions:* Recent work in perturbative QCD, the high-energy theory of the strong interaction, has determined that thermalization is guaranteed to occur for sufficiently high energies and sufficiently heavy nuclei in ultra relativistic heavy ion collisions. The system formed in the collision achieves thermal equilibrium surprisingly rapidly compared to the time required for it to fly apart, and the mechanism for achieving the equilibrium is an unexpected one. The thermal equilibrium condition, when achieved, greatly simplifies the interpretation of the particle spectrum ejected from the collision and permits much simpler calculations to describe the reaction.
- *New Theoretical Tool Ties Together Many Different Phenomena:* Generalized Parton Distributions (GPD's) were invented in recent years to describe certain exclusive high-energy electromagnetic reactions on the proton and neutron. GPD's have now been broadly linked to a much larger variety of electromagnetic observables or processes such as elastic form factors, high-energy meson production, inclusive deep-inelastic-scattering measurements, and virtual Compton scattering. The impact of this is that these distributions, when measured, will be able to be cross-correlated among these several very different types of reactions, testing the correctness of this theory and providing a compact description of a wide range of disparate phenomena.
- *Advances in Few-Body Reactions:* Low-energy properties of three-body systems such as ^{3}He have long been successfully described by a complicated method called Faddeev calculations. This method, while exact in principle, could not be extended to higher energies: the procedure fails to be practical because the number of angular momentum states becomes very large. A technical breakthrough in computational methods now permits a full three-dimensional solution of the Faddeev equations without using angular momentum decomposition; this will permit the method to be extended to higher energies. The first test of the new calculations against the older method has shown excellent agreement, verifying the new approach to very high accuracy.

- *Indicators of Quark-Gluon Plasma Formation:* While a number of indicators for the quark-gluon plasma have been proposed by theorists in the field, a particularly interesting method developed recently is that of event-by-event fluctuations in the ratio of particle types. A quark-gluon plasma is hoped to be formed in ultra-relativistic heavy-ion collisions such as those studied at RHIC. Fluctuations in the ratio of positively charged particles to negatively charged particles give a direct measure of the charge fluctuations per unit entropy. Since quarks in the quark-gluon plasma have only fractional charges (1/3 or 2/3 the charge of composite particles), the fluctuations are expected to be much smaller for the quark-gluon plasma compared to that in normal nuclear matter. This simple-sounding prediction has continued to hold up under detailed scrutiny by numerous researchers.

FACILITY AND TECHNICAL ACCOMPLISHMENTS

Medium Energy Nuclear Physics

- In FY 2001, the *Continuous Electron Beam Accelerator Facility at the Thomas Jefferson National Accelerator Facility Provided 140 Microamperes of Nearly 80% Polarized Beam at 5.7 GeV* (42% greater than the design energy of 4 GeV). These high intensity, highly polarized beam capabilities are unique in the world for electron accelerators. A newly developed diode laser with a Ti:Sapphire optical amplifier will make it possible to increase the intensity of this polarized beam by a factor of more than 500. In the past three years of full operations, 32 experiments have been completed and another 50 are partially completed, resulting in about 100 published papers and 60 Ph.D. theses.
- *CEBAF Represents the World's Most Powerful Superconducting Radio Frequency (SRF) Accelerator.* The SRF cavities have exceeded their design specifications by 50%, making it possible for CEBAF to accelerate 6 GeV beams. It is expected that further advances in SRF technology and the production of a new compact cryomodule could lead to a relatively simple and inexpensive upgrade of CEBAF's top energy to 12 GeV. R&D funding is provided in FY 2003 for this upgrade that is identified in the most recent NSAC long range planning exercise as a high priority opportunity that should be pursued.
- *RHIC Accelerates the Highest Energy Polarized Protons to Date.* The RHIC Spin program at Brookhaven National Laboratory successfully accelerated polarized protons in the RHIC rings to an energy of approximately 32 GeV with 20% polarization during its commissioning run in FY 2001 and reached an energy of 100 GeV in early FY 2002. This demonstrated that polarized protons can be successfully accelerated in the rings and set a record for the highest energy polarized proton beam ever achieved. This is not an easy accomplishment because the polarized protons are subject to depolarizing resonances as their energy is increased. Special approaches had to be developed to maintain the polarization during acceleration.
- The *BLAST Detector* at the MIT/Bates facility is nearing completion, and in FY 2002 a unique research program will be initiated to study the structure of the nucleon and few-body nuclei. The successful storage of 200 milliamperes of polarized beams in the South Hall Ring in FY 2001 demonstrated that the needed beam capabilities have been developed to carry out the BLAST research program in FY 2002-2004.
- *Fabrication of the G0 Detector* at the Thomas Jefferson National Accelerator Facility (TJNAF) is on cost and schedule to be completed in FY 2002 and initiate commissioning. It utilizes the very high intensity polarized electron beam developed at TJNAF in mapping out the strange quark contribution to nucleon structure over a wide range of momentum transfer.

- *Scintimammography and Molecular Imaging Developed at TJNAF:* In the past few years, the detector group at TJNAF has developed high resolution gamma imagers for biomedical applications. This is a device that "senses" gamma rays emitted by a tumor after absorption of a biological tracer and then builds an image of the tumor, thus improving breast cancer detection. In combining scintimammography and digital x-ray techniques, the group has designed a mini gamma camera for use in conjunction with a commercially available x-ray guidance system for stereotactically guided core needle breast biopsies.
- *Hyperpolarized Gas Provides Enhanced MRI Imaging:* A new technique has been developed by university researchers that enhances MRI imaging of lungs through the use of "hyperpolarized gas." The technique, initially developed to provide polarized targets for nuclear physics experiments, uses lasers to polarize large volumes of noble gases that can then be inhaled. The MRI equipment detects the resonance of the polarized gas to provide an image of the air volume of the lungs. The process is presently undergoing clinical trials.

Heavy Ion Nuclear Physics

- *Construction of the Relativistic Heavy Ion Collider (RHIC)* at Brookhaven National Laboratory was completed in FY 1999 on cost and schedule (TPC of $616,530,000). Commissioning started in FY 1999 and data taking started in FY 2000, as scheduled. During the FY 2000 run RHIC reached about 10% of its design luminosity (collision rate), as planned. RHIC reached operation at full luminosity for gold-gold collisions early in FY 2002.
- *Real Time Pattern Recognition and Tracking:* The STAR Time Projection Chamber is one of the most advanced instruments used to study heavy ion collisions, providing digital information from over 100,000 sensors. Scientists have developed software algorithms and built a farm of high-speed computers that sift through the sensor data to carry out pattern recognition. Images of thousands of tracks that are emitted in each head-on gold-gold collision are reconstructed in a fraction of a second in real time. The stunning STAR-burst pictures were published by news media throughout the world.
- *RHIC Detector Enhancements Remain on Cost and Schedule:* Fabrication of the STAR Silicon Vertex Detector (SVT), a high-resolution, high-granularity, charged-particle tracking system very close to the collision region, was successfully completed in FY 2000 and installed in FY 2001. The RHIC Data Analysis System was completed in FY 2000 and successfully recorded and stored the acquired experimental data that has been analyzed and published in several papers. One PHENIX Muon Arm will be completed and commissioned in FY 2001; the second Arm (funded substantially by Japanese collaborators) will be completed in FY 2002. The Electro-Magnetic Calorimeter (EMCal) for STAR began production fabrication of modules in FY 2000, will commission existing modules in FY 2001, and is on schedule for completion of the planned system in FY 2003. An enhancement of the EMCAL, providing additional modules for full coverage of the barrel and optimizing the performance for the RHIC Spin Program, will commence in FY 2003.

Low Energy Nuclear Physics

- *Production of Accelerated Radioactive Ion Beams:* In FY 2001 over 100 neutron-rich radioactive beams were produced and accelerated at the HRIBF at ORNL, the only facility in the world where these high-quality, high-energy beams are available for research. These accelerated neutron-rich radioactive beams are suitable for a variety of nuclear spectroscopy studies. The first spectroscopy experiments with these low-intensity beams utilized a combination of gamma-ray, charged-particle, and recoil-particle spectrometers, and included Coulomb excitation experiments and fusion and incomplete-fusion reactions.

- *Development of Crucial Technologies for the Rare Isotope Accelerator (RIA):* A prototype of the fast ion gas catcher, a technology that greatly extends the exotic beam production capability of RIA, was designed, built and successfully tested at ANL. A test of a full-scale version of the gas catcher will be mounted in the near future. The Versatile Electron Cyclotron Resonance (ECR) for Nuclear Science (VENUS) ion source, under construction at LBNL, is a test bed for technologies that will provide the high intensity ion source for the RIA driver linac and can be used to produce higher intensity beams at the other operating facilities such as ATLAS. Prototypes of several of the superconducting radiofrequency accelerator cavities have been built at ANL, including an intermediate energy cavity not previously designed.
- *First Nuclear Physics Experiments at the High Intensity Gamma-ray Source (HIγS):* The first nuclear physics experiments have begun at HIγS at TUNL for gamma-ray energies below 12 MeV. HIγS uses a special optical cavity at the Duke University Free Electron Laser to generate a narrow beam of mono-energetic high-energy gamma rays. An upgrade begun in FY 2001 will make this facility unique in the world in terms of the gamma-ray flux, energy range and attainable energy resolution it will provide for nuclear physics measurements.
- *The KamLAND Neutrino Detector*: The detector for the KamLAND experiment in Japan is nearing completion. This experiment will search for oscillation of neutrinos produced in distant nuclear reactors to test one of the possible solutions that are compatible with current atmospheric neutrino oscillation results. Scientists from the U.S., jointly supported by the Nuclear and High-Energy Physics programs, are collaborating with Japanese scientists in the construction and operation of KamLAND.
- *High Precision Mass Measurements:* In FY 2001 the first high-precision mass measurements of unstable nuclei have been accomplished with the Canadian Penning Trap at ATLAS (ANL). One of the technique's early uses will be the measurement of the mass of certain Z=N nuclei to completely characterize the Gamow-Teller beta decay of these nuclei, and place constraints on the Standard Model of weak interactions.
- *Development of Segmented Germanium Detectors:* Measurements using a 36-fold segmented germanium crystal at LBNL yield a three-dimensional position resolution of less that 1 mm for the determination of the position of a gamma-ray interaction in the crystal. When all of the interaction positions of a scattered gamma ray are known, the full energy and origin direction of the gamma ray can be reconstructed. This is a critical step in the development of a state-of-the-art tracking detector array that will be 1000 times more sensitive than Gammasphere, presently the most powerful gamma-ray detector in the world.
- *Development of a New Source for Ultra-Cold Neutrons:* Development of a source of ultra-cold neutrons is underway at LANL, and will be completed in FY 2003. Using a prototype source, scientists at LANL have exceeded by a factor of three the world's previous record for number of ultracold neutrons trapped. Further gains are expected with the full-scale source. This ultra-cold neutron source will allow the measurement of the details of neutron decay, and test aspects of the Standard Model.

PROGRAM SHIFTS

In the FY 2003 budget request the scientific scope of the nation's nuclear physics program is maintained. The FY 2003 budget request is focused on optimizing the utilization of its major user facilities. Facility operations are provided a 10% increase in funding in FY 2003 that will result in a 21% increase in beam hours for research compared to FY 2002. 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 effective utilization of the facilities. Funding for university and national laboratory research is increased about 4% compared to FY 2002, maintaining approximate constant level of effort. Funding for capital equipment is held essentially flat compared to FY 2002 and a 25% increase in R&D activities directed at RIA.

The Scientific Discovery through Advanced Computing (*SciDAC)* program is an Office of Science initiative to address major scientific challenges that require advances in scientific computing using terascale resources. An effort managed by the Office of High Energy and Nuclear Physics (HENP) 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 FY2001 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 collaboration involved represents essentially the entire U.S. community in this area with efforts from both nuclear and high-energy physics communities and strong involvement of both of the Nuclear Physics program's major accelerator facilities, TJNAF and RHIC. 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, 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.

Scientific Facilities Utilization

The Nuclear Physics request includes $260,140,000 to maintain support of the Department's scientific user facilities. This investment will provide research time for several thousand scientists in universities and other Federal laboratories. It will also leverage both federally and privately sponsored research, consistent with the Administration's strategy for enhancing the U.S. national science investment.

The proposed funding will support operations at the six National User Facilities supported by the Nuclear Physics program: the Relativistic Heavy Ion Collider (RHIC) complex at Brookhaven National Laboratory (BNL), the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (TJNAF), the Bates Linear Accelerator Center at Massachusetts Institute of Technology (MIT), and the three low energy facilities: the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory (ORNL), the Argonne Tandem Linac Accelerator System (ATLAS) facility at Argonne National Laboratory (ANL), and the 88-Inch Cyclotron at Lawrence

Berkeley National Laboratory (LBNL). Further information on these facilities can be found in the Site Description and Detailed Justifications under the subprogram in which they are funded.

These facilities provided about 20,000 hours of beams in FY 2001 for a research community of about 2,500 scientists. The FY 2003 President's Budget Request will support facility operations that will provide ~20,700 hours of beams for research, an increase of ~21% over the anticipated beam hours in FY 2002.

Workforce Development

The Nuclear Physics program supports development of the 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, 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, national security and the stock market.

About 800 postdoctoral research associates and graduate students supported by the Nuclear Physics program in FY 2001 were involved in a large variety of experimental and theoretical research projects. Nearly one quarter 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. In FY 2003, emphasis is placed on operations and research efforts at the national user facilities. The funding level will result in approximately the same number of postdoctoral research associates and graduate students that can be supported compared to FY 2002.

Funding Profile

(dollars in thousands)

	FY 2001 Comparable Appropriation	FY 2002 Original Appropriation	FY 2002 Adjustments	FY 2002 Comparable Current Appropriation	FY 2003 Request
Nuclear Physics					
Medium Energy Nuclear Physics ..	113,410	117,953	-443	117,510	123,590
Heavy Ion Nuclear Physics	152,112	156,292	-674	155,618	167,977
Low Energy Nuclear Physics.........	62,650	62,685	-263	62,422	66,158
Nuclear Theory	23,622	23,580	-95	23,485	24,645
Subtotal, Nuclear Physics	351,794	360,510	-1,475	359,035	382,370
General Reduction.........................	0	-1,475	1,475	0	0
Total, Nuclear Physics........................	351,794 [a] [b]	359,035	0	359,035	382,370

Public Law Authorization:

Public Law 95-91, "Department of Energy Organization Act"

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

[a] Excludes $7,760,000 that has been transferred to the SBIR program and $466,000 which has been transferred to the STTR program.

[b] Excludes $488,000 transferred to Science Safeguards and Security program in an FY 2001 reprogramming.

Funding by Site

	(dollars in thousands)				
	FY 2001	FY 2002	FY 2003	$ Change	% Change
Albuquerque Operations Office					
Los Alamos National Laboratory	10,378	9,643	9,123	-520	-5.4%
Sandia National Laboratory	4	0	0	0	--
Total, Albuquerque Operations Office	10,382	9,643	9,123	-520	-5.4%
Chicago Operations Office					
Argonne National Laboratory	17,912	16,532	17,548	+1,016	+6.1%
Brookhaven National Laboratory	140,791	138,671	149,004	+10,333	+7.5%
Fermi National Accelerator Laboratory	50	0	0	0	--
Chicago Operations Office	54,513	50,840	52,111	+1,271	+2.5%
Total, Chicago Operations Office	213,266	206,043	218,663	+12,620	+6.1%
Oakland Operations Office					
Lawrence Berkeley National Laboratory	18,703	17,689	18,615	+926	+5.2%
Lawrence Livermore National Laboratory	755	614	507	-107	-17.4%
Oakland Operations Office	17,368	15,971	16,278	+307	+1.9%
Total, Oakland Operations Office	36,826	34,274	35,400	+1,126	+3.3%
Oak Ridge Operations Office					
Oak Ridge Institute for Science & Education	690	570	189	-381	-66.8%
Oak Ridge National Laboratory	15,879	15,307	16,870	+1,563	+10.2%
Thomas Jefferson National Accelerator Facility	74,135	73,830	79,138	+5,308	+7.2%
Total, Oak Ridge Operations Office	90,704	89,707	96,197	+6,490	+7.2%
Washington Headquarters	616	19,368	22,987	+3,619	+18.7%
Total, Nuclear Physics	351,794 [a] [b]	359,035	382,370	+23,335	+6.5%

[a] Excludes $7,760,000 that has been transferred to the SBIR program and $466,000 which has been transferred to the STTR program.

[b] Excludes $488,000 which was transferred to Science Safeguards and Security program in an FY 2001 reprogramming.

Site Description

Argonne National Laboratory

Argonne National Laboratory (ANL) in Argonne, Illinois, is a Multiprogram Laboratory located on a 1,700 acre site in suburban Chicago. ANL has a satellite site located in Idaho Falls, Idaho. The major Nuclear Physics program activity at ANL supported by the Low Energy subprogram is the operation and research program at the ATLAS national user facility. Other activities include: (1) a Medium Energy group which carries out a program of research at TJNAF, Fermilab, RHIC and DESY in Germany; (2) R&D directed towards the proposed Rare Isotope Accelerator (RIA) facility; (3) a Nuclear Theory group, which carries out theoretical calculations and investigations in subjects supporting the experimental research programs in Medium Energy and Low Energy physics; and (4) data compilation and evaluation activities as part of the National Data Program.

The **Argonne Tandem Linac Accelerator System (ATLAS)** facility provides variable energy, precision beams of stable ions from protons through uranium, at energies near the Coulomb barrier (up to 10 MeV per nucleon) using a superconducting linear accelerator. Most work is performed with stable heavy-ion beams, however, about 6% of the beams are exotic (radioactive) beams. The ATLAS facility features a wide array of experimental instrumentation, including a world-leading atom trap apparatus. The Gammasphere detector, which ATLAS shares on a rotating basis with the LBNL 88-Inch Cyclotron, coupled with the Fragment Mass Analyzer is a unique world facility for measurement of nuclei at the limits of angular momentum (high-spin states). ATLAS is a world leader in superconducting linear accelerator technology, with particular application to the proposed Rare Isotope Accelerator (RIA) facility. The combination of versatile beams and powerful instruments enables the ~125 users annually at ATLAS to conduct research in a broad program in nuclear structure and dynamics, nuclear astrophysics, and fundamental interaction studies.

Brookhaven National Laboratory (BNL)

Brookhaven National Laboratory is a Multiprogram Laboratory located on a 5,200 acre site in Upton, New York. The major Nuclear Physics program effort at BNL, supported by the Heavy Ion subprogram, is the operation and research program of the new Relativistic Heavy Ion Collider (RHIC). Other activities include (1) a Medium Energy group that will use polarized protons in RHIC to understand the internal "spin" structure of the protons, (2) the Laser Electron Gamma Source (LEGS) group, supported by the Medium Energy subprogram, that uses a unique polarized photon beam to carry out a program of photonuclear spin physics at the National Synchrotron Light Source (NSLS), (3) a Nuclear Theory group that does research primarily in the area of relativistic heavy ion physics, (4) a Low Energy group that plays an important role in the research program at the Sudbury Neutrino Observatory (SNO) that is measuring the solar neutrino flux, and (5) the DOE managed National Nuclear Data Center (NNDC) that is the central U.S. site for national and international nuclear data and compilation efforts.

The Relativistic Heavy Ion Collider (RHIC) Facility, completed in 1999, is a major new and unique international facility used by about 1,100 scientists from 19 countries. RHIC uses the Tandem, Booster, and Alternating Gradient Synchrotron (AGS) accelerators in combination to inject beams into two rings of superconducting magnets of almost 4 km circumference with 6 intersection regions where the beams collide. It can accelerate and collide a variety of heavy ions, including gold beams, up to an energy of 100 GeV per nucleon. RHIC will search for the predicted "quark-gluon plasma," a form of nuclear matter thought to have existed microseconds after the "Big Bang." Operations began in FY 2000 and first results have already been published. RHIC can also accelerate and collide polarized protons at energies up to 250 GeV for a research program directed at understanding the quark structure of the proton. Four detectors have been fabricated to provide complementary measurements, but with some overlap in order to cross-calibrate the measurements: (1) The core of the Solenoidal Tracker At RHIC (STAR) detector, built at a cost of ~$80,000,000, is a large Time Projection Chamber (TPC) located inside a solenoidal magnet that tracks thousands of charged particles emanating from a single head-on gold-gold collision. There are also end-cap TPC's. A large modular barrel Electro-Magnetic Calorimeter (EMCal), being fabricated with completion in FY 2003, measures deposited energy for high-energy charged and neutral particles and contains particle-photon discrimination capability. An enhancement to this calorimeter is being developed for the RHIC Spin program. An end-cap Calorimeter, also for the RHIC Spin program, is being funded by the NSF (TEC~$6,910,000; completion in FY 2004). A Silicon Vertex Tracker has very high tracking resolution for charged particles close to the collision vertex that greatly increases the tracking capabilities for the very short-lived multi-strange particles. (2) The Pioneering High-Energy Nuclear Interacting eXperiment (PHENIX) detector, built at a cost of ~$87,000,000, has a particular focus on the measurement of rarer probes at high event detection rate. It consists of two transverse smaller acceptance arms that can track charged particles within a magnetic field especially to higher momentum; it provides excellent discrimination among photons, electrons, and hadrons. There is also a Silicon Vertex Detector that can measure the total number of charged particles produced in a collision, but without particle identification. There are also two large muon tracking and identification systems in the forward and backward directions. (3) The PHOBOS detector, built at a cost of ~$7,600,000, is a very compact detector that uses mostly silicon pad sensors for charged particle detection and tracking, with a focus on measurements to very low momentum. It consists of two small-acceptance tracking arms located within a magnetic field and a very large coverage multiplicity detector that measures the total event charged-particle multiplicity and distribution. (4) The Broad Range Hadron Magnetic Spectrometer (BRAHMS) built at a cost of ~$6,200,000, has two very small acceptance magnetic spectrometer arms that be can rotated to scan the broadest range of angles. It is especially designed to study the charged particle distributions in the forward and backward directions.

The **Alternating Gradient Synchrotron (AGS)** provides high intensity pulsed proton beams up to 33 GeV on fixed targets and secondary beams of kaons, muons, pions, and anti-protons. Experiments explore the quark constituents of light nuclei, and test the theories of quantum chromo-dynamics and electro-weak forces. The AGS is the injector of (polarized) proton and heavy-ion beams into RHIC, and its operations are supported by the Heavy Ion subprogram as part of the RHIC facility. Operation of the AGS for fixed targets and secondary beams is terminated in FY 2003.

The **National Nuclear Data Center (NNDC)** is the central U.S. site for national and international nuclear data and compilation efforts. The U.S. Nuclear Data program is the United States repository for information generated in low- and intermediate-energy nuclear physics research worldwide. This information consists of both bibliographic and numeric data. The NNDC is a resource that maintains the U.S. expertise in low- and intermediate-energy nuclear physics by providing evaluated nuclear data for the user community. The NNDC is assisted in carrying out this responsibility by other Nuclear Data program funded scientists at U.S. National Laboratories and universities.

Lawrence Berkeley National Laboratory (LBNL)

Lawrence Berkeley National Laboratory is a Multiprogram Laboratory located in Berkeley, California. The laboratory is on a 200 acre site adjacent to the Berkeley campus of the University of California. A major Nuclear Physics effort at LBNL, supported by the Low Energy subprogram, is the operations and the research program of the 88-Inch Cyclotron, a national user facility. Other activities include (1) a Relativistic Nuclear Collisions group, with activities primarily at RHIC, where the group has been a major player in the development of the STAR detector; (2) a Low Energy group which has a major role in the implementation and operation of the Sudbury Neutrino Observatory (SNO) detector in Canada, and provides the project management of the U.S. collaboration in the KamLAND detector in Japan which is looking for evidence of neutrino mass; (3) a Nuclear Theory group that carries out a program with emphasis on the theory of relativistic heavy ion physics; (4) a Nuclear Data group whose activities support the National Nuclear Data Center at BNL; and (5) a technical effort involved in RIA R&D.

The **88-Inch Cyclotron** facility provides high intensity stable beams from protons to bismuth at energies above the Coulomb barrier (up to 15 MeV per nucleon). The electron-cyclotron resonance (ECR) ion sources at the facility are state-of-the-art and copied around the world. The Gammasphere array, widely regarded as the world's most powerful gamma-ray detector, is used to study nuclei at the extremes of angular momentum and excitation energy. The Berkeley Gas-filled Separator, a world-class instrument, is used for discovery experiments in superheavy elements. The 88-Inch Cyclotron is used annually by a community of about 230 scientists.

Lawrence Livermore National Laboratory (LLNL)

Lawrence Livermore National Laboratory is a Multiprogram Laboratory located on an 821 acre site in Livermore, California. Nuclear Physics supports research in nuclear structure studies carried out with the GENIE detector that was installed and is maintained by the LLNL group at the LANSCE facility at Los Alamos National Laboratory, in relativistic heavy ions as part of the PHENIX collaboration, for nuclear data and compilation activities, and for a technical effort involved in RIA R&D.

Los Alamos National Laboratory (LANL)

Los Alamos National Laboratory is a Multiprogram Laboratory located on a 27,000 acre site in Los Alamos, New Mexico. Nuclear Physics supports a broad program of research including: (1) a program of neutron beam research that utilizes beams from the LANSCE facility; (2) a relativistic heavy ion effort using the PHENIX detector at the new Relativistic Heavy Ion Collider (RHIC); (3) research directed at the study of the quark substructure of the nucleon in experiments at Fermilab, and at the "spin" structure of nucleons at RHIC using polarized proton beams; (4) the development of the Sudbury Neutrino Observatory (SNO) detector as well as involvement in the SNO and MiniBoone research programs; (5) a broad program of theoretical research into a number of topics in nuclear physics; (6) nuclear data and compilation activities as part of the national nuclear data program; and (7) a technical effort involved in RIA R&D.

Oak Ridge Institute for Science and Education (ORISE)

Oak Ridge Institute for Science and Education is located on a 150 acre site in Oak Ridge, Tennessee. Nuclear Physics support is provided through ORISE for activities in support of the Holifield Radioactive Ion Beam Facility (HRIBF) and its research program.

Oak Ridge National Laboratory (ORNL)

Oak Ridge National Laboratory is a Multiprogram Laboratory located on a 24,000 acre site in Oak Ridge, Tennessee. The major effort at ORNL is the Low Energy program support for research and operations of the Holifield Radioactive Ion Beam Facility (HRIBF) that is operated as a national user facility. Also supported is (1) a relativistic heavy ion group that is involved in a research program using the PHENIX detector at RHIC; (2) a theoretical nuclear physics effort at ORNL that emphasizes investigations of nuclear structure and astrophysics; (3) nuclear data and compilation activities that support the national nuclear data effort; and (4) a technical effort involved in RIA R&D.

The **Holifield Radioactive Ion Beam Facility (HRIBF)** is the only radioactive nuclear beam facility in the U.S. to use the isotope separator on-line (ISOL) method and is used annually by about 100 scientists. It provides a wide range of both proton-rich and neutron-rich nuclei to a suite of instruments designed for studies in nuclear structure, dynamics and astrophysics using radioactive beams. The HRIBF accelerates secondary radioactive beams to higher energies (up to 10 MeV per nucleon) than any other facility in the world with such a broad selection of ions. The HRIBF conducts R&D on ion sources and low energy ion transport for radioactive beams.

Thomas Jefferson National Accelerator Facility (TJNAF)

Thomas Jefferson National Accelerator Facility (TJNAF) is a laboratory operated by the Nuclear Physics program located on 273 acres in Newport News, Virginia. Constructed over the period FY 1987-1995 for a cost of $513,000,000 (Total Project Cost), TJNAF began operations in FY 1995. Support for the research and operations of TJNAF are provided by the Medium Energy subprogram. The center piece of TJNAF is the **Continuous Electron Beam Accelerator Facility (CEBAF)**, a unique international electron-beam user facility for the investigation of nuclear and nucleon structure based on the underlying quark substructure that is used annually by 690 U.S. and foreign researchers. CEBAF consists of two multi-pass, superconducting linear accelerators connected by recirculating magnetic arcs. Polarized and unpolarized electron beams up to 5.7 GeV can be provided by CEBAF simultaneously to 3 different experimental halls, Halls A, B, and C. Hall A is designed for spectroscopy and few-body measurements. There are two high-resolution spectrometers, one for detection of the scattered electron from the beam and another for detection of the scattered particle. Hall B has a large acceptance detector, CLAS, for detecting multiple charged particles coming from a scattering reaction. Hall C is designed for flexibility to incorporate a wide variety of different experiments. Its core equipment consists of two medium resolution spectrometers for detecting high momentum or unstable particles. A large variety of major instruments are available for studying the scattering of and particle production from the electrons with fixed gas and solid targets. Fabrication of the G0 detector, a joint NSF-DOE project in Hall C that will allow a detailed mapping out of the strange quark contribution to nucleon structure, will be completed during FY 2002. As of FY 2002, Hall A will have completed 20 experiments and Hall C will have completed 18. The complex large-acceptance spectrometer in Hall B will have completed 65% of the data taking for 41 experiments. Support is also provided by the nuclear theory subprogram for a group whose program of investigations supports the experimental program of the laboratory. An accelerator R&D group is supported for projects important to the Nuclear Physics program (e.g., the proposed 12 GeV upgrade of CEBAF, and R&D for RIA).

All Other Sites

The Nuclear Physics program funds 180 research grants at 85 colleges/universities located in 35 states. Among these is a grant with the Massachusetts Institute of Technology (MIT) for the operation of the ***Bates Linear Accelerator Center*** as a national user facility used by about 110 scientists. The Bates facility, with electron beams up to 1 GeV, conducts experiments to study the properties and constituents of protons and light nuclei at energies below those of CEBAF. The research program probes the properties of the proton such as its shape and polarizability, and the charge distribution and magnetism of the deuteron. A major instrument for making these measurements will be the Bates Large Acceptance Spectrometer Toroid (BLAST) detector, whose fabrication will be completed in FY 2002. BLAST will observe collisions of polarized electrons in thin polarized gas targets located in the South Hall Pulse Stretcher Ring. Additional unique experiments are performed with the Out-Of Plane Spectrometer (OOPS). The Bates experimental program is scheduled to be concluded in 2004 and phased out in FY 2005-2006.

Grants for the operation of accelerator facilities at four university laboratories are supported by the Low Energy subprogram for research in selected and specialized areas conducted primarily by the in-house faculty members and students. The ***Triangle Universities Nuclear Laboratory (TUNL)*** utilizes a tandem Van de Graaff and polarized beams and targets to test and refine the theory of the nuclear force and its currents. A suite of instrumentation has been built up to take advantage of this unique combination of capabilities and to study fundamental symmetries and reactions important to nuclear astrophysics. ***The Texas A&M Cyclotron Institute (TAMU)*** operates a modern superconducting cyclotron to deliver a wide range of stable and selected radioactive beams for medium energy heavy-ion reaction studies, tests of fundamental constants of the standard model, and nuclear astrophysics. Modern instrumentation takes advantage of the heavy-ion beams, and a number of foreign collaborators use the facility. ***The Yale Tandem Van de Graaff*** provides a variety of stable beams for an extensive suite of instruments that, along with the opportunity for extended running times, provides the capability for detailed experiments on symmetry, collective structures, and evolution of properties in nuclei and nuclear astrophysics. The ***University of Washington Tandem Van de Graaff*** provides precisely characterized proton beams for extended running periods for research in fundamental nuclear interactions and nuclear astrophysics. These four accelerator facilities offer niche capabilities and opportunities not available at the national user facilities, or many foreign low-energy laboratories, such as specialized sources and targets, opportunities for extended experiments, and specialized instrumentation. These facilities operate in a university environment and thus provide a unique setting for the training and education of graduate students in the U.S., where they have the opportunity to be involved in all aspects of low energy nuclear research. These centers of excellence have in the past and continue today to produce the next generation of national leaders in nuclear science research.

The ***Institute for Nuclear Theory (INT)*** at the University of Washington is a premier international center for new initiatives and collaborations in nuclear theory research. Established in 1990, the INT conducts three programs each year on topics identified by an international advisory committee. U.S. and foreign researchers spend varying lengths of time at the Institute during the 2-3 month period of each program to establish collaborations and carry out projects. The institute also supports several workshops per year, some of which are hosted on-site. Currently, approximately 350 physicists visit the Institute per year, with an average stay of 3.5 weeks. Of these, approximately 20% are experimentalists, indicating the broad influence of the INT on nuclear physics research. About one-third of the attendees come from abroad, demonstrating the international stature of the Institute and its world leadership.

There are several major impacts of the INT operations. The first is that it fosters collaboration among researchers. These collaborative efforts, often multidisciplinary in nature, would not arise without the opportunity to spend an extended time focusing on specialty topics in an intellectually stimulating environment. A second major impact is the training of young people. Of the postdoctoral researchers who have been associated with the Institute over the last seven years, seven are now in academic positions and three more have staff positions at national laboratories. There are additional faculty, postdocs, and students in the local University of Washington nuclear theory group who synergistically interact with the INT activities, providing additional student and postdoctoral training. The third major impact is the work of the research group associated with the INT. The senior members of this group have a significant international stature and play a scientific leadership role both in their research work and in activities serving the scientific community.

For 2001, the three programs planned or underway are: “Correlations in Nucleons and Nuclei”; “Neutron Stars”; and “Lattice QCD and Hadron Phenomenology”. In addition, there are three workshops: “RHIC-INT Workshop 2001”; “Theories of Nuclear Forces and Few-Nucleon Systems”; and “Computing $\sigma(DD \rightarrow \alpha\pi^{o})$ and Charge Symmetry Breaking.” These topics are at the core of modern nuclear physics, and the list displays an impressive breadth of scientific purview.

Medium Energy Nuclear Physics

Mission Supporting Goals and Objectives

The Nuclear Physics program supports the basic research necessary to identify and understand the fundamental features of atomic nuclei and their interactions. The Medium Energy Nuclear Physics subprogram supports fundamental research that is ultimately aimed at achieving a quantitative understanding of the structure of the atomic nucleus in terms of the quarks and gluons, the objects that are believed to be the building blocks of the sub-atomic particles. Equally important is the achievement of an understanding of the "strong force," one of the four fundamental forces in nature, and the force that holds the nucleus of the atom together. Presently, the program supports different experimental approaches to gaining this knowledge: (1) determining the internal quark structure by electron scattering, (2) determining dynamic degrees of freedom by measuring the excited states of hadrons, (3) measuring the effects of the quark and gluon polarizations within the nucleon, and (4) determining the role of the "sea" of virtual quarks and gluons which also contributes to the properties of protons and neutrons. Measurements are normally carried out with beams of electrons or protons whose intrinsic spins have all been lined up in the same direction (polarized beams) to determine what role the intrinsic spins of the quarks and gluons play in the structure of the nucleon. In addition, the program supports research in understanding the structure of light nuclei and studies directed at testing fundamental symmetries. Most of this work is done at the primary research facility, Thomas Jefferson National Accelerator Facility (TJNAF), but the program also supports research at the Bates Linear Accelerator Center, the Relativistic Heavy Ion Collider at Brookhaven, the Stanford Linear Accelerator Center, Fermilab, and at several facilities in Europe. These facilities produce beams of sufficient energy (small enough wavelength) that they can probe at a scale within the size of a proton or neutron.

The two national user facilities, TJNAF and MIT/Bates, supported in Medium Energy Nuclear Physics, serve a nationwide community of about 300 Department of Energy and about 300 National Science Foundation supported scientists and students from over 140 American institutions, of which over 80% are colleges and universities. Both facilities provide major contributions to education at all levels. At both TJNAF and Bates, the National Science Foundation (NSF) has made a major contribution to new experimental apparatus in support of the large number of NSF users. A significant number of foreign scientists collaborate in the research programs of both facilities. The research program at the TJNAF, for example, involves about 300 scientists per year from 19 foreign countries; many of these scientists are from Conseil Europeen pour la Recherche Nucleaire (CERN) member states. At TJNAF, foreign collaborators have also made major investments in experimental equipment.

Funding Schedule

	(dollars in thousands)				
	FY 2001	FY 2002	FY 2003	$ Change	% Change
Research					
University Research	16,506	15,300	15,575	+275	+1.8%
National Laboratory Research	15,357	15,980	16,815	+835	+5.2%
Other Research	457	5,415	5,405	-10	-0.2%
Subtotal, Research	32,320	36,695	37,795	+1,100	+3.0%
Operations					
TJNAF Operations	66,666	67,515	72,513	+4,998	+7.4%
Bates Operations	12,973	12,425	13,282	+857	+6.9%
Other Operations	1,451	875	0	-875	--
Subtotal, Operations	81,090	80,815	85,795	+4,980	+6.2%
Total, Medium Energy Nuclear Physics	113,410	117,510	123,590	+6,080	+5.2%

Detailed Program Justification

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
Research	**32,320**	**36,695**	**37,795**
▪ **University Research**	**16,506**	**15,300**	**15,575**

These activities comprise a broad program of research, and include 43 grants at 35 universities in 17 states and the District of Columbia in support of about 165 scientists and 110 graduate students. These research efforts utilize not only each of the accelerator facilities supported under the Medium Energy program, but also use other U.S. and foreign accelerator laboratories. Included in University Research is Bates Research, the effort performed at the MIT/Bates Linear Accelerator Center by MIT scientists. Other University Research includes all other university-based efforts using many research facilities, including activities by MIT scientists that are not carried out at Bates.

▸ **Bates Research**	**3,985**	**2,520**	**2,835**

MIT scientists along with other university researchers have completed “mirror-symmetry violation” studies on the proton and deuteron in the North Experimental Hall. The experiment (SAMPLE) provides important information on the quark flavor contribution to the proton's spin magnetism.

Preparations are being made for a new program of research to study the structure of the nucleon and the nature of the nucleon-nucleon force, utilizing the new Bates Large Acceptance Spectrometer Toroid (BLAST) detector. Funding in FY 2003 is increased to effectively carry out the Bates research program. **Performance will be measured by** the initiation of measurements with BLAST on schedule in FY 2002 using thin gas targets and the high current circulating electron beam in the South Hall Pulse Stretcher Ring.

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
▸ **Other University Research**	**12,521**	**12,780**	**12,740**

In FY 2003 university research funds are about constant compared to FY 2002. The highest priority university research supports the activities associated with our main facilities at TJNAF, RHIC, and Bates. At the FY 2003 funding level, a shift in support from lower priority activities will be necessary to properly support these high priority activities. University scientists are collaborating on important ongoing and future experiments at TJNAF. These experiments are largely focused on the study of nucleon structure and its internal dynamics. Planned measurements in Hall A include the electric form factor of the proton and new parity-violation measurements to look for the "strange quark" content of the proton. New, higher-resolution measurements of the ratio of the electric to magnetic form factors of the proton are scheduled. Plans are also underway to carry out a new program of hypernuclear spectroscopy in Hall A in cooperation with researchers from Japan who will provide a new high-resolution spectrometer. A series of studies of the excited states of the proton will continue in Hall B. In Hall C, the newly constructed "G0" experiment will be commissioned in FY 2002 and begin experimental runs in FY 2003. "G0" will allow a "complete mapping" of the strange quark content of the nucleon using parity-violation techniques.

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. BLAST will be used to perform precision polarization measurements of the proton and nuclear structure measurements on light nuclei. It will also be used to measure critical cross sections to improve our understanding of the oxygen-carbon cycle in stellar burning.

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 presently carried out by the HERMES (HERa MEasurements with Spin) experiment at the DESY laboratory in Hamburg, Germany will be reduced as the RHIC-spin physics program grows.

Supported also are university researchers involved in polarization experiments conducted at the SLAC (Stanford Linear Accelerator Center) facility, aimed at making a precise determination of the weak mixing angle, an important fundamental parameter of the Standard Model of Particle Physics, and fundamental measurements at the Paul Scherrer Institute in Switzerland to measure the proton charge radius using muons captured in atomic orbits.

▪ **National Laboratory Research**..	**15,357**	**15,980**	**16,815**

Included is: (1) the research supported at the Thomas Jefferson National Accelerator Facility (TJNAF), that houses the nation's, and the world's, unique 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.

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
▸ **TJNAF Research**	**5,746**	**5,770**	**5,945**

Scientists at TJNAF, with support of the user community, assembled the large and complex new experimental apparatus for Halls A, B, and C. TJNAF scientists provide experimental support and operate the apparatus for safe and effective utilization by the user community. TJNAF scientists participate in the laboratory's research program, and collaborate in research at other facilities.

As of FY 2002, Hall A will have completed 20 experiments and Hall C will have completed 18. The complex large-acceptance spectrometer in Hall B will have completed 65% of the data taking for 41 experiments. TJNAF researchers participate in all of these experiments.

TJNAF scientists are participating in the assembly of a new detector for the G0 experiment, in cooperation with the National Science Foundation (NSF contribution of $3,605,000) for combined TEC of $7,570,000. The G0 detector will map out the contribution of the strange quark to the nucleon; it will be commissioned in FY 2002.

▸ **Other National Laboratory Research**.........................	**9,611**	**10,210**	**10,870**

Support for researchers at National Laboratories is increased by 6.5% relative to FY 2002 levels to address forefront science at accelerator and non-accelerator facilities. These activities include:

Argonne National Laboratory scientists are pursuing research programs at TJNAF, at the DESY Laboratory in Germany, and have proposed measurements of the quark structure of the nucleon at the new Main Injector at Fermilab. The theme running through this entire effort is the search for a detailed understanding of the internal quark-gluon structure of the nucleon. They have also made important advances in the technique of Atom Trap Trace Analysis to be used in measurements of rare isotopes for precision studies of nuclear structure and a measurement of the integrated solar neutrino flux over a long time scale (approximately one million years).

At Brookhaven National Laboratory, the Medium Energy Research group, which in previous years has concentrated on hadron beam experiments at the AGS, has changed its major emphasis to “RHIC Spin”. This is the set of experiments planned for RHIC that will use colliding polarized proton beams to investigate the spin content of the nucleon and, in particular, what role gluons play. In FY 2002-2003, additional funding is being provided to this group to assure that appropriate scientific effort has been assembled in support of the RHIC Spin effort.

Also at Brookhaven, Laser Electron Gamma Source (LEGS) scientists will be utilizing a new spectrometer and a recently-developed polarized “ice” target for a program of spin physics at low energies. This unique facility produces its polarized “gammas” by back scattering laser light from the circulating electron beam at the National Synchrotron Light Source (NSLS). In FY 2003, the research program utilizing the new equipment will commence.

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003

At Los Alamos National Laboratory, scientists and collaborators have developed 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 Booster Neutrino Experiment (BooNE), uses neutrinos generated from the Fermi National Accelerator Laboratory Booster proton beam; data collection is planned to commence in FY 2002.

Los Alamos scientists also are involved in experiments at Fermilab and at RHIC (RHIC Spin) that will probe the structure of the virtual quark "sea" of 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.

	FY 2001	FY 2002	FY 2003
▪ **Other Research**	**457**	**5,415**	**5,405**

In FY 2001 $4,273,000 was transferred to the SBIR program and $466,000 was transferred to the STTR program. This section includes $4,403,000 for SBIR and $479,000 for STTR in FY 2002 and $4,346,000 for SBIR and $510,000 for STTR in FY 2003 and other established obligations that the Medium Energy Nuclear Physics subprogram must meet.

	FY 2001	FY 2002	FY 2003
Operations	**81,090**	**80,815**	**85,795**
▪ **TJNAF Operations**	**66,666**	**67,515**	**72,513**

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.

	FY 2001	FY 2002	FY 2003
▸ **TJNAF Accelerator Operations**	**42,790**	**42,910**	**46,413**

Funding for accelerator operations in FY 2003 supports a 4,200 hour (28-week) running schedule. In FY 2001, the accelerator routinely delivered beams of differing energies and currents simultaneously to the three experimental halls. A maximum beam energy of 5.7 GeV has been delivered to experiments. High current, high polarization beam capability is now also available and is being used for experiments.

	(hours of beam for research)		
	FY 2001	FY 2002	FY 2003
TJNAF	4180	3900	4200

Funding of $500,000 is provided for R&D for the proposed upgrade of CEBAF to 12 GeV. AIP funding includes polarized injector and beam handling components as well as other additions and modifications to the accelerator facilities. GPP funding is provided for minor new construction and utility systems.

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
▸ **TJNAF Experimental Support**....................................	**23,876**	**24,605**	**26,100**

Operating and equipment funding is provided for the experimental support needed to effectively carry out the TJNAF experimental program.

Support is increased by $1,495,000 (6.0%) 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.

The G0 detector, a major item of equipment with a Total Estimated Cost of $7,570,000 has been assembled. DOE's contribution was $3,965,000 and the National Science Foundation contributed $3,605,000 to this detector. With G0 fabrication completed in FY 2002, TJNAF is shifting their base capital equipment towards assembly and installation of ancillary equipment items such as polarized targets for experimental Halls A, B, 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. **Performance will be measured by** the completion of fabrication, commissioning and initiation of measurements with the G0 detector in FY 2002.

▪ **Bates Operations**	**12,973**	**12,425**	**13,282**

Funding is provided to support accelerator operations at the MIT/Bates Linear Accelerator Center.

Bates Operations in FY 2003 will be focused on the initiation of the research program of the BLAST detector completed in FY 2002. The new BLAST detector will observe collisions in thin gas targets located on the South Hall Pulse Stretcher Ring. **Performance will be measured by** the commissioning of the BLAST detector and the initiation of its research program in FY 2003. When the scientific program of BLAST commences, the Bates research effort will concentrate on this new experimental facility. Upon completion of the BLAST research program in FY 2004, it is now planned that the Bates facility will begin a two-year phaseout. Starting in FY 2005, Decontaminating and Decommissioning (D&D) activities will be initiated. The D&D cost and schedule will be determined at that time.

	(hours of beam for research)		
	FY 2001	FY 2002	FY 2003
Bates...	1800	2100	2700

Accelerator operations in FY 2003 are funded at a level to provide the needed beams to carry out the research program in the South Hall Ring using the BLAST detector. Capital Equipment and AIP funding is maintained at the FY 2002 level to support maintenance of the accelerator and experimental facilities.

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
▪ **Other Operations**	**1,451**	**875**	**0**

Operation of the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory for a limited target program is terminated.

Total, Medium Energy Nuclear Physics	**113,410**	**117,510**	**123,590**

Explanation of Funding Changes from FY 2002 to FY 2003

	FY 2003 vs. FY 2002 ($000)
Research	
▪ **University Research**	
▸ The MIT/Bates research support (+12.5% over FY 2002) is provided to effectively carry out the Bates research program whose focus is the new BLAST detector.	+315
▸ Research support at Other Universities is slightly decreased (0.3%). Lower priority activities will be phased out in order to maintain manpower and focus efforts on the high priority activities at TJNAF, RHIC-Spin, and Bates.	-40
Total, University Research	+275
▪ **National Laboratory Research**	
▸ Funding for TJNAF and other National Laboratory groups is increased by about 4%. Resources will be directed to maintaining manpower and focus on the high-priority activities at TJNAF and RHIC-Spin.	+835
▪ **Other Research**	
▸ Estimated SBIR/STTR and other obligations decrease	-10
Total Research	+1,100
Operations	
▪ **TJNAF Operations**	
▸ **TJNAF Accelerator Operations:** Funding for accelerator operations is increased by about $3,413,000 (+8.3%) relative to FY 2002 in order to provide a 4200 hour (28 week) running schedule. A decrease of $500,000 for AIP is offset by an increase of $500,000 for R&D for the proposed 12 GeV upgrade of CEBAF. GPP is increased by $90,000 (to $440,000).	+3,503

	FY 2003 vs. FY 2002 ($000)
▸ **TJNAF Experimental Support:** Experimental Support is increased by $1,495,000 in order to provide increased manpower and equipment needed for carrying out the experimental program. Overall Capital Equipment funding ($6,100,000) remains the same as FY 2002.	+1,495
Total, TJNAF Operations	+4,998
▪ **Bates Operations**	
▸ The increased funding for Bates operations increases the running schedule over FY 2002 to carry out research with the new BLAST detector. Bates will provide 2700 beam hours that will be focused on the commissioning of the BLAST detector and the initiation of its research program.	+857
▪ **Other Operations**	
▸ Funding of the operation of the AGS at BNL for producing secondary meson beams for fixed-target experiments is terminated.	-875
Total Operations	+4,980
Total Funding Change, Medium Energy Nuclear Physics	+6,080

Heavy Ion Nuclear Physics

Mission Supporting Goals and Objectives

The Heavy Ion Nuclear Physics subprogram supports research directed at understanding the properties of nuclear matter over the wide range of conditions created in nucleus-nucleus collisions, particularly the predicted phase changes from the liquid to gas state and from normal to quark matter. Using beams of accelerated heavy ions at intermediate bombarding energies, research is focused on the study of the fragmentation of nuclei in highly violent collisions and the flow of nuclear matter in less violent collisions. From such studies of the flow of nuclear matter, one can obtain information regarding the equation of state of nuclear matter; such information is important in understanding the dynamics of supernova explosions. At much higher relativistic bombarding energies, collisions producing hot**,** dense nuclear matter are studied with the goal of observing the deconfinement of normal matter into the quark-gluon plasma. This form of matter is predicted to have been the early phase of the universe, a millionth of a second after the Big Bang. Scientists and students at universities and national laboratories are funded to carry out this research at the DOE supported Relativistic Heavy Ion Collider (RHIC) facility, as well as at the National Science Foundation (NSF) and foreign supported accelerator facilities.

The Heavy Ion Nuclear Physics subprogram supports operation of RHIC at Brookhaven National Laboratory (BNL). This is a unique world-class facility that addresses fundamental questions about the nature of nuclear matter. With it one can study collisions of heavy nuclei at energies over 10 times of that previously available at any other facility in the world, namely at CERN. The RHIC is also the only accelerator facility in the world that provides collisions of polarized protons with polarized protons. From these collisions, important and unique information can be obtained regarding the composition of the gluons that provide the binding of the quarks to make the nucleons, the protons and neutrons that make up the nucleus. The construction of RHIC was completed in August 1999, and first collisions were observed in June 2000. The RHIC facility is utilized by over 1,100 DOE, NSF, and foreign supported researchers. The RHIC experimental program is determined with the guidance of a Program Advisory Committee, consisting of distinguished scientists, that reviews and evaluates proposed experiments and advises the BNL Associate Director for Nuclear and High Energy Physics regarding their merit and scientific priority. Capital Equipment and Accelerator Improvement Project (AIP) funds are provided for additions, modifications, and improvements to the research accelerators and ancillary experimental facilities to maintain and improve the reliability and efficiency of operations, and to provide new experimental capabilities. An annual peer review of the effectiveness of RHIC operations and its research program is conducted by the program.

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.

Funding Schedule

	(dollars in thousands)				
	FY 2001	FY 2002	FY 2003	$ Change	% Change
Research					
University Research	11,776	11,390	11,635	+245	+2.2%
National Laboratory Research	20,760	20,324	21,194	+870	+4.3%
Other Research	0	2,903	3,291	+388	+13.4%
Subtotal, Research	32,536	34,617	36,120	+1,503	+4.3%
Operations					
RHIC Operations	103,991	103,505	117,497	+13,992	+13.5%
Other Operations	15,585	17,496	14,360	-3,136	-17.9%
Subtotal, Operations	119,576	121,001	131,857	+10,856	+9.0%
Total, Heavy Ion Nuclear Physics	152,112	155,618	167,977	+12,359	+7.9%

Detailed Program Justification

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
Research	**32,536**	**34,617**	**36,120**
▪ **University Research**	**11,776**	**11,390**	**11,635**

Support is provided for the research of about 130 scientists and 75 graduate students at 26 universities in 18 states.

– Researchers using primarily the NSF supported National Superconducting Cyclotron Laboratory at Michigan State University, at Texas A&M University, and at foreign facilities in France, Germany, 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.

– Research using relativistic heavy ion beams is 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 now becomes available to study for the first time. The university groups provide core manpower for the operation of and data analysis for the RHIC detectors. There is a $245,000 increase compared to FY 2002 that provides a 2.2% increase in grant funding.

▪ **National Laboratory Research**	**20,760**	**20,324**	**21,194**

Support is provided for the research programs of scientists at five National Laboratories (BNL, LBNL, LANL, LLNL and ORNL). These scientists provide essential manpower for the operations of the RHIC detectors. 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. The 4.2% increase provides an approximate constant level of effort.

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
► **BNL RHIC Research**..	**10,990**	**10,065**	**9,153**

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 2003 with RHIC operating at its design luminosity (collision rate). All four detectors will be capable of discovering signatures of any new forms of nuclear matter in the heavy ion collisions. In FY 2003 funding for capital equipment decreases by $1,012,000 with the completion of projects. The PHENIX muon instrumentation will be fully ready for commissioning. Funding begins for production of modules for the Electromagnetic Calorimeter Enhancement for the STAR RHIC-spin program. Although it is anticipated that this survey work with gold ions will be substantially complete by the end of the FY 2002 run, comparison running with light-ion beams, particularly the deuteron – nucleus collision operation, will not commence before FY 2003.

- The muon instrumentation for PHENIX allows measurement of the yields of muons ("heavy electrons") that probe the early stages of quark-gluon plasma formation will be completed in FY 2002. The Japanese and French are contributing substantial support for the PHENIX muon arms; they are also critical components of the detection systems for measurements in the PHENIX RHIC Spin program.
- The Electromagnetic Calorimeter for STAR provides capability to distinguish electrons from photons, and extends the measurement of particle energy to high energies. The detector system is also a critical component for the RHIC Spin program for STAR. Production of calorimeter modules began in FY 2000 and will be completed in FY 2003. An enhancement to the Electromagnetic Calorimeter, providing additional modules for full coverage of the barrel as well as improved electron/photon discrimination required for the RHIC Spin program, will be initiated in FY 2003.

► **Other National Laboratory Research**.............................	**9,770**	**10,259**	**12,041**

Researchers at LANL, LBNL, LLNL, and ORNL provide leadership in the commissioning of the PHENIX muon arm and the STAR electromagnetic calorimeter, as well as play leadership roles in carrying out the research utilizing these detectors. At LBNL an analysis system for RHIC data, in alliance with the National Energy Research Scientific Computing Center (NERSC), is a major resource for data analysis by the STAR collaboration and at LLNL substantial computing resources are made available for PHENIX data analysis. A 7.0% increase of $638,000 for research groups compared to FY 2002 is provided to help restore approximately constant level of effort for the National Laboratory research effort that has been reduced by steady attrition in recent years. An increase of $1,144,000 for capital equipment is provided for computing and other projects important for the RHIC program.

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
▪ **Other Research**	**0**	**2,903**	**3,291**

In FY 2001 $2,848,000 was transferred to the SBIR program. This section includes $2,903,00 for SBIR in FY 2002 and $3,291,000 for SBIR in FY 2003.

Operations	**119,576**	**121,001**	**131,857**
▪ **RHIC Operations**	**103,991**	**103,505**	**117,497**

The Relativistic Heavy Ion Collider (RHIC) is anticipated to reach nearly full data production capabilities by the end of the planned running period in FY 2002. RHIC is a unique facility whose colliding relativistic heavy ion beams will permit exploration of hot, dense nuclear matter and recreate the transition from quarks to nucleons that characterized the early evolution of the universe. Studies with colliding heavy ion beams provide researchers with an opportunity to explore a new regime of nuclear matter and nuclear interactions that up to now has only been characterized theoretically. Already during the initial brief run in FY 2000, new features were observed in the data, indicating that conditions are favorable for quark-gluon formation and hints of some characteristic signatures of its existence. The flurry of scientific papers that have been published from these initial results has generated much attention in the press. During the FY 2001-FY 2002 running periods, preparations of RHIC for its spin-physics program will continue, with the anticipation that this experimental program will begin in FY 2003.

▸ **RHIC Accelerator Operations**	**75,275**	**76,345**	**86,950**

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. RHIC produced its first collisions in June 2000. Beam time for research increased significantly in FY 2001 with a 13-week operating schedule (1880 hours). FY 2002 funding provides 1,650 hours of beam for research and beam studies and for commissioning operations with polarized protons. FY 2003 funding will support a 22-week schedule (3300 hours) for research. **Performance will be measured by** initiating the first round of experiments with collisions with other ions to compare to results of gold-gold collisions. Capital equipment funding is provided for normal maintenance projects and AIP funding is provided for needed improvement projects. An increase of $400,000 is provided for AIP in order to upgrade the RHIC crygenics system, by replacing turbine oil skids and removing the seal gas compressor, eliminating a single-point failure.

RHIC Operations

	(hours of beam for research)		
	FY 2001	FY 2002	FY 2003
RHIC	1880	1650	3300

	FY 2001	FY 2002	FY 2003
	(dollars in thousands)		
▸ **RHIC Experimental Support**	**28,716**	**27,160**	**30,547**

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) will reach their initial planned potential by FY 2002. About 1,100 scientists and students from 90 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.

	FY 2001	FY 2002	FY 2003
▪ **Other Operations**	**15,585**	**17,496**	**14,360**

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 in meeting its requirement for safe and reliable facilities operation. In FY 2003 funding for GPP remains at the same level as FY 2002 while GPE and other costs are reduced.

	FY 2001	FY 2002	FY 2003
Total, Heavy Ion Nuclear Physics	**152,112**	**155,618**	**167,977**

Explanation of Funding Changes from FY 2002 to FY 2003

	FY 2003 vs. FY 2002 ($000)
Research	
▪ **University Research**	
▸ FY 2003 funding for grants for University Research increases by 2.2%, maintaining a comparable effort to FY 2002. Lower priority activities will be reduced in order to focus efforts on those activities at RHIC identified as providing the most promising physics opportunities.	+245
▪ **National Laboratory Research**	
▸ **BNL RHIC Research:** Research support is increased by $100,000 (1.6%) to effectively carry out research with the enhanced detectors at full luminosity at RHIC. Capital equipment is decreased by $1,012,000.	- 912
▸ **Other National Laboratory Research:** Research support for operations is increased by $638,000 (7.0%) to enhance effort compared to FY 2002. Capital equipment increases by $1,144,000 compared with FY 2002.	+1,782
Total, National Laboratory Research	+870

	FY 2003 vs. FY 2002 ($000)
▪ **Other Research:**	
▸ Estimated SBIR and other obligations increase.	+388
Total, Research	+1,503
Operations	
▪ **RHIC Operations**	
▸ **Accelerator Operations:** An increase of $10,205,000 (+14.0%) in operating funds provides an estimated 3,300 hours for research, providing 1,650 hours more than in FY 2002. An increase of $400,000 is provided for Accelerator Improvement Project funding (to a total of $2,900,000) to a level that can sustain operations.	+10,605
▸ **Experimental Support:** Funding is increased by $2,290,000 (+9.5%) compared to FY 2002. An increase of $1,097,000 is provided in capital equipment to support operations at full luminosity.	+3,387
Total, RHIC Operations	+13,992
▪ **Other Operations**	
▸ FY 2003 funding for General Plant Projects to Brookhaven National Laboratory is approximately constant compared with FY 2002. Funding for General Plant Equipment decreases by $972,000. Other operations decrease by $2,164,000 compared with FY 2002	-3,136
Total, Operations	+10,856
Total Funding Change, Heavy Ion Nuclear Physics	+12,359

Low Energy Nuclear Physics

Mission Supporting Goals and Objectives

The Low Energy Nuclear Physics subprogram supports research directed at understanding the structure of nuclei, nuclear reaction mechanisms, and experimental tests of fundamental symmetries, including neutrino oscillations. 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. 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. 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 that 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 1996 NSAC 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 ongoing 2001 NSAC long-range planning process is identifying RIA as the highest priority for a major new construction project. Starting in FY 2000, R&D activities have been supported in preparation for a request for approval for construction. Continued pre-conceptual funding for these R&D activities is supported in FY 2003.

The research of this subprogram is generally conducted using beams provided by accelerator facilities either operated by this subprogram or at other domestic or foreign facilities. The Low Energy Nuclear Physics subprogram supports the operation of three national user facilities: the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory, the Argonne Tandem Linac Accelerator System (ATLAS) facility at Argonne National Laboratory, and the 88-Inch Cyclotron facility at the Lawrence Berkeley National Laboratory. These facilities are utilized by DOE-, NSF-, and foreign-supported researchers whose experiments undergo peer review prior to approval for beam time. 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, about 15-25 graduate students at different stages of their education, and historically has produced a large fraction of the 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, as 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 study of neutrinos from the sun is an example. The Sudbury Neutrino Observatory (SNO) detector is studying the production rate and properties of solar neutrinos. The Kamioka Large Anti-Neutrino Detector (KamLAND) will study the properties of anti-neutrinos produced by nuclear power reactors. Both of these experiments address the important and interesting question of whether neutrinos have a mass. The answer to this very fundamental question has profound implications for our understanding of the basic building blocks of matter and the evolution of the universe, and the dynamics of "core collapse" supernovae.

Funding Schedule

	(dollars in thousands)				
	FY 2001	FY 2002	FY 2003	$ Change	% Change
Research					
University Research	17,856	16,849	17,591	+742	+4.4%
National Laboratory Research	20,017	19,883	20,044	+161	+0.8%
Other Research	3,044	3,830	4,743	+913	+23.8%
Subtotal Research	40,917	40,562	42,378	+1,816	+4.5%
Operations	21,733	21,860	23,780	+1,920	+8.8%
Total, Low Energy Nuclear Physics	62,650	62,422	66,158	+3,736	+6.0%

Detailed Program Justification

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
Research	**40,917**	**40,562**	**42,378**
▪ **University Research**	**17,856**	**16,849**	**17,591**

Support is provided for the research of 140 scientists and 90 graduate students at 29 universities in 21 states. Nuclear Physics university scientists perform research as user groups 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 and the production mechanisms of the chemical elements in stars and supernovae. FY 2003 funding for university accelerator facilities, and for researchers and students is increased by ~3.6% compared to FY 2002. Funding for capital equipment projects is increased by $189,000. Research activities include:

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003

- 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, LBNL – 88-Inch Cyclotron 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 which 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**..	**20,017**	**19,883**	**20,044**

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**............	**14,394**	**13,851**	**14,455**

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 2002 the three user facilities support 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 undergoing commissioning and initiating its first experiments.

– At ANL the research focuses on the use of stable and selected radioactive beams from ATLAS, coupled to ion traps and the Fragment Mass Analyzer to study fundamental processes and properties of nuclei, and to study nuclei at the extremes of isotope stability. Studies are undertaken with traps to measure atomic masses with high precision and search for effects in beta decay outside the standard decay model. The Advanced Penning Trap is being commissioned and tested.

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003

– At LBNL the research focuses on the use of stable beams from the 88-Inch Cyclotron with Gammasphere and the Berkeley Gas-filled Spectrometer (BGS) to study nuclei at high angular momentum and deformation, and the heaviest of elements. The world-leading effort to search for and characterize new very heavy elements and isotopes will continue. Conceptual design of a high-sensitivity gamma-ray tracking detector, 1000 times more sensitive than Gammasphere, is continuing. Test modules, electronics and data analysis algorithms are undergoing development.

	FY 2001	FY 2002	FY 2003
▸ **Other National Laboratory Research**........................	**5,623**	**6,032**	**5,589**

Scientists at BNL, LBNL, LLNL and LANL play important roles in a number of high-priority accelerator- and non-accelerator-based experiments directed towards fundamental questions. These 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, the first results from SNO were reported, indicating strong evidence for neutrino oscillations. In FY 2001, the second phase of the SNO experiment began. This phase measures neutrino types to which the solar neutrino have been transformed; preliminary results from this phase are possible in late FY 2002.

– The KamLAND experiment in Japan will measure the rate and properties of anti-neutrinos produced by several distant nuclear power reactors in an attempt to establish and measure the mass of the neutrino. Although KamLAND is less sensitive than SNO to the variety of neutrino oscillations it has the advantage of comparing the measured fluxes to known sources. **Performance will be measured** by the collection of first data with the KamLAND detector in FY 2003.

– 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.

	FY 2001	FY 2002	FY 2003
▪ **Other Research**..	**3,044**	**3,830**	**4,743**
▸ **RIA R&D Activities**...	**2,844**	**2,800**	**3,500**

Funds are provided for R&D and pre-conceptual design activities directed at the development of an advanced 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 2001 Nuclear Science Advisory Committee (NSAC) Long Range Plan as a compelling scientific opportunity and as the highest priority for new construction. The proposed RIA facility is a new paradigm for producing intense beams of very short-lived nuclei that emerged from the 1998 NSAC Taskforce study involving international experts. 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

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003

phenomena. The increased funding for FY 2003 supports some of the needed R&D activities in both critical accelerator components and detector development. **Performance will be measured** by the demonstration of the fast ion gas catcher at full beam energy, a critical capability for RIA.

▸ **SBIR and Other**	**200**	**1,030**	**1,243**

In FY 2001 $639,000 was transferred to the SBIR program. This section includes $655,000 for SBIR in FY 2002 and $868,000 for SBIR in FY 2003 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.

Operations	**21,733**	**21,860**	**23,780**

Support has been provided for the operation of three National User Facilities, the Argonne Tandem-Linac Accelerator System (ATLAS) at ANL, the 88-Inch Cyclotron facility at LBNL and the Holifield Radioactive Ion Beam Facility (HRIBF) at ORNL, for studies of nuclear reactions, structure and fundamental interactions.

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.

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.

The 88-Inch Cyclotron facility provides primarily stable heavy-ion beams for research. Gammasphere and the Berkeley Gas-filled Spectrometer provide world-class instruments to study rapidly spinning nuclei, and search for and characterize the heaviest of elements and isotopes. An innovative BEARS (Berkeley Experiments with Accelerated Radioactive Species) system has been developed to provide selected light radioactive-ion beams for experiments.

Included in the funding shown are Capital Equipment and Accelerator Improvement Project (AIP) funds provided to each of the operating facilities for the enhancement of the accelerator systems and experimental equipment.

In FY 2003 these low energy facilities will carry out about 100 experiments involving over 360 U.S. and foreign researchers. Planned beam hours for research are indicated below:

	(hours of beam for research)		
	FY 2001	FY 2002	FY 2003
Total beam hours for research	12,175	9,500	10,500

Total, Low Energy Nuclear Physics	**62,650**	**62,422**	**66,158**

Explanation of Funding Changes from FY 2002 to FY 2003

	FY 2003 vs. FY 2002 ($000)
Research	
▪ **University Research**	
► FY 2003 funding for researchers and students is increased by 3.6% from FY 2002. Priority will be given to effectively operating the university accelerator facilities, utilizing the national user facilities, and supporting those activities where recent investments have been made, such as SNO and KamLAND. Funding for equipment also increases by $189,000 compared to FY 2002 with the continuation of the HIγS (High Intensity Gamma Source) upgrade at TUNL.	+742
▪ **National Laboratory Research**	
► **National User Facilities Research:** FY 2003 funding provides an increase of about 4.4% to enhance research efforts and activities at the three user facilities.	+604
► **Other National Laboratory Research**: Research funding is about constant compared to FY 2002. Manpower and effort will be focused on the high priority activities at the national user facilities, SNO and KamLAND. Equipment funds are reduced by $454,000 as projects are completed with no new starts.	-443
Total, National Laboratory Research	+161
▪ **Other Research**	
► **RIA R&D:** In FY 2003 $3,500,000 is provided for R&D activities directed at the development of an advanced Rare Isotope Accelerator (RIA) facility. The R&D funding is directed at projects identified in a 3-year R&D plan that has been developed for work that will be performed at ANL, LANL, LBNL, LLNL, ORNL, TJNAF and Michigan State University.	+700
► **SBIR and Other:** Estimated SBIR and other obligations increase slightly.	+213
Total, Other Research	+913
Total Research	+1,816
Operations	
▪ In FY 2003 operations are increased by 8.8% compared to FY 2002 to operate the three user facilities providing an increase in an estimated 1,000 hours of beam time for research. Funding for capital equipment and accelerator improvement projects to support these operations increases by $70,000 (+1.7%).	+1,920
Total Funding Change, Low Energy Nuclear Physics	+3,736

Nuclear Theory

Mission Supporting Goals and Objectives

Progress in nuclear physics, as in any science, depends critically on improvements in the theoretical techniques and on the development of new insights that will lead to a theoretical foundation that can be used to predict and interpret experimental results. The goal of the Nuclear Theory subprogram is to make such progress in understanding the characteristics of atomic nuclei and nuclear matter and the fundamental forces involved, utilizing the new results that come from the experimental programs discussed previously and new capabilities that become available.

There are three major frontiers in nuclear theory today. The first involves understanding the properties and behavior of nuclei. In the past, significant progress had been made from the development of theoretical models that view nuclei as interacting ensembles of protons and neutrons. This paradigm of the nucleus is now being revolutionized as new calculational and conceptual tools are being developed which permit microscopic calculations that previously had not been possible. Similarly, collective models, in which the nucleus is treated as a drop of fluid or in which pairs of neutrons or protons are treated as single particles, have achieved great success in describing many aspects of nuclear behavior too complicated to treat with protons and neutrons. With the possibility of new experimental results for nuclei far from stability from studies with radioactive beams, there is hope for developing a "standard model" for nuclei that is applicable across the periodic table. With the establishment of Quantum ChromoDynamics as the fundamental theory of the strong nuclear interaction, a second frontier of nuclear theory is to understand nuclei and the nucleon in terms of their constituent quarks and gluons. This goal is pursued through scientific investigations at the Thomas Jefferson National Accelerator Facility (TJNAF). The third major frontier of nuclear theory is to understand the properties of hot, dense nuclear matter, the central topic of research at the Relativistic Heavy Ion Collider (RHIC). Various approaches from nuclear theory have recently been applied to nuclear astrophysics topics such as supernova explosions, nucleosyntheses of the elements, and properties of neutrinos from the sun, as well as topics from fundamental symmetry investigations.

The Nuclear Theory subprogram supports research carried out at universities and National Laboratories. Some of the investigations depend crucially on access to forefront computing, and to the development of efficient algorithms to use these forefront devices. A very significant component of the program is the Institute for Nuclear Theory (INT), where there is an ongoing series of special topic programs and workshops that includes experimentalists. The Institute is a seedbed for new collaborations, ideas, and directions in nuclear physics.

The program is greatly 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 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 and particle physics.

Included in this 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.

Funding Schedule

	(dollars in thousands)				
	FY 2001	FY 2002	FY 2003	$ Change	% Change
Theory Research					
University Research	11,797	10,475	11,045	+570	+5.4%
National Laboratory Research	6,948	8,120	8,590	+470	+5.8%
Subtotal Theory Research	18,745	18,595	19,635	+1,040	+5.6%
Nuclear Data Activities	4,877	4,890	5,010	+120	+2.5%
Total, Nuclear Theory	23,622	23,485	24,645	+1,160	+4.9%

Detailed Program Justification

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
Theory Research	**18,745**	**18,595**	**19,635**
▪ **University Research**	**11,797**	**10,475**	**11,045**

The research of about 160 university scientists and 85 graduate students is supported through 54 grants at 41 universities in 25 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 postdoc support is a major element of this program.

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.

	FY 2001	FY 2002	FY 2003
▪ **National Laboratory Research**	**6,948**	**8,120**	**8,590**

Research programs are supported at six National Laboratories (ANL, BNL, LANL, LBNL, ORNL and TJNAF).

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

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003

- Funding is provided for new activities to model and calculate complex astrophysical nuclear processes, for example, in stellar supernovae explosions, and the quark/gluon-based structure of nuclei using "lattice gauge" techniques. Both efforts require investments in new computational modeling and simulation research and show great promise in pushing our understanding of the physics of these disciplines to new levels.

	FY 2001	FY 2002	FY 2003
Nuclear Data	**4,877**	**4,890**	**5,010**

The Nuclear Data program collects, evaluates, archives, and disseminates information on nuclear properties and reaction processes for the community and the nation. The focal point for its national and international activities is at the DOE-managed National Nuclear Data Center (NNDC) at Brookhaven National Laboratory.

The NNDC relies on the U.S. Nuclear Data Network (USNDN), a network of DOE supported individual nuclear data professionals located in universities and at other 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).

	FY 2001	FY 2002	FY 2003
Total, Nuclear Theory	**23,622**	**23,485**	**24,645**

Explanation of Funding Changes from FY 2002 to FY 2003

	FY 2003 vs. FY 2002 ($000)
University Research	
FY 2003 funding level is increased by 5.4 % compared to FY 2002. This provides increased funding for students and focused funding for priority targeted research.	+ 570
National Laboratory Research	
FY 2003 funding level is increased by 5.8% compared to FY 2002. This will permit retention of productive researchers in existing groups and a minimal expansion of priority targeted research.	+ 470
Nuclear Data	
FY 2003 funding level is increased by 2.5% compared to FY 2002. Lower priority activities will be phased out in order to maintain manpower in the higher priority activities.	+120
Total Funding Change, Nuclear Theory	+1,160

Capital Operating Expenses & Construction Summary

Capital Operating Expenses

(dollars in thousands)

	FY 2001	FY 2002	FY 2003	$ Change	% Change
General Plant Projects	7,104	6,439	6,560	+121	+1.9%
Accelerator Improvement Projects	5,419	5,450	5,400	-50	-0.9%
Capital Equipment	31,505	30,162	30,220	+58	+0.2%
Total, Capital Operating Expenses	44,028	42,051	42,180	+129	+0.3%

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

(dollars in thousands)

	Total Estimated Cost (TEC)	Prior Year Approp-riations	FY 2001	FY 2002	FY 2003 Request	Accept-ance Date
PHENIX Muon Arm Instrumentation	12,897	11,535	1,362	0	0	FY 2002
BLAST Large Acceptance Detector	5,200	4,000	1,200	0	0	FY 2001
STAR EM Calorimeter	8,600	2,100	2,897	3,000	603	FY 2003
STAR EM Calorimeter Enhancement	4,700	0	0	0	2,400	FY 2004
G0 Experiment Detector	3,965	2,890	1,016	59	0	FY 2002
Total, Major Items of Equipment		20,525	6,475	3,059	3,003	