Nuclear Physics

Overview

One of the enduring mysteries of the universe is the nature of matter—what are its basic constituents and how do they interact to form the properties we observe? The largest contribution by far to the mass of the matter we are familiar with comes from protons and heavier nuclei. The mission of the Nuclear Physics (NP) program is to discover, explore, and understand all forms of nuclear matter. Although the fundamental particles that compose nuclear matter—quarks and gluons—are themselves relatively well understood, exactly how they interact and combine to form the different types of matter observed in the universe today and during its evolution remains largely unknown. Nuclear physicists seek to understand not just the familiar forms of matter we see around us, but also exotic forms such as those which existed in the first moments after the Big Bang and that exist today inside neutron stars, and to understand why matter takes on the specific forms now observed in nature.

Nuclear physics addresses three broad, yet tightly interrelated, scientific thrusts: **Quantum Chromodynamics (QCD)**, **Nuclei and Nuclear Astrophysics**, and **Fundamental Symmetries** that can be probed by studying neutrons and nuclei.

- **QCD** seeks to develop a complete understanding of how the fundamental particles that compose nuclear matter, the quarks and gluons, assemble themselves into composite nuclear particles such as protons and neutrons, how nuclear forces arise between these composite particles that lead to nuclei, and what forms of bulk, strongly interacting matter can exist in nature, such as the quark-gluon plasma.
- **Nuclei and Nuclear Astrophysics** seeks to understand how protons and neutrons combine to form atomic nuclei, including some now being observed for the first time, and how these nuclei have arisen during the 13.8 billion years since the birth of the cosmos.
- **Fundamental Symmetries** seeks to develop a better understanding of fundamental interactions by studying the properties of neutrons and by targeted, single focus experiments using nuclei to study whether the neutrino is its own anti-particle. Neutrinos are very light, nearly undetectable fundamental particles produced during interactions involving the weak force, through which they were first indirectly observed in nuclear beta decay experiments.

The quest to understand the properties of different forms of nuclear matter requires both theoretical and experimental efforts. Theoretical approaches are based on a description of the interactions of quarks and gluons described by the theory of QCD, which employs today's most advanced computers. Other theoretical research that models the forces between nucleons seeks to understand and predict the structure of nuclear matter. Most experimental approaches in nuclear physics use large accelerators that collide particles at nearly the speed of light, producing short-lived forms of matter for investigation. Comparing experimental observations and theoretical predictions tests the limits of our understanding of nuclear matter and suggests new directions for both experimental and theoretical research.

At the heart of the NP program are highly trained scientists who conceive, plan, execute, and interpret transformative experiments. NP supports university and national laboratory scientists and a variety of international collaborations. It provides more than 90 percent of the nuclear science research funding in the U.S. with an average of 85 Ph.D. degrees granted annually to students for research supported by the program. NP research is guided by DOE's mission and priorities, and it helps develop the core expertise needed to achieve the goals of the NP program. National laboratory scientists work and collaborate with academic scientists and other national laboratory experimental and theoretical researchers to collect and analyze data and to construct, support, and maintain the detectors and facilities used in experiments. The national laboratories also provide state-of-the-art resources for targeted detector and accelerator R&D for future upgrades and new facilities. This research develops knowledge, technologies, and scientists to design and build next-generation NP accelerator facilities. It is also of relevance to such machines being developed by other domestic and international programs.

The world-class user facilities and the associated instrumentation necessary to advance the U.S. nuclear science program supported by NP are large and complex, and account for a significant portion of NP's budget. Three scientific user facilities are currently supported, each with unique capabilities: the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL); the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (TJNAF); and the Argonne Tandem Linac Accelerator System (ATLAS) at Argonne National Laboratory (ANL). These facilities provide particle beams for an international user community of 3,000 research scientists. Approximately 38 percent of these researchers are from institutions outside of the U.S. and provide very significant benefits to leverage the U.S.

program through contributed capital, human capital, experimental equipment, and intellectual contributions. Researchers supported by other SC programs (High Energy Physics, Basic Energy Sciences), DOE Offices (National Nuclear Security Administration [NNSA] and Nuclear Energy), Federal agencies (National Science Foundation [NSF], National Aeronautics and Space Administration [NASA], and Department of Defense [DOD]), and industries also use NP scientific user facilities and their core competencies to carry out their research programs. Following completion in FY 2014 of the accelerator upgrade portion of the 12 GeV CEBAF Upgrade project and the successful demonstration in December 2014 of the key performance parameters for the gluonic excitations (GlueX) detector in Hall D, fabrication of the remaining detectors in experimental Halls B and C continues and will be completed in FY 2017. Construction of a world-class nuclear physics scientific user facility with unique capabilities in nuclear structure and astrophysics, the Facility for Rare Isotope Beams (FRIB), continues at Michigan State University (MSU).

Involving students in the development and construction of NP facilities and advanced instrumentation, along with the development of accelerator technology and computational techniques, helps to develop the highly trained workforce needed in the field of nuclear science. In addition to significant advances in discovery science, these facilities and techniques provide collateral benefits such as the creation of new technologies with broad-based applications in industry and society. NP supports short- or mid-term accelerator R&D that is specific to the programmatic needs of its current or planned facilities. In the process, technological advances and core competencies in accelerator science developed by NP are also often relevant to other applications and SC programs. For example, superconducting radio frequency (SRF) particle acceleration developed for NP programmatic missions has provided technological advances for a broad range of applications including materials research, cancer therapy, food safety, bio-threat mitigation, waste treatment, and commercial fabrication. The Office of Science programs coordinate closely on the different types of accelerator R&D activities to exploit synergies.

Highlights of the FY 2017 Budget Request

Support for university and laboratory research in NP increases, continuing the commitment made in FY 2016 to advance high priority research in such areas as nuclear structure, nuclear astrophysics, the study of matter at extreme conditions, hadronic physics, fundamental properties of the neutron, neutrinoless double beta decay, and isotope production and processing techniques. The Request also supports the initiation of the Gamma-Ray Energy Tracking Array (GRETA) Major Item of Equipment (MIE), a premiere gamma-ray tracking device that will exploit world-leading capabilities of FRIB. GRETA was identified by the nuclear science community in the 2007 Long Range Plan as an instrument that will “revolutionize gamma-ray spectroscopy and provide sensitivity improvements of several orders of magnitude.” The high priority and urgency placed upon realizing the advanced capabilities GRETA will provide was reaffirmed by the nuclear science community in the 2015 Long Range Plan for Nuclear Science which was released in October 2015[a]. GRETA is being initiated to exploit the full scientific potential of FRIB, providing unique opportunities to advance the rare-isotope science and investigate reactions of critical importance for nuclear structure and nuclear astrophysics. Although existing detectors enable the start of an initial science program at FRIB, GRETA will enable vast new nuclear structure studies. Funding increases for operations at CEBAF to support initiation of the full scientific program with the recently upgraded 12 GeV machine and new scientific equipment in the experimental halls. Operations of the RHIC facility are increased by 550 hours above the FY 2016 Enacted level to enable studies of spin physics and explorations of new phenomena to illuminate the properties of the quark gluon plasma. Operations of the ATLAS facility continue to exploit the capabilities of the Californium Rare Ion Breeder Upgrade (CARIBU) as well as newly completed instrumentation. Support for the Isotope Development and Production for Research and Applications subprogram (DOE Isotope Program) maintains mission readiness for the production of stable and radioactive isotopes that are in short supply for research and a wide array of applications. Research investments in this subprogram are increased for a new graduate traineeship activity in the fields of radiochemistry and nuclear chemistry with an emphasis in isotope production; and to develop new cutting-edge approaches for important isotopes that are not currently available to the public in sufficient quantities, such as the establishment of a full-scale production capability of the promising alpha-emitter, actinium-225, to enable clinical trials for cancer therapy. An increase in research in isotope production techniques is in line with the recently completed assessment of the DOE Isotope Program by the Nuclear Science Advisory Committee (NSAC)[b]. After several years of research supported by the Isotope Program, funding is requested for an MIE project, the Stable Isotope Production Facility (SIPF), to enable the production of a broad range of enriched stable isotopes, a capability that has not been available in the U.S. for almost 20 years. Finally,

[a] http://science.energy.gov/np/
[b] http://science.energy.gov/np/nsac/reports/

construction continues according to the baselined profile for the FRIB project, which will provide intense beams of rare isotopes for a wide variety of studies in nuclear structure, nuclear astrophysics, and fundamental symmetries. In the FY 2017 Budget Request, funding for the Working Capital Fund (WCF) is transferred to Science Program Direction to establish a consolidated source of funding for goods and services provided by the WCF. An exception is CyberOne, which will continue to be funded through the Office of Science (SC) Safeguards and Security program. In FY 2016 and prior years, SC WCF costs were shared by SC research programs and Science Program Direction.

Nuclear Physics
Funding ($K)

	FY 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request[b]	FY 2017 vs. FY 2016
Medium Energy Nuclear Physics					
Research	35,646	35,429	37,802	40,017	+2,215
Operations	97,050	97,050	98,670	104,139	+5,469
SBIR/STTR and Other	18,196	1,863	19,321	19,643	+322
Total, Medium Energy Nuclear Physics	**150,892**	**134,342**	**155,793**	**163,799**	**+8,006**
Heavy Ion Nuclear Physics					
Research	33,894	33,013	35,822	36,431	+609
Operations	166,072	166,072	172,088	179,700	+7,612
Total, Heavy Ion Nuclear Physics	**199,966**	**199,085**	**207,910**	**216,131**	**+8,221**
Low Energy Nuclear Physics					
Research	48,377	50,764	51,383	54,394	+3,011
Operations	26,819	27,029	27,402	25,499	-1,903
Total, Low Energy Nuclear Physics	**75,196**	**77,793**	**78,785**	**79,893**	**+1,108**
Nuclear Theory					
Theory Research	35,715	35,620	38,033	38,583	+550
Nuclear Data	7,381	7,554	7,742	7,882	+140
Total, Nuclear Theory	**43,096**	**43,174**	**45,775**	**46,465**	**+690**
Isotope Development and Production for Research and Applications					
Research	4,815	4,815	6,033	10,344	+4,311
Operations	15,035	15,035	15,304	19,026	+3,722
Total, Isotopes[c]	**19,850**	**19,850**	**21,337**	**29,370**	**+8,033**
Subtotal, Nuclear Physics	**489,000**	**474,244**	**509,600**	**535,658**	**+26,058**

[a] Reflects the transfer of Small Business Innovation/Technology Transfer Research (SBIR/STTR) funds within the Office of Science.
[b] A transfer of $1,315,000 to Science Program Direction is to consolidate all Working Capital Funds in one program.
[c] All appropriations for the Isotope Development and Production for Research and Applications subprogram fund a payment into the Isotope Production and Distribution Program Fund as required by P.L. 101–101 and as modified by P.L. 103–316.

	FY 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request[b]	FY 2017 vs. FY 2016
Construction					
06-SC-01, 12 GeV CEBAF Upgrade, TJNAF	16,500	16,500	7,500	0	-7,500
14-SC-50, Facility for Rare Isotope Beams	90,000	90,000	100,000	100,000	0
Total, Construction	**106,500**	**106,500**	**107,500**	**100,000**	**-7,500**
Total, Nuclear Physics	**595,500**	**580,744**	**617,100**	**635,658**	**+18,558**

SBIR/STTR:

- FY 2015 Transferred: SBIR: $12,967,000; STTR: $1,789,000
- FY 2016 Projected: SBIR: $14,134,000; STTR: $2,120,000
- FY 2017 Request: SBIR: $15,824,000; STTR: $2,225,000

Nuclear Physics
Explanation of Major Changes ($K)

	FY 2017 vs. FY 2016
Medium Energy Nuclear Physics: Increased funding is provided for the ramp up from commissioning to operations of the upgraded CEBAF to launch the 12 GeV physics program. The focus of the 12 GeV science program is to advance the understanding of strongly interacting matter and its description in QCD, and to search for evidence of new physics beyond the Standard Model. The increase will support 12 GeV researchers from national laboratories and universities to implement, commission, and operate the new experiments at CEBAF.	**+8,006**
Heavy Ion Nuclear Physics: Funding for operations of RHIC is increased to support 550 hours above the FY 2016 Enacted level to enable world-leading research in heavy ion nuclear physics and spin physics, and deferred maintenance. A 3,040 hour run in FY 2017 will enable incisive tests of our understanding of QCD as applied to the spin structure of the proton and to explore new phenomena in quark gluon plasma formation. Targeted increases in research funding support participation in RHIC runs, U.S. commitments in LHC heavy ion computing, and continued modest participation in the heavy ion program at the LHC, including implementation of new experimental capabilities for the heavy ion LHC ALICE detector.	**+8,221**
Low Energy Nuclear Physics: Operations funding for the ATLAS facility is increased to reinstate critical mechanical engineering expertise and support needed for accelerator target development. The ATLAS facility continues to provide critical capabilities for nuclear structure and astrophysics research, with beam time demands from the user community continuing to far exceed availability. Increased research funding is requested for targeted, high priority activities, including development and implementation of instrumentation in nuclear structure and astrophysics at ATLAS and FRIB, and operations support of the KATRIN experiment (an international tritium-beta-decay experiment to determine the mass of the neutrino). The Request includes $500,000 to initiate the Gamma-Ray Energy Tracking Array (GRETA) MIE in FY 2017, a high resolution gamma array tracking device for FRIB to provide a combination of high efficiency, peak-to-background ratio, and excellent energy and position resolution needed to fully exploit the opportunities at FRIB, for both fast fragmentation and reaccelerated beams. GRETA will revolutionize gamma-ray spectroscopy providing more than an order of magnitude increased sensitivity for gamma ray coincidence measurements. It will provide world-unique opportunities to advance the rare-isotope science and investigate reactions of critical importance for nuclear structure and nuclear astrophysics. Disposition activities of the Holifield Radioactive Ion Beam Facility (HRIBF) ramp down.	**+1,108**
Nuclear Theory: The requested increase enhances support for theory research efforts at laboratories and universities, and the U.S. Nuclear Data Program. Increased support is provided for a collaborative theory effort focused on the science at FRIB to promote interpretation of future FRIB experimental results.	**+690**

	FY 2017 vs. FY 2016
Isotope Development and Production for Research and Applications: The Request includes $2,500,000 to initiate the Stable Isotope Production Facility (SIPF), an MIE to cost-effectively provide a domestic capability for production of enriched stable isotopes, building upon the R&D prototype supported by the subprogram to develop new technology for general stable isotope enrichment. This facility will help mitigate dependence of the U.S. on foreign suppliers and is aligned with NSAC recommendations to provide this capability. Many stable isotope supplies are depleted from the national inventory and are needed for important research and security applications. The stable isotope enrichment prototype is operated to enable optimization of future production campaigns and design of the future facility. Isotope research efforts at national laboratories and universities are enhanced, in particular to support R&D efforts on developing full-scale production capabilities of alpha-emitters for medical applications, such as cancer therapy; and a new graduate traineeship activity in the fields of radiochemistry and nuclear chemistry with an emphasis in isotope production is initiated. Mission readiness of the isotope production and processing facilities at Brookhaven, Oak Ridge, and Los Alamos National Laboratories are maintained for isotope production, and production capabilities at university facilities are also supported for research isotopes.	**+8,033**
Construction: FY 2017 construction funding will continue at the same level as the FY 2016 Enacted level for the Facility for Rare Isotope Beams according to the approved baseline profile; these are the peak funding years for this project. The final year of construction funding for the 12 GeV CEBAF Upgrade project was provided in FY 2016.	**-7,500**
Total, Nuclear Physics	**+18,558**

Basic and Applied R&D Coordination
The NP mission supports the pursuit of unique opportunities for R&D integration and coordination with other DOE Program Offices, Federal Agencies, and non-Federal entities. For example, researchers from the High Energy Physics (HEP), NP, and Advanced Scientific Computing Research (ASCR) programs coordinate and leverage forefront computing resources and technical expertise through the Lattice Quantum Chromodynamics (LQCD) and SciDAC projects to determine the properties of as-yet unobserved exotic particles predicted by the theory of Quantum Chromodynamics, advance progress towards a model of nuclear structure with predictive capability, and dramatically improve modeling of neutrino interactions during core collapse supernovae. The U.S. Nuclear Data Program provides evaluated cross-section and decay data relevant to reactor design (e.g., of interest to the Nuclear Energy [NE] and Fusion Energy Sciences [FES] programs), materials under extreme conditions (of interest to the Basic Energy Sciences [BES] and FES programs), and nuclear forensics (National Nuclear Security Administration [NNSA], Department of Homeland Security [DHS], and Federal Bureau of Investigations [FBI]). NP research develops technological advances relevant to the development of advanced fuel cycles for next generation nuclear reactors (NE); advanced cost-effective accelerator technology and particle detection techniques for medical diagnostics and treatment (National Institutes of Health [NIH], HEP); and research in developing neutron, gamma, and particle beam sources with applications in cargo screening and nuclear forensics (NNSA, DHS, and FBI).

R&D coordination and integration are hallmarks of the NP Isotope Development and Production for Research and Applications subprogram (DOE Isotope Program), which produces commercial and research isotopes in short supply and critical for basic research and applications. It also supports research for the development of new or improved production and separation techniques of stable and radioactive isotopes. NP continues to further align the Federal, industrial, and research stakeholders of the DOE Isotope Program and has strong communication between the various communities. To ascertain current and future demands of the research and applied communities, NP organizes working groups, workshops, symposia, and discussions with Federal agencies and community and industrial stakeholders on a continuous basis. It also works collaboratively with other DOE Offices (NNSA and NE) to help ensure adequate supplies of isotopes needed for their missions, such as lithium-7 (Li-7), which is used by nuclear power plants as a coolant reagent. The DOE Isotope Program conducts annual Federal workshops to identify isotope demand and supply across a broad range of Federal agencies (including NIH, NASA, FBI, DOD, DHS, DOT, NSF, and DOE) to ensure that isotopes are available for the federal complex to accomplish its missions.

Program Accomplishments
RHIC engineers the shape of small drops of quark gluon plasma. The quark gluon plasma (QGP), discovered at RHIC, is a state of matter that existed under the extreme conditions that occurred shortly after the Big Bang. In recent experiments, scientists identified flow patterns in the particles coming from very high energy collisions of protons and lead nuclei in LHC data. The results implied that small droplets of QGP were surprisingly being formed in the proton-lead collisions. Utilizing its unique flexibility to collide Helium-3 and deuterium nuclei with gold nuclei, new data from RHIC provides strong evidence that small droplets of QGP can, in fact, be created in lighter systems. The emergent RHIC results provide important information on the size of those droplets, and key information on understanding the conditions needed for forming this exotic form of matter.

New science leadership capabilities enabled by construction of world-class facilities. Following on-budget and ahead-of-schedule completion of the accelerator upgrade portion of the 12 GeV CEBAF Upgrade project at TJNAF in FY 2014, the project is progressing towards completion with the fabrication of new detectors in three separate halls. One of these detectors, the gluonic excitations (GlueX) detector in the newly constructed experimental Hall D, was completed in December 2014, and successfully demonstrated its design performance. The detector is now being calibrated and commissioned in preparation for the launch of the full 12 GeV physics program in FY 2017.

"Coldest cubic meter in the universe." The Cryogenic Underground Observatory for Rare Events (CUORE) is an experiment to search for neutrinoless double beta decay, a rare process that would indicate whether neutrinos are their own antiparticle, which could have a profound effect on the understanding of the dominance of matter over anti-matter in the cosmos. CUORE, located at the Gran Sasso Laboratory in Italy, is an international experiment with strong U.S. participation. A large volume of detectors must be cooled to temperatures just above absolute zero. The thermally insulating detector container, called the CUORE Cryostat and is one cubic meter in volume, recently achieved a temperature of 6 thousandths of a degree Kelvin above absolute zero. At this temperature, the CUORE Cryostat contains the coldest cubic meter volume in the known universe. The cryostat is currently undergoing additional commissioning test runs before initiating measurements to surpass the record setting sensitivity of its predecessor, CUORE-0.

Reactor Antineutrino Anomaly Calculations from the U.S. Nuclear Data Program (USNDP). All nuclear reactors emit antineutrinos resulting from the decay of isotopes produced in the nuclear reactions. Several recent studies of the antineutrinos emitted by nuclear power reactors have suggested that there may be an “anomaly” of roughly 6% in the total measured antineutrino flux, conjectured to possibly provide evidence for “Beyond the Standard Model” physics, such as the existence of a fourth neutrino in addition to the three types currently known. Performing a comprehensive “bottom-up” analysis of the current state of knowledge, USNDP physicists used their extensive databases that store all known properties of all nuclei to calculate the expected reactor antineutrino flux in detail, summing over 800 important unstable secondary nuclei. The initial results suggest that some of the unusual aspects of reactor antineutrino emission may have their origin in previously unknown details of conventional nuclear physics, solving the apparent origin of this intriguing anomaly.

Improved calculations for neutrino scattering off nuclei. Precise theoretical knowledge of the interactions of neutrinos with nuclei is essential to interpreting the results of a suite of next generation experiments. This theoretical work is inherently a nuclear physics endeavor as it relates to interactions which occur within the nuclear medium. A collaboration of ANL, LANL, and Old Dominion University scientists carried out calculations of electron and neutrino interactions with helium-4 and carbon-12 nuclei. The new theoretical calculations are similar for neutrinos and electrons allowing for direct comparisons to electron scattering data to verify the calculations. The calculated helium-4 electron scattering results agree well with experiment and illuminate the essential ingredients that need to be taken into account in reliable calculations of electron and neutrino interactions with nuclei. This leads the way to calculations on heavier nuclei as more computer power becomes available, and will be the key for the interpretation of neutrino-scattering experiments in the future.
Novel method for electron spectroscopy to be applied to neutrino mass determination. Researchers participating in the Project-8 collaboration have made the first observation of radiation from a single electron using a new technique, dubbed Cyclotron Radiation Emission Spectroscopy (CRES). The technique allows precise measurement of the energies of moderately relativistic electrons, such as those emitted in the beta decay of tritium. This success opens a completely different pathway toward a sensitive measurement of neutrino mass. Previous methods have set a laboratory upper limit of 2 eV on the masses of the three neutrino states. Neutrino oscillations set a lower limit of 0.02 eV on their average mass. With further development, the CRES method may be able to improve current limits by a factor of ten, exploring a large part, and perhaps all, of the remaining window for neutrino mass. This research was recently identified as a top ten 2015 physics breakthrough of the year.

Technical feasibility of new production route demonstrated for lithium-7 hydroxide for power reactors. Lithium-7 hydroxide is essential to the safe and reliable operation of pressurized water reactors to produce electricity. The salt is used as a neutralizer to maintain proper alkalinity/acidity of the cooling water in these reactors. Domestic power-plant users are completely reliant upon imports of lithium-7 hydroxide from foreign countries. Unpredictable foreign production capacity and growing demand are increasing the risks that domestic users will be unable to obtain adequate supply. In research funded by the Isotope Program, scientists at ORNL and the Y-12 National Security Complex have demonstrated technical feasibility of a new method of production of highly enriched lithium-7 using an environmentally friendly technology. The feasibility of applying these research results to full-scale production is now being considered.

Nuclear Physics
Medium Energy Nuclear Physics

Description

The Medium Energy Nuclear Physics subprogram focuses primarily on experimental tests of the theory of the strong interaction, known as Quantum Chromodynamics (QCD). According to QCD, all observed nuclear particles, collectively known as hadrons, arise from the strong interaction of quarks, antiquarks, and gluons. The protons and neutrons inside nuclei are the best known examples of hadrons. QCD, although difficult to solve computationally, predicts what hadrons exist in nature, and how they interact and decay. Specific questions addressed within this subprogram include:

- What is the internal landscape of the protons and neutrons (collectively known as nucleons)?
- What does QCD predict for the properties of strongly interacting matter?
- What is the role of gluons and gluon self-interactions in nucleons and nuclei?

Various experimental approaches are used to determine the distribution of up, down, and strange quarks, their antiquarks, and gluons within protons and neutrons, as well as clarifying the role of gluons in confining the quarks and antiquarks within hadrons. Scattering experiments are used to clarify the effects of the quark and gluon spins within nucleons, and the effect of the nuclear environment on the quarks and gluons. The subprogram also supports experimental searches for higher-mass "excited state" and exotic hadrons predicted by QCD, as well as studies of their various production mechanisms and decay properties.

Medium Energy Nuclear Physics supports research and operations of the subprogram's primary research facility, CEBAF at TJNAF, as well as the spin physics research that is carried out using RHIC at BNL. CEBAF provides high quality beams of polarized electrons that allow scientists to extract information on the quark and gluon structure of protons and neutrons from measurements of how the electrons scatter when they collide with nuclei. CEBAF also uses polarized electrons to make precision measurements to search for processes that violate a fundamental symmetry of nature, called parity, in order to search for physics beyond what is currently described by the Standard Model. These capabilities are unique in the world. The increase in beam energy provided by the 12 GeV CEBAF Upgrade opens up exciting new scientific opportunities, and will secure continued U.S. world leadership in this area of physics. The project will be completed in FY 2017, and the highly anticipated science program will be launched. Some of the science goals of the 12 GeV experimental program include the search for exotic new quark anti-quark particles to advance our understanding of the strong force, evidence of new physics from sensitive searches for violations of nature's fundamental symmetries, and a detailed microscopic understanding of the internal structure of the proton, including the origin of its spin, and how this structure is modified when the proton is inside a nucleus. Research at RHIC in FY 2017 using colliding beams of spin-polarized protons, a capability unique to RHIC, will provide information on the origin of the spin of the proton in a kinematic range complementary to that at CEBAF to extend present knowledge beyond the kinematic boundaries accessible at CEBAF alone. Research support for both facilities includes laboratory and university scientific and technical staff needed to implement and execute experiments and to conduct the data analysis necessary to extract scientific results. Complementary special focus experiments that require different capabilities are also supported at the High Intensity Gamma Source (HIGS) at Triangle Universities Nuclear Laboratory, Europe, and elsewhere. Efforts are supported at the Research and Engineering Center of the Massachusetts Institute of Technology (MIT), which has specialized infrastructure used to develop and fabricate advanced instrumentation and accelerator equipment.

The "SBIR/STTR and Other" category within this subprogram provides funding in accordance with the Small Business Innovation Development Act and subsequent related legislation. It also includes funding to meet other NP obligations, such as the annual Lawrence Awards and Fermi Awards for honorees selected by DOE for outstanding contributions to science.

<u>Research</u>

Research groups at TJNAF, BNL, ANL, LANL, and LBNL, and approximately 130 scientists and 105 graduate students at 29 universities will carry out research programs and conduct experiments at CEBAF, RHIC, and elsewhere, and will participate in the development and fabrication of advanced instrumentation, including state-of-the-art detectors that also have applications in areas such as medical imaging instrumentation and homeland security. TJNAF staff research efforts will focus on launching the full 12 GeV experimental program, including the implementation of experiments, acquiring data, and performing data analysis at the four CEBAF experimental Halls A, B, C, and D. Scientists conduct research to advance knowledge and to identify and develop the science opportunities and goals for next generation instrumentation and facilities. An active visiting scientist program at TJNAF and bridge positions with regional universities are also supported as a cost-effective approach to augmenting scientific expertise at the laboratory and boosting research experience opportunities.

ANL scientists play a leadership role in many of the new experiments in the 12 GeV scientific program, and are heavily engaged in experiment commissioning, instrumentation development, and data taking. They also lead an experiment at Fermilab to determine the antiquark contribution to the structure of the proton. ANL scientists continue precise measurements of the electric dipole moments of laser-trapped atoms as part of an intensive world-wide effort to set limits on QCD parameters and contribute to the search for possible explanations of the excess of matter over antimatter in the universe; first measurements were obtained in FY 2015. Research groups at BNL and LBNL play leading roles in determining the spin structure of the proton through data taking and the development and fabrication of advanced instrumentation for RHIC, as well as contributing to data acquisition and analysis efforts. Researchers at MIT and at TJNAF are developing high current, polarized electron sources for next generation NP facilities.

Accelerator R&D research proposals from universities and laboratories specific to improving operations of current NP facilities or developing new NP facilities are evaluated by peer review through a single competition for funding that is included under the Medium Energy and Heavy Ion subprograms.

<u>Operations</u>
CEBAF's polarized electron beam capabilities are used to study the contributions of quarks and gluons to the properties of hadrons by a user community with a strong international component. Accelerator Operations support is provided for the accelerator physicists at TJNAF that operate CEBAF as well as for maintenance, power costs, capital infrastructure investments, and accelerator improvements, as the facility transitions to full operations following the completion of the 12 GeV CEBAF Upgrade project. Investments in accelerator improvements, including the modernization of the accelerator injector components, aim to provide more than an order of magnitude improvement in the beam quality for 12 GeV era parity violating physics experiments. This class of experiments is very sensitive to false asymmetries and imperfections in beam properties in the polarized source and the injector area. Support is provided for the most important efforts in developing advances in superconducting radiofrequency (SRF) technology relevant to improving operations of the existing machine. The core competency in SRF technology plays a crucial role in many DOE projects and facilities outside of nuclear physics (such as the Basic Energy Sciences project LCLS II) and has broad applications in medicine and homeland security. For example, SRF research and development at TJNAF has led to improved land-mine detection techniques and carbon nanotube and nano-structure manufacturing techniques for constructing super-lightweight composites such as aircraft fuselages. TJNAF also has a core competency in cryogenics and has developed award-winning techniques that have led to more cost-effective operations at TJNAF and several other SC facilities; their cryogenics expertise is being applied to the FRIB project and LCLS-II. Accelerator capital equipment investments are targeted toward instrumentation needed to support the laboratory's core competencies in SRF and cryogenics. TJNAF accelerator physicists help train the next generation of accelerator physicists, enabled in part by a close partnership with other institutions with accelerator physics expertise. Experimental Support is provided for the scientific and technical staff as well as for materials and supplies for implementation, integration, assembly, and operation of the large and complex CEBAF experiments. Modest capital equipment investments for experimental support at TJNAF provide scientific instrumentation for the major experiments, including data acquisition computing and supporting infrastructure.

Medium Energy Nuclear Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Medium Energy Nuclear Physics $155,793,000	**$163,799,000**	**+$8,006,000**
Research $37,802,000	**$40,017,000**	**+$2,215,000**
Researchers focused on the 12 GeV experimental program at TJNAF continue to implement and develop experimental instrumentation and prepare for the new Hall D physics capabilities and the 12 GeV experimental program which starts in full in FY 2017. Analysis efforts of RHIC polarized proton beam data to learn more about the origin of the proton's spin, and support for short and mid-term accelerator R&D continues.	The highly anticipated 12 GeV experimental program will be launched at CEBAF, taking data with new instrumentation in all halls, including the newly constructed Hall D. Science goals include the search for exotic new quark anti-quark particles, sensitive searches for violations of nature's fundamental symmetries, and a detailed microscopic understanding of the internal structure of the proton. Researchers will participate in the RHIC spin run in FY 2017 to study the spin structure of the proton.	Increased funding supports the 12 GeV researchers from national laboratories and universities to mount, implement, and operate the new experiments at CEBAF.
Operations $98,670,000	**$104,139,000**	**+$5,469,000**
Funding supports continued machine development, and its associated incremental power costs, to support the full, future 12 GeV research program, including engineering operations to Hall D and commissioning of newly installed hall equipment for physics running starting in FY 2017. Funding is provided for Other Project Costs (within project TPC), as part of the 12 GeV CEBAF Upgrade project profile. The major milestone in FY 2016 is to establish first beams to Halls B and C for commissioning activities.	The newly upgraded CEBAF facility will begin full operations. Funding will support a total of 2,890 hours (about 87% utilization) of running for beam commissioning, tuning and research, including about 330 hours funded from the final year of Other Project Costs as part of the 12 GeV CEBAF Upgrade project profile (within project TPC). Experiments will be implemented and commissioned in all four halls and are operated for data taking.	The increase supports the ramp-up in operating time from commissioning activities in FY 2016 to support of the 12 GeV scientific program in FY 2017, which includes the required operations staff, power costs, materials and supplies, and maintenance activities needed to bring this complex scientific user facility back to full operation mode.
SBIR/STTR and Other $19,321,000	**$19,643,000**	**+$322,000**
Funding is provided in accordance with the Small Business Innovation Development Act and subsequent related legislation, as well as for other DOE and Office of Science obligations.	Funding will be provided in accordance with the Small Business Innovation Development Act and subsequent related legislation, as well as for other DOE and Office of Science obligations.	The increase in SBIR/STTR funding, which reflects the increase in the mandated percentage set-aside from 3.45% to 3.65% in FY 2017, is partially offset by the transfer of $1,315,000 to Science Program Direction to consolidate funding for the Working Capital Fund.

Nuclear Physics
Heavy Ion Nuclear Physics

Description

The Heavy Ion Nuclear Physics subprogram focuses on studies of nuclear matter at extremely high densities and temperatures, directed primarily at answering the overarching questions within the Quantum Chromodynamics (QCD) scientific thrust, including:

- What are the phases of strongly interacting matter, and what roles do they play in the cosmos?
- What governs the transition of quarks and gluons into pions and nucleons?
- What determines the key features of QCD and their relation to the nature of gravity and space-time?

At the Relativistic Heavy Ion Collider (RHIC) facility, scientists continue to pioneer the study of condensed quark-gluon matter at the extreme temperatures characteristic of the infant universe. The goal is to explore and understand unique manifestations of QCD in this many-body environment and their influence on the universe's evolution. Complementary research capability is also provided at the Large Hadron Collider (LHC) at CERN. In the aftermath of collisions at RHIC and at the LHC, researchers have seen signs of the same quark-gluon plasma that is believed to have existed shortly after the Big Bang. With careful measurements, scientists are accumulating data that offer insights into the processes early in the creation of the universe, and how protons, neutrons, and other bits of normal matter developed from that plasma. Important avenues of investigation are directed at learning more about the physical characteristics of the quark-gluon plasma including exploring the energy loss mechanism for quarks and gluons traversing the plasma, determining the speed of sound in the plasma, and locating the critical point for the transition between the plasma and normal matter.

The RHIC facility places heavy ion research at the frontier of discovery in nuclear physics. RHIC serves two large-scale international experiments called PHENIX and STAR. The RHIC facility is uniquely flexible, providing a full range of colliding nuclei at variable energies spanning the transition to the quark-gluon plasma discovered at RHIC. The facility continues to set new performance records, with Run-15 integrated luminosity exceeding the sum of all previous runs. The FY 2017 run will test the present understanding of QCD as applied to the spin structure of the proton, and will explore new phenomena that have emerged in quark gluon plasma formation. R&D and pre-conceptual design aimed at upgrades of existing detectors at RHIC continue, with efforts focused on proposed upgrades to PHENIX to probe the QGP with precision, high rate measurements. Short and mid-term accelerator R&D is conducted at RHIC in a number of areas including the cooling of high-energy hadron beams; high intensity polarized electron sources; and high-energy, high-current energy recovery linear (ERL) accelerators. The RHIC facility is used by about 1,200 DOE, NSF, and foreign agency-supported researchers annually.

Collaboration in the heavy ion program at the LHC at CERN provides U.S. researchers the opportunity to investigate states of matter under substantially different initial conditions than those provided by RHIC, providing complementary information regarding the matter that existed during the infant universe. Data collected by the ALICE, CMS, and ATLAS detectors confirm that the quark-gluon plasma discovered at RHIC is also seen at the higher energy and comparison with the results at RHIC has led to important new insights. U.S. researchers are making important scientific contributions to the emerging results from all three LHC experiments. In ALICE and CMS U.S. researchers are participating in developing and upgrading instrumentation for future heavy ion campaigns at the LHC.

<u>Research</u>

Heavy ion research groups at BNL, LBNL, LANL, ORNL, and approximately 110 scientists and 85 graduate students at 24 universities are supported to participate in experiments at RHIC and the LHC.

The university and national laboratory research groups provide the scientific personnel and graduate students needed for taking data with the RHIC and LHC heavy ion experiments; analyzing data; publishing results; conducting R&D of next-generation detectors; developing and implementing scientific equipment; and planning for future experiments. BNL and LBNL provide computing infrastructure for petabyte-scale data analysis and state-of-the-art facilities for detector and instrument development. At LBNL, a large-scale computational system, the NP-supported Parallel Distributed Systems Facility (PDSF), is a major shared resource used for the analysis of RHIC and LHC data in alliance with the National Energy Research Scientific Computing Center (NERSC), which is supported by SC's Advanced Scientific Computing Research (ASCR) program. Additional computing resources at ORNL and Vanderbilt University are provided for LHC data analysis.

Accelerator R&D research proposals for short and mid-term accelerator R&D from universities and laboratories specific to improving operations of current NP facilities or developing new NP facilities are evaluated by peer review through a single competition for funding that is included under the Heavy Ion and Medium Energy subprograms.

Operations

Support is provided for the operations, power costs, capital infrastructure investments, and accelerator improvement projects of the RHIC accelerator complex at BNL. The accelerator complex includes the Electron Beam Ion Source (EBIS), Booster, and the Alternating Gradient Synchrotron (AGS) accelerators that together serve as the injector for RHIC. Staff provides experimental support to the facility, including the development, implementation, and commissioning of scientific equipment associated with the RHIC program. Through operations of the RHIC complex, important core competencies are nurtured in accelerator physics techniques to improve RHIC performance and support the NP mission. These core competencies provide collateral benefits to applications in industry, medicine, homeland security, and other scientific projects outside of NP. RHIC accelerator physicists are providing leadership to the effort to address technical feasibility issues of relevance to a possible next-generation collider for the NP program, including beam cooling techniques and energy recovery linacs. Accelerator Improvement Projects focus on cooling of low energy heavy ion beams with bunched electron beam, which is projected to increase the luminosity by up to another factor of 10. The full system is planned to be completed and commissioned in FY 2018. Accelerator physicists also play an important role in the training of next generation accelerator physicists, with support of graduate students and post-doctoral associates.

RHIC operations allow for parallel and cost-effective operations of the Brookhaven Linac Isotope Producer Facility (BLIP), supported by NP for the production of research and commercial isotopes critically needed by the Nation, and of the NASA Space Radiation Laboratory Program for the study of space radiation effects applicable to human space flight.

Heavy Ion Nuclear Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Heavy Ion Nuclear Physics $207,910,000	**$216,131,000**	**+$8,221,000**
Research $35,822,000	**$36,431,000**	**+$609,000**
Researchers continue to participate in the collection and analysis of new data from RHIC enabled by the recently completed STAR Heavy Flavor Tracker (HFT) MIE. The FY 2014 run was the commissioning run for the HFT, and provided important first results, but not final precision measurements. The 2015 run generated the baseline data from proton+proton and proton+Au collisions, and the FY 2016 run will generate the definitive Au+Au data, which will address unexplained phenomena with charm and bottom quarks to inform our understanding of the perfect liquid discovered at RHIC in 2005. NP also provides scientific leadership to the heavy ion efforts at the international ALICE, CMS, and ATLAS LHC experiments, as well as the required funding to the LHC for U.S. commitments for management and operating costs. Mid- and short-term accelerator R&D relevant to NP programmatic needs is also supported.	Researchers will continue to participate in the analysis and collection of data from RHIC to explore new phenomena in quark gluon plasma formation. Efforts continue to develop instrumentation aimed at probing the QGP with precision measurements. NP will continue to provide scientific leadership to the heavy ion efforts at the international ALICE, CMS, and ATLAS LHC experiments, as well as providing the required funding to the LHC for U.S. commitments for management and operating costs, computing, and contributions towards upgrades of the ALICE detector. Mid- and short-term accelerator R&D relevant to NP programmatic needs will also be supported.	Increased funding maintains high priority efforts at universities and national laboratories associated with implementing the RHIC science program, and provides support for U.S. scientists to participate in small-scale ALICE instrumentation upgrades at the LHC.
Operations $172,088,000	**$179,700,000**	**+$7,612,000**
RHIC operations will provide for 2,490 beam hours, which is approximately 20 weeks and equal to 61 percent utilization, in support of the planned RHIC research program that is taking advantage of dramatic improvements in collider performance and versatility made possible by recent RHIC upgrades. The FY 2016 run (Run-16) is essential to understand results on heavy quark propagation in the quark-gluon plasma discovered at RHIC. The high statistics data planned for Run-16 addresses these phenomena and are required for researchers to interpret the data acquired from the last two years.	RHIC operations increase by 550 hours over FY 2016 to a total of 3,040 beam hours, which is approximately 24 weeks and equal to 74 percent utilization, in support of the planned RHIC research program. RHIC staff will continue to develop and implement instrumentation needed for the experimental campaigns. Continued implementation of electron beam cooling will lead to further increases in luminosity. Accelerator science staff will continue to reduce technical risks associated with a proposed electron ion collider.	Funding provides for increased operations, staffing levels, power costs, maintenance, and materials needed to reliably deliver 3,040 hours of beam.

Nuclear Physics
Low Energy Nuclear Physics

Description

The Low Energy Nuclear Physics subprogram focuses on answering the overarching questions associated with two scientific thrusts, Nuclei and Nuclear Astrophysics, and Fundamental Symmetries that can be probed by studying neutrons and nuclei.

Questions associated with Nuclei and Nuclear Astrophysics include:

- What is the nature of the nuclear force that binds protons and neutrons into stable nuclei and rare isotopes?
- What is the origin of simple patterns in complex nuclei?
- What is the nature of neutron stars and dense nuclear matter?
- What is the origin of the elements in the cosmos?
- What are the nuclear reactions that drive stars and stellar explosions?

This subprogram addresses these questions through support of research to develop a comprehensive description of nuclei using beams of stable and rare isotopes to yield new insights and reveal new nuclear phenomena. The subprogram also measures the cross sections of the nuclear reactions that power stars and lead to spectacular stellar explosions, which are responsible for the synthesis of the elements.

Questions addressed in the area of Fundamental Symmetries that can be probed by studying neutrons and nuclei include:

- What is the nature of the neutrinos, what are their masses, and how have they shaped the evolution of the cosmos? What experimental approach for a next generation, ton-scale neutrino-less double beta day detector is capable of achieving the sensitivity necessary to determine if the neutrino is its own anti-particle?
- Why is there now more matter than antimatter in the universe? Is there evidence from the electric-dipole moments of atomic nuclei and the neutron that demonstrate our current understanding of the fundamental laws governing nuclear physics is incomplete?
- Will evidence for time-reversal violation in electron scattering and possible lepton number violation in the decay of nuclei indicate forces present at the dawn of the universe that disappeared from view as the universe evolved?

This subprogram addresses these questions through precision studies using neutron beams and decays of nuclei, including neutrinoless double-beta decay. Beams of cold and ultracold neutrons are used to study fundamental properties of neutrons. Precision studies to observe or set a limit on violation of time-reversal invariance—the principle that the physical laws should not change if the direction of time is reversed—in nucleonic, nuclear, and atomic systems investigate fundamental questions in nuclear physics, astrophysics, and cosmology.

The ATLAS scientific user facility is the only DOE-supported facility in Nuclear Structure and Nuclear Astrophysics, serving a combined international community of more than 400 scientists. ATLAS provides high-quality beams of all the stable elements up to uranium as well as selected beams of short-lived nuclei for experimental studies of nuclear properties under extreme conditions and reactions of interest to nuclear astrophysics. ATLAS is the world's premiere facility for stable beams, and it also provides some capabilities in radioactive or rare isotope beams with the Californium Rare Ion Breeder Upgrade (CARIBU) ion source. The facility continues to provide higher intensity stable beams and improved quality radioactive beams with modest accelerator improvements. Technologically cutting-edge and unique instrumentation are a hallmark at the facility, and the ATLAS Facility continues to be significantly oversubscribed by the user community.

Disposition activities of the ORNL Holifield Radioactive Ion Beam Facility (HRIBF), which ceased operations in FY 2012, are on-track and continue with decreasing funding in FY 2017.

Accelerator operations are supported at two university Centers of Excellence with specific goals and unique physics programs: the Cyclotron Institute at Texas A&M University (TAMU) and accelerator facilities at the Triangle Universities Nuclear Laboratory (TUNL) at Duke University. A third university center, the Center for Experimental Nuclear Physics and Astrophysics (CENPA) at the University of Washington, provides unique expertise and capabilities for instrumentation development. NP also supports a small in-house nuclear science program at the LBNL 88-Inch Cyclotron, which provides important capabilities in materials irradiation to external users.

The Facility for Rare Isotope Beams (FRIB), under construction at Michigan State University (MSU), will advance understanding of rare nuclear isotopes and the evolution of the cosmos by providing beams of rare isotopes with neutron and proton numbers far from those of stable nuclei in order to test the limits of nuclear existence. The Gamma-Ray Energy Tracking Array (GRETA) MIE is one of the primary tools that the community. and NSAC have identified to leverage the capabilities of FRIB, and SC proposes to begin fabrication in FY 2017. GRETA will have ten times the gamma-ray resolving power for the vast majority of experiments, and up to a factor of 100 for those requiring multiple gamma-ray correlations. GRETA's unprecedented combination of full coverage with high efficiency, and excellent energy and position resolution, will extend the reach of FRIB's ability to study the nuclear landscape, provide new opportunities to discover and characterize key nuclei for electric dipole moment (EDM) searches, and open new areas of study in nuclear astrophysics.

Research

Low Energy research groups at ANL, BNL, LBNL, LANL, LLNL, ORNL, and PNNL, and approximately 170 scientists and 110 graduate students at 41 universities are supported. About two-thirds of the scientists conduct nuclear structure and astrophysics research primarily using specialized instrumentation at the ATLAS scientific user facility, as well as the smaller accelerator facilities at university-based Centers of Excellence. Scientists are also involved in the development of instrumentation for the ATLAS facility. The GRETA MIE, discussed above, will be initiated in FY 2017 to provide unprecedented gamma-ray tracking capabilities for the future FRIB facility. GRETA will revolutionize gamma-ray spectroscopy providing more than an order of magnitude increased sensitivity for gamma ray coincidence measurements. The remaining groups primarily conduct research in fundamental symmetries, including experiments at the Fundamental Neutron Physics Beamline (FNPB) at the Spallation Neutron Source; double beta-decay experiments such as the Cryogenic Underground Observatory for Rare Events (CUORE) experiment at Gran Sasso Laboratory in Italy and the Majorana Demonstrator R&D effort at the Sanford Underground Research Facility in Lead, South Dakota; a measurement of the neutrino mass with the Karlsruhe Tritium Neutrino (KATRIN) experiment at the Karlsruhe Institute of Technology in Karlsruhe, Germany; and R&D to measure the neutron electric dipole moment. Support is also provided to the university Centers of Excellence to maintain and nurture their unique capabilities.

Operations

ATLAS provides highly reliable stable and selected radioactive beams and specialized instrumentation for scientists to conduct research on nuclear structure and nuclear astrophysics. Support is provided for the operations, power costs, capital infrastructure investments, experimental support, and accelerator improvement projects of ATLAS. The recently installed Electron Beam Ion Source (EBIS) enhances the performance of the CARIBU radioactive beam system by increasing fluxes of radioactive ion beams and enabling shorter-lived isotopes to be reaccelerated, thereby offering new research capabilities to scientists. Researchers remain engaged in the continuous development of small-scale, yet cutting-edge instrumentation for new experiments at ATLAS, providing the facility with unique world-wide capabilities. Instrumentation efforts in FY 2017 will focus on developing and implementing an in-flight radioactive ion separator to increase the intensity of radioactive beams by several orders of magnitude and deliver beams to a larger number of beam lines in the facility.

The ATLAS facility nurtures a core competency in accelerator science with superconducting radio frequency cavities for heavy ions that are relevant to the next generation of high-performance proton and heavy ion linacs. This competency is important to the Office of Science mission and international stable and radioactive ion beam facilities. Efforts continue in developing technology that could reduce the backlog of experiments and increase available beam time, such as the capability to operate stable and radioactive ion beams simultaneously.

Low Energy Nuclear Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Low Energy Nuclear Physics $78,785,000	**$79,893,000**	**+$1,108,000**
Research $51,383,000	**$54,394,000**	**+$3,011,000**
University and laboratory nuclear structure and nuclear astrophysics efforts continue to focus on research at ATLAS, university-based Centers of Excellence, as well as the highest priority instrumentation development efforts to realize unique scientific opportunities afforded by stopped, slow, and fast beams at FRIB. Data taking continues at the Majorana Demonstrator to demonstrate technical feasibility of a next generation detector in double beta decay. Support continues for maintenance and operations of the GRETINA detector, operations of the KATRIN experiment, and R&D at the FNPB on the feasibility of setting a world leading limit on the electric dipole moment of the neutron (nEDM).	University and laboratory nuclear structure and nuclear astrophysics efforts will continue to focus on research at ATLAS, university-based Centers of Excellence, and high priority instrumentation development efforts to realize unique scientific opportunities at FRIB and ATLAS. Data taking will continue with the Majorana Demonstrator to demonstrate feasibility of this candidate technology for a next generation detector in double beta decay. U.S. participation in the operations of the international KATRIN and CUORE experiments will continue, as does ongoing R&D at the FNPB on the feasibility of setting a world leading limit on the electric dipole moment of the neutron (nEDM). A new MIE, GRETA, will be initiated to provide world-unique opportunities to advance the rare-isotope science and investigate nuclear reactions of critical importance for nuclear structure and nuclear astrophysics at FRIB.	Funding is increased to initiate GRETA, a new MIE that will provide an order of magnitude increased sensitivity for gamma ray coincidence measurements at FRIB. Instrumentation development efforts increase to realize the unique opportunities at FRIB. R&D for the nEDM research effort increases to determine feasibility of setting world leading limit on the electric dipole moment of the neutron. U.S. commitments and obligations increase for the operating CUORE and KATRIN experiments.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Operations $27,402,000	**$25,499,000**	**-$1,903,000**
Continued operation of ATLAS in a 7 day per week mode is a high priority as demand for ATLAS beam time continues to far exceed availability. FY 2016 funding supports 5,900 hours of beam time, and a program of modest upgrades continues for the only operating DOE-supported scientific user facility in nuclear structure and astrophysics. Support continues for equipment disposition activities at HRIBF.	Operation of ATLAS in a 7 day per week mode continues to be a high priority as demand for ATLAS beam time continues to far exceed availability. ATLAS continues to operate extremely reliably, and funding will support 5,900 hours of beam time. The Request will provide modest funding for an additional mechanical engineer to reduce risk and address experimental support needs. Modest upgrades and equipment development will continue in order to maintain unique instrumentation capabilities and a vigorous research program in nuclear structure and nuclear astrophysics. Activities will decrease in FY 2017 for equipment disposition activities at HRIBF, as planned.	Funding decreases due to the ramp down of disposition activities at HRIBF, partially offset by an increase needed to support ATLAS operations.

Nuclear Physics
Nuclear Theory

Description

The Nuclear Theory subprogram provides the theoretical support needed to interpret the wide range of data obtained from the experimental nuclear science subprograms and to advance new ideas and hypotheses that identify potential areas for future experimental investigations. Nuclear Theory addresses all three of NP's scientific thrusts. One major theme of theoretical research is the development of an understanding of the mechanisms and effects of quark confinement and deconfinement. A quantitative description of these phenomena through QCD is one of this subprogram's greatest intellectual challenges. New theoretical and computational tools are also being developed to describe nuclear many-body phenomena; these approaches will likely also see important applications in condensed matter physics and in other areas of the physical sciences. Another major research area is nuclear astrophysics, which includes efforts to understand the origins of the elements and the consequences that neutrino masses have for nuclear astrophysics.

This subprogram supports the Institute for Nuclear Theory (INT) at the University of Washington. The second year of new five-year topical collaborations within the university and national laboratory communities will be supported in FY 2017 to address high-priority topics in nuclear theory that merit a concentrated theoretical effort. The Nuclear Theory subprogram also supports the U.S. Nuclear Data Program (USNDP), which collects, evaluates, and disseminates nuclear physics data for basic nuclear research and for applied nuclear technologies and their development.

Much of the research supported by the Nuclear Theory subprogram requires extensive access to leading-edge supercomputers. One area that has a particularly pressing demand for large, dedicated computational resources is Lattice QCD (LQCD). LQCD calculations are critical for understanding and interpreting many of the experimental results from RHIC, LHC, and CEBAF. A five-year computer hardware project "LQCD-ext II" started in FY 2015 and is carried out jointly with HEP to ensure effective coordination. It follows the previous joint efforts that address the computational requirements of LQCD research by continuing to provide specialized computing resources for LQCD research. Both HEP and NP require this type of computing capability in order to conduct simulations that address their distinct science programs. The partnering of the two Offices ensures effective coordination to maximize the leverage available for this activity from the infrastructure and intellectual capital of both programs and to prevent duplication of effort on resource-intensive calculations inherently central to quantum chromodynamics and particle physics research.

SciDAC, a collaborative program with ASCR that partners scientists and computer experts in research teams to address major scientific challenges that require supercomputer facilities performing at current technological limits, is also supported within this subprogram. The NP SciDAC program operates on a five year cycle, and supports computationally intensive research projects jointly with other SC and DOE offices in areas of mutual interest. SciDAC-3 awards were made in FY 2012 and will continue through FY 2016. A new group of SciDAC-4 awards will be selected in FY 2017.

Theory Research

The Nuclear Theory subprogram supports the research programs of approximately 160 university scientists and 120 graduate students at 50 universities, as well as nuclear theory groups at seven national laboratories (ANL, BNL, LANL, LBNL, LLNL, ORNL, and TJNAF). This research has the goals of improving our fundamental understanding of nuclear physics, interpreting the results of experiments carried out under the auspices of the experimental nuclear physics program, and identifying and exploring important new areas of research. Three topical collaborations [JET (QCD in the heavy-ion environment); NuN (neutrinos and nucleosynthesis in hot and dense matter); and TORUS (low-energy nuclear reactions for unstable isotopes)] completed their work in FY 2015. Based on mission need, the success of the initial cohort of topical collaborations, and community support of this program, a new round of 5-year topical collaborations is being initiated in FY 2016 to bring together theorists to address specific high-priority theoretical challenges. The three new collaborations are: the Beam Energy Scan Theory (BEST) Collaboration, the Coordinated Theoretical Approach to Transverse Momentum Dependent Hadron Structure in QCD (TMD) Collaboration, and the Nuclear Theory for Double-Beta Decay and Fundamental Symmetries (DBD) Collaboration. The BEST and TMD proposals are intimately related to lattice QCD, one of nuclear theory's greatest intellectual challenges. BEST addresses "hot" QCD and the RHIC beam-energy scan, while TMD deals with "cold" QCD, three-dimensional hadron structure and spin physics, and looks forward in the direction of a future electron ion collider (EIC). DBD is focused on using the most up-to-date methods of nuclear structure theory to calculate nuclear matrix elements for double beta decay cross section and to carry out other fundamental symmetry related calculations. A new focused effort on FRIB theory has been initiated and will be expanded in FY 2017. This effort is critical to ramping up theory efforts associated with the planned FRIB scientific program in order to optimize the interpretation of the experimental results.

Nuclear Data

The USNDP provides current, accurate, and authoritative data for workers in pure and applied areas of nuclear science and engineering. It addresses this goal primarily through maintaining and providing public access to extensive nuclear physics databases, which summarize and cross-correlate the results of over 100 years of research on nuclear science. These databases are an important national and international resource, and they currently serve approximately three million retrievals of nuclear data annually. The USNDP also addresses important gaps in nuclear data through targeted experiments and the development and use of theoretical models. The program involves the combined efforts of approximately 50 nuclear scientists at 10 national laboratories and universities, and is managed by the National Nuclear Data Center (NNDC) at BNL. In FY 2017, two recently established USNDP university efforts will receive continued support, one at Michigan State University, in association with FRIB, and the other at the University of California at Berkeley, in association with the existing Bay Area Nuclear Data groups at LBNL and LLNL.

Nuclear Theory

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Nuclear Theory $45,775,000	**$46,465,000**	**+$690,000**
Theory Research $38,003,000	**$38,583,000**	**+$550,000**
Funding continues to support the highest priority theoretical research at universities and national laboratories for the interpretation of experimental results obtained at NP facilities. Theorists concentrate on applying QCD to nucleon structure and hadron spectroscopy, to the force between nucleons, and to the structure of light nuclei. Advanced dynamic calculations to describe relativistic nuclear collisions, nuclear structure and reactions, and topics related to fundamental symmetries focus on activities in preparation for the research program at the upgraded CEBAF 12 GeV facility, the research program at the planned FRIB facility, and ongoing and planned fundamental symmetries experiments. Funding continues to support ongoing SciDAC-3 grants and the LQCD ext-II computing project. Support is provided to initiate the second round of theory topical collaborations.	Funding will continue to support the highest priority theoretical research at universities and national laboratories for the interpretation of experimental results obtained at NP facilities, and the exploration of new ideas and hypotheses that identify potential areas for future experimental investigations. Theorists will focus on applying QCD to a wide range of problems from nucleon structure and hadron spectroscopy, through the force between nucleons, to the structure of light nuclei. Advanced dynamic calculations to describe relativistic nuclear collisions, nuclear structure and reactions, and topics related to fundamental symmetries will continue to focus on activities related to the research program at the upgraded 12 GeV CEBAF facility, the research program at the planned FRIB, and ongoing and planned fundamental symmetries experiments. Funding will also support a new group of SciDAC-4 grants, the second year of the theory topical collaborations initiated in FY 2016, and the ongoing LQCD ext-II computing project with HEP.	Funding increases to support the highest priority theoretical research efforts across the Nuclear Physics program, and to expand support for a theoretical collaboration focused on the science at FRIB.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Nuclear Data $7,742,000	**$7,882,000**	**+$140,000**
Nuclear data evaluation is the prime nuclear data product, combining experiment with theory and linking basic science with applications. The emphasis in FY 2016 is on the compilation and evaluation of nuclear reaction and nuclear structure data which will include advanced nuclear reaction modeling and uncertainty quantification; maintaining and developing nuclear data formats and data verification codes; and archiving nuclear physics data and disseminating it using up to date technology.	The primary emphasis in the Nuclear Data Program in FY 2017 will continue to be on the compilation and evaluation of nuclear reaction and nuclear structure data which will include advanced nuclear reaction modeling and uncertainty quantification; maintaining and developing nuclear data formats and data verification codes; and archiving nuclear physics data and disseminating it using up to date technology. In addition, a modest experimental component to address gaps in the existing nuclear data will be considered.	Funding increases to support recently established university efforts at MSU (in association with FRIB) and the University of California, Berkeley (in association with LBNL and LLNL), in support of USNDP activities.

Nuclear Physics
Isotope Development and Production for Research and Applications[a]

Description

The Isotope Development and Production for Research and Applications subprogram (DOE Isotope Program) supports the production, distribution, and development of production techniques for radioactive and stable isotopes in short supply and critical to the Nation. Isotopes are commodities of strategic importance for the Nation that are essential for energy exploration and innovation, medical applications, national security, and basic research. The goal of the program is to make key isotopes more readily available to meet U.S. needs. To achieve this goal, the program incorporates all isotope related R&D and production capabilities, including facilities and technical staff, required for supply chain management of critically important isotopes. The subprogram also supports R&D efforts associated with developing new and more cost-effective and efficient production and processing techniques, and on the production of isotopes needed for research purposes. The R&D activities also provide collateral benefits for training, contributing to workforce development, and helping to ensure a future U.S.-based expertise in the fields of nuclear chemistry and radiochemistry. These disciplines are foundational not only to radioisotope production, but to many other critical aspects of basic and applied nuclear science as well.

All funding from the Isotope Development and Production for Research Applications subprogram is executed through the Isotope Production and Distribution Program revolving fund. The isotope revolving fund maintains its financial viability by utilizing the appropriations from this subprogram along with revenues from the sale of isotopes and services. These resources are used to maintain the staff, facilities, and capabilities at user-ready levels and to support peer-reviewed research and development activities related to the production of isotopes. Isotopes sold to commercial customers are priced to recover the full cost of production, or the market price (whichever is higher). Research isotopes are sold at a reduced price to ensure high priority research requiring them does not become cost prohibitive. Investments in new capabilities are made to meet the growing demands of the Nation and foster future research in applications that will support national security and the health and welfare of the public.

Isotopes are critical national resources used to improve the accuracy and effectiveness of medical diagnoses and therapy, to enhance national security, and to improve the efficiency of industrial processes, and provide precise measurement and investigative tools for materials, biomedical, environmental, archeological, and other research. Some examples are:

- strontium-82 for cardiac imaging;
- californium-252 for well logging, homeland defense, and energy security;
- germanium-68 for the development of gallium-68 radiopharmaceuticals for cancer imaging;
- berkelium-249, californium-251, and curium-248 for use as targets for discovery of new superheavy elements;
- selenium-75 for industrial radiography;
- actinium-225, bismuth-213, lead-212, thorium-227, and radium-223 for cancer and infectious disease therapy research;
- nickel-63 for molecular sensing devices, and lithium-6 and helium-3 for neutron detectors for homeland defense applications;
- lithium-7 as a coolant reagent for pressurized water nuclear power plants;
- tungsten-188, strontium-90, and cobalt-60 for cancer therapy;
- arsenic-73 as a tracer for environmental research; and
- silicon-32 for oceanographic studies related to climate modeling.

Stable and radioactive isotopes are vital to the missions of many Federal agencies including the National Institutes of Health (NIH), the National Institute of Standards and Technology, the Environmental Protection Agency, the Department of Agriculture, the Department of Homeland Security (DHS), NNSA, and DOE Office of Science programs. NP continues to work in close collaboration with federal organizations to develop strategic plans for isotope production and to establish effective communication to better forecast isotope needs and leverage resources. Each year, NP conducts an annual workshop, attended by representatives of all Federal agencies that require stable and radioactive isotopes, to provide a comprehensive assessment of national needs for isotope products and services, to inform priorities for investments in research for developing new isotope production and processing techniques, to communicate advances in isotope production research and availability, and to communicate concerns about potential constrained supplies of important isotopes to the federal

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[a] All appropriations for the Isotope Development and Production for Research and Applications subprogram fund a payment into the Isotope Production and Distribution Program Fund as required by P.L. 101–101 and as modified by P.L. 103–316.

agencies. The Isotope Program participates in a number of federal Working Groups and Interagency groups to promote communication, including the White House Office of Science and Technology Policy (OSTP) working group on molybdenum-99 (Mo-99), the National Science and Technology Committee (NSTC) Subcommittee on Critical and Strategic Mineral Supply Chains, the Interagency Group on Helium-3, which it leads, that reports to the White House National Security Staff, and the OSTP Interagency Working Group on Alternatives to High-Activity Radioactive Sources (GARS). NP participates in the Certified Reference Material Working Group which assures material availability for nuclear forensics applications that support national security missions and also the Nuclear Regulatory Committee on Alternatives to Sealed Sources. As a service, the Isotope Program collects demand and usage information on helium-4 from the federal complex and provides it to the Bureau of Land Management (BLM) so that BLM can optimize their plans for the helium-4 federal reserve.

While the Isotope Program is not responsible for the production of Mo-99, which is the most widely used isotope in diagnostic medical imaging in the Nation, it works closely with NNSA, the lead entity responsible for domestic Mo-99 production, offering technical and management support. Consistent with the National Defense Authorization Act for Fiscal Year 2013, NP also oversees proceedings of the Nuclear Science Advisory Committee in response to a charge to annually assess progress by NNSA toward ensuring a domestic supply of Mo-99. Additionally, NP participates in the international High-Level Group on the Security of Supply of Medical Isotopes lead by the Organisation for Economic Co-operation and Development (OECD).

The mission of the Isotope Program is facilitated by the National Isotope Development Center (NIDC), which is a virtual center that interfaces with the user community and manages the coordination of isotope production across the facilities and business operations involved in the production, sale, and distribution of isotopes. The NIDC includes the Isotope Business Office, which is located at ORNL.

Research

Research is supported to develop new or improved production or separation techniques for high priority isotopes in short supply. Research investments tackle challenges in the efficiency of producing critical isotopes, and develop production methods for isotopes of interest to federal agencies and other stakeholders, when no production route is in existence, enabling new applications and research. Priorities in research isotope production are informed by guidance from NSAC as described in the 2015 Long Range Plan for the DOE-NP Isotope Program published in July 2015 under the title "Meeting Isotope Needs and Capturing Opportunities for the Future." The Isotope Program has also funded research to demonstrate technical feasibility of modern stable isotope enrichment devices to provide the Nation with small-scale enrichment capabilities that have been absent since the DOE calutrons ceased operation in 1998. The U.S. is currently dependent on foreign sources for supplies of stable isotopes; the U.S. inventory has been depleted in the cases of some specific isotopes. The R&D program also develops domestic production capabilities for important radioisotopes for which the U.S. is dependent on foreign sources.

Another high priority is a long-term research effort to produce actinium-225, an isotope that shows great promise in the treatment of diffuse cancers and infections if it can be produced in sufficient quantity and quality. In work performed in FY 2015, production research efforts focused on demonstrating that the accelerator produced isotope functions equivalently to the material derived from the decay of thorium-229 which is presently the only viable source of small quantities of actinium-225. Samples of the isotope produced by the accelerator production approach have been evaluated by several different researchers involved in medical applications research and results indicate that the accelerator produced material works virtually identically to the thorium-229 generated material. The accelerator route of production has the potential to provide quantities sufficient to support both research trials and ultimately clinical applications in the future. Research into the development of methods to consistently provide high production and recovery yields of astatine-211 for cancer therapy at the University of Washington have also proven successful, and the university site is preparing to start the production of this promising isotope for the Isotope Program. Also, in anticipation of the opportunity FRIB will provide as a unique source of many important isotopes for research and applications, scientists are exploring technologies to potentially harvest some of the isotopes that will be produced during physics research experiments. Recent research results have also demonstrated technical feasibility of a potential new production route for lithium-7, an isotope used as a coolant reagent in pressurized water nuclear power plants. Currently, the U.S. is dependent upon foreign supplies of lithium-7 which are not always reliable; this successful research could provide a path for re-establishing domestic production of lithium-7.

Starting in FY 2017, NP will provide support for a graduate traineeship activity in radiochemistry and nuclear chemistry with an emphasis in isotope production to assure the ongoing availability of the very specialized workforce necessary to produce radioactive and enriched stable isotopes, including target processing and radionuclide purification using remote handling facilities such as hot-cells, glove-boxes, robotics and other forms of automation. The DOE Isotope Program, as well as other fields in the physical sciences, depend heavily on highly trained people in the disciplines of radiochemistry and nuclear chemistry to support its mission. Several recent reports have pointed to a shortage of production expertise and trained personnel in these disciplines. This new initiative is planned for $1,000,000 per year for 5 years, and will support 10-20 students per year.

Operations

The Isotope Program is steward of the Isotope Production Facility (IPF) at Los Alamos National Laboratory (LANL) and the Brookhaven Linac Isotope Producer (BLIP) facility at BNL, and provides support for hot cell facilities for processing and handling irradiated materials and purified products at ORNL, BNL, and LANL. Facilities at other sites are used as needed, such as the Idaho National Laboratory reactor for the production of cobalt-60, the Pacific Northwest National Laboratory for processing and packaging strontium-90, the Y-12 National Security Complex for processing and packaging lithium-6 and lithium-7, and the Savannah River Site for the extraction and distribution of helium-3. In addition to isotope production at DOE facilities, the Isotope Program is funding production at universities with capabilities beyond those available in the stewarded facilities, such as an alpha-particle cyclotron at the University of Washington that developed full-scale production of astatine-211 to support research into the use of the isotope in cancer therapy.

The DOE Isotope Program has invested R&D funds since 2009 to develop stable isotope separation technology at ORNL, a high priority identified by the NSAC Subcommittee on Isotopes in 2009. The R&D effort is on track for completion in FY 2016, which will result in a prototype capability to produce small research quantities of enriched stable isotopes starting in FY 2017. The prototype demonstration has been established in a location that is capable of expansion and the resulting capability developed is completely scalable to produce kg quantities of enriched stable isotopes in a cost-effective manner. The FY 2017 Request includes funding to initiate the Stable Isotope Production Facility (SIPF) MIE to help meet the demand for a domestic capability to produce enriched stable isotopes for basic research, medical and industrial applications. Examples of discovery research efforts which could benefit from the requested facility are neutrinoless double beta decay experiments in nuclear physics and dark matter experiments in high-energy physics that are interested in kg quantities of enriched stable isotopes, which are not presently available in the U.S. Similarly, the accelerator-production route for Mo-99, a critical medical isotope for cardiac imaging, relies on a feedstock of enriched Mo isotopes, which are also unavailable domestically. Stable isotopic nuclides of heavier elements used for agricultural, nutritional, industrial, environmental, ecological, and computing applications could also be produced.

Isotope Development and Production for Research and Applications

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Isotope Development and Production for Research and Applications $21,337,000	**$29,370,000**	**+$8,033,000**
Research $6,033,000	**$10,344,000**	**+$4,311,000**
Funding continues support for competitive R&D awards to universities and laboratories, as well as for support to laboratory research groups at LANL, BNL, and ORNL. Development of production techniques for alpha-emitting radionuclides for medical therapy continues to be a priority, and is being implemented through a concerted collaborative R&D effort by experts at the national laboratories, particularly at BNL, LANL, and ORNL. Research at universities and national laboratories is also leading to new isotope production technologies and effectively engaging and training students and post-docs in nuclear chemistry and radiochemistry.	Funding will continue support for competitive R&D activities at universities and laboratories. Priorities for the development of production routes for isotopes in short supply will continue to be guided by the NSAC reports and federal input regarding what isotopes are needed to accomplish federal missions in research and homeland security. Development of production techniques for alpha-emitting radionuclides for medical therapy will continue to be a priority. Research at universities and national laboratories will also continue, leading to new isotope production technologies and effectively engaging and training students and post-docs in nuclear chemistry and radiochemistry. A new graduate traineeship activity in radiochemistry and nuclear chemistry with an emphasis in isotope production will be initiated in FY 2017.	Consistent with recommendations of the July 2015 NSAC report, support is increased in FY 2017 to enable innovative approaches to produce and process critical isotopes for the Nation, including R&D into the production of the high priority alpha-emitters for clinical trials; such isotopes could revolutionize cancer therapy by effectively treating cancers that have already metastasized. Another focus is R&D on developing domestic production capabilities for important isotopes for which the U.S. is dependent on foreign sources. The request also supports a traineeship for between 10 and 20 graduate students per year in radiochemistry and nuclear chemistry, nurturing a critical expertise needed for isotope production, and with benefits to many fields in physics and chemistry in general.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Operations $15,304,000	**$19,026,000**	**+$3,722,000**
Support provides for infrastructure and maintenance of facilities, core competencies in isotope production and development, and for the NIDC. The maintenance of aging facilities continues to be a funding priority to maintain isotope production capabilities. Funding for program investments and production of particular isotopes is informed by the Nuclear Science Advisory Committee's updated long-range plan for the Isotope Program (completed in FY 2015) and the Federal workshop held in the fall of 2015.	Support will provide for infrastructure and maintenance of facilities, core competencies in isotope production and development, and for the NIDC. The maintenance of aging facilities continues to be a funding priority to maintain isotope production capabilities. Funding for program investments and production of particular isotopes will be informed by the recently released Nuclear Science Advisory Committee's updated long-range plan for the Isotope Program and by information obtained from the Isotope Program's annual Federal workshops. Operations support for the prototype capability to produce small research quantities of enriched stable isotopes will be initiated, and funding is requested for an MIE for a stable isotope capability.	Funding is requested to initiate the Stable Isotope Production Facility (SIPF) MIE to provide a domestic capability for the production of stable enriched isotopes for research and applications. Building upon R&D supported by the Isotope Program which established technical feasibility of a cost-effective approach for re-establishing this capability in the U.S., this MIE will enable replenishment of the U.S. stable isotope inventory which has been depleted for several key isotopes, and help mitigate U.S. dependence on foreign supplies of stable isotopes. Stable isotopic nuclides of heavier elements are used for agricultural, nutritional, industrial, environmental, ecological and computing applications. Increased funding is also requested to initiate operations of the prototype stable isotope capability and to maintain mission readiness of all isotope program facilities.

Nuclear Physics
Construction

Description

Funding in this subprogram provides for design and construction of scientific research facilities needed to meet overall objectives of the Nuclear Physics program. Currently NP has two ongoing projects, for which only one will be receiving construction line item funding in FY 2017.

The 12 GeV CEBAF Upgrade at TJNAF, which was identified in the 2007 NSAC Long-Range Plan as the highest priority for the U.S. Nuclear Physics program, will enable scientists to address one of the mysteries of modern physics—the mechanism of quark confinement. FY 2016 was the last year of construction funding for the project and FY 2017 will support the final year of commissioning. Completion is planned by September 2017.

Construction of the Facility for Rare Isotope Beams (FRIB) at Michigan State University (MSU) continues according to baselined project plans. FRIB will provide intense beams of rare isotopes for world-leading research opportunities in nuclear structure, nuclear astrophysics, and fundamental symmetry studies that will advance knowledge of the origin of the elements and the evolution of the cosmos. It offers a facility for exploring the limits of nuclear existence and identifying new phenomena, with the possibility that a broadly applicable theory of the structure of nuclei will emerge. FRIB will provide an essential scientific tool for over 1,300 scientists each year from across academic, industrial and government institutions. The project is funded through a cooperative agreement with Michigan State University and was established as a control point in the FY 2014 appropriation. Prior to that time, funding was provided within the Low Energy subprogram.

Construction

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Construction $107,500,000	**$100,000,000**	**-$7,500,000**
06-SC-01, 12 GeV CEBAF Upgrade, TJNAF $7,500,000	**$0**	**-$7,500,000**
With the scheduled commissioning of the Hall D experimental equipment in FY 2015, the FY 2016 federal funds support procurements, fabrication, installation, and commissioning of the experimental equipment primarily in Halls B and C; and address continuing project risks in order to optimize the successful completion of this project within the current TEC baseline. FY 2016 is the final year of TEC funding for the project as it works towards completion (CD-4B) by the end of FY 2017.	FY 2016 was the final year of TEC funding. Project completion (CD-4B) is planned by the end of FY 2017.	The decrease reflects the last year of construction line item funding in FY 2016.
14-SC-50, Facility for Rare Isotope Beams (FRIB) $100,000,000	**$100,000,000**	**$0**
Work on conventional facilities continues as well as construction of items such as the linear accelerator (linac) tunnel and the target, linac support, and cryoplant areas. The technical systems are fully underway including efforts such as major procurements, fabrication, and assembly for technical components such as the linac, cryomodules, and experimental systems.	FY 2017 funding will support the completion of some key conventional construction such as the target high bay, linac support area, and the cryoplant area. It also will enable the start of work on the cryogenics plant and distribution system which are on the project's critical path. The major procurements, fabrication, and assembly efforts will continue on the technical systems such as the linac front end, cryomodules, and experimental systems.	FY 2017 funding is the same as FY 2016, consistent with the baselined project profile; these are the peak years of funding for FRIB.

Nuclear Physics
Performance Measure

In accordance with the GPRA Modernization Act of 2010, the Department sets targets for, and tracks progress toward, achieving performance goals for each program. The following table shows the targets for FY 2015 through 2017. Details on the Annual Performance Report can be found at http://energy.gov/cfo/reports/annual-performance-reports.

	FY 2015	FY 2016	FY 2017
Performance Goal (Measure)	**NP Facility Operations—Average achieved operation time of NP user facilities as a percentage of total scheduled annual operation time.**		
Target	≥ 80%	≥ 80%	≥ 80%
Result	Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the Office of Science's scientific user facilities take a great deal of time, money, and effort to prepare, and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		
Performance Goal (Measure)	**NP Construction/MIE Cost & Schedule—Cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects.**		
Target	< 10%	< 10%	< 10%
Result	Met	TBD	TBD
Endpoint Target	Adhering to the cost and schedule baselines for a complex, large scale, science project is critical to meeting the scientific requirements for the project and for being good stewards of the taxpayers' investment in the project.		
Performance Goal (Measure)	**Conduct fundamental research to discover, explore, and understand all forms of nuclear matter.**		
Target	Measure bulk properties, particle spectra, correlations and fluctuations in gold + gold collisions at Relativistic Heavy Ion Collider (RHIC) to search for evidence of a critical point in the Quantum Chromodynamics (QCD) matter phase diagram.	Perform measurements for identified hadrons with heavy flavor valence quarks to constrain the mechanism for parton energy loss in the quark-gluon plasma at the Relativistic Heavy Ion Collider (RHIC).	Demonstrate the capability to extend the sensitivity of searches for neutrinoless double-beta decay by at least a factor of 5.
Result	Met	TBD	TBD
Endpoint Target	Increase the understanding of the existence and properties of nuclear matter under extreme conditions, including that which existed at the beginning of the universe. Measure fundamental properties of neutrinos to improve our current understanding of the interactions of elementary particles.		

Nuclear Physics
Capital Summary ($K)

	Total	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Capital Operating Expenses Summary							
Capital equipment	n/a	n/a	14,750	5,993	15,452	18,264	+2,812
General plant projects (GPP)	n/a	n/a	2,000	2,000	2,000	2,000	0
Accelerator improvement projects (AIP)	n/a	n/a	4,249	3,649	4,377	4,472	+95
Total, Capital Operating Expenses	**n/a**	**n/a**	**20,999**	**11,642**	**21,829**	**24,736**	**+2,907**
Capital Equipment							
Gamma-Ray Energy Tracking Array (GRETA) MIE[a]	52,000-67,000	n/a	0	0	0	500	+500
Stable Isotope Production Facility (SIPF) MIE[b]	9,500 -10,500	n/a	0	0	0	2,500	+2,500
Total Non-MIE Capital Equipment	n/a	n/a	14,750	5,993	15,452	15,264	-188
Total, Capital Equipment	**n/a**	**n/a**	**14,750**	**5,993**	**15,452**	**18,264**	**+2,812**
General Plant Projects							
General plant projects under $5 million TEC	n/a	n/a	2,000	2,000	2,000	2,000	0
Accelerator Improvement Projects (AIP)							
RHIC Low Energy Electron Cooling	8,300	2,800	2,300	2,300	1,869	1,331	-538
Other projects under $5 million TEC	n/a	n/a	1,949	1,349	2,508	3,141	+633
Total, Accelerator Improvement Projects	**n/a**	**n/a**	**4,249**	**3,649**	**4,377**	**4,472**	**+95**
General Plant Projects							
General plant projects under $5 million TEC			2,000	2,000	2,000	2,000	0
Accelerator Improvement Projects (AIP)							
Other projects under $5 million TEC			4,522	4,573	4,625	4,678	0
Total, Accelerator Improvement Projects			**4,522**	**4,573**	**4,625**	**4,678**	**0**

[a] This project is not yet baselined. This project received CD-0 in September, 2015 with a cost range of $52,000,000 to $67,000,000.
[b] This project is not yet baselined. This project received CD-0 in September, 2015 with a cost range of $9,500,000 to $10,500,000.

Major Items of Equipment Descriptions

Low Energy Nuclear Physics

The *Gamma-Ray Energy Tracking Array (GRETA) detector* directly supports the Nuclear Physics mission by addressing the goal to understand the structure of nuclear matter, the processes of nuclear astrophysics, and the nature of the cosmos. A successful implementation of this detector will represent a major advance in gamma-ray tracking detector technology that will impact nuclear science, as well as detection techniques in homeland security and medicine. GRETA will provide unprecedented gains in sensitivity, addressing several high priority scientific topics, including how weak binding and extreme proton-to-neutron asymmetries affect nuclear properties and how the properties of nuclei evolve with changes in excitation energy and angular momentum. GRETA will provide transformational improvements in efficiency, peak-to-total ratio and higher position resolution than the current generation of detector arrays. Particularly, the capability of reconstructing the position of the interaction with millimeter resolution is needed to fully exploit the physics opportunities of FRIB. Without GRETA, FRIB will rely on existing instrumentation. In that event, beam-times necessary for the proposed experiments will be expanded significantly, and some proposed experiments will not be feasible at all. CD-0 was approved in September 2015 with an estimated Total Project Cost of $52,000,000–$67,000,000. CD-1 is planned for FY 2017. The FY 2017 Request for GRETA of $500,000 is the first year of Total Estimated Cost (TEC) funding.

Isotope Development and Production for Research and Applications

The *Stable Isotope Production Facility (SIPF).* The DOE Isotope Program has invested R&D funds since 2009 to develop stable isotope separation technology at ORNL, a high priority identified by the NSAC Subcommittee on Isotopes in 2009. The R&D effort is on track for completion in FY 2016, which will result in a prototype capability to produce small research quantities of enriched stable isotopes starting in FY 2017. The capability has been established in a location which is capable of expansion; the capability is completely scalable to produce kg quantities of enriched stable isotopes in a cost-effective manner. There is a high demand for a domestic capability to produce enriched stable isotopes for basic research, medical and industrial applications. For example, neutrinoless double beta decay experiments in nuclear physics and dark matter experiments in high-energy physics are interested in kg quantities of enriched stable isotopes, which are not available in the U.S. The accelerator-production route for Mo-99, a critical medical isotope for cardiac imaging, which is being supported by NNSA, relies on a feedstock of enriched Mo isotopes, which are also not available domestically. Stable isotopic nuclides of heavier elements are used for agricultural, nutritional, industrial, environmental, ecological and computing applications could also be produced. Funding is requested in FY 2017 for this Major Item of Equipment to initiate fabrication of a domestic production facility for full-scale production of stable enriched isotopes to help mitigate the dependence of the U.S. on foreign suppliers and meet the high demands for enriched stable isotopes for the Nation. Funding would provide the needed infrastructure and services, optimize the design of small centrifuges to isotopes of interest, and purchase multiple units of the electromagnetic separators and small gas centrifuge cascades. CD-0 was approved September 2015 with an estimated Total Project Cost of $9,500,000–$10,500,000. CD-1 is planned for FY 2017. The FY 2017 Request for SIPF of $2,500,000 is the first year of TEC funding.

Nuclear Physics
Construction Projects Summary ($K)

	Total	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
06-SC-01, 12 GeV CEBAF Upgrade, TJNAF							
TEC	310,500	286,500	16,500	16,500	7,500	0	-7,500
OPC	27,500	17,500	4,500	4,500	4,500	1,000	-3,500
TPC	338,000	304,000	21,000	21,000	12,000	1,000	-11,000
14-SC-50, Facility for Rare Isotope Beams							
DOE TPC	635,500[a]	128,000[b]	90,000	90,000	100,000	100,000	0
Total, Construction (TPC) All Construction Projects	**n/a**	**n/a**	**111,000**	**111,000**	**112,000**	**101,000**	**-11,000**

Funding Summary ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Research	165,828	167,195	176,815	187,151	+10,336
Scientific User Facilities Operations	280,663	280,873	288,957	303,038	+14,081
Other Facility Operations	24,313	24,313	24,507	22,826	-1,681
Projects					
Major Items of Equipment	0	0	0	3,000	+3,000
Facility for Rare Isotope Beams	90,000	90,000	100,000	100,000	0
12 GeV Upgrade TEC	16,500	16,500	7,500	0	-7,500
Total Projects	106,500	106,500	107,500	103,000	-4,500
Other[c]	18,196	1,863	19,321	19,643	+322
Total Nuclear Physics	**595,500**	**580,744**	**617,100**	**635,658**	**+18,558**

[a] This is the DOE TPC; MSU's cost share is $94,500,000 bringing the total project cost to $730,000,000. FRIB is funded with operating dollars through a Cooperative Agreement financial assistance award with a work breakdown structure (WBS) that is slightly different from typical federal capital assets. The WBS totals $730,000,000 including MSU's cost share. Because the WBS scope is not pre-assigned to DOE or MSU funds, DOE's baseline of $635,500,000 cannot be broken down between TEC and OPC.

[b] A portion of the PY funding was provided within the Low Energy subprogram. The FY 2014 appropriation established FRIB as a control point.

[c] Includes SBIR/STTR funding in FY 2015 Enacted and FY 2016–FY 2017.

Scientific User Facility Operations ($K)

The treatment of user facilities is distinguished between two types: TYPE A facilities that offer users resources dependent on a single, large-scale machine; TYPE B facilities that offer users a suite of resources that is not dependent on a single, large-scale machine.

Definitions:
Achieved Operating Hours – The amount of time (in hours) the facility was available for users.

Planned Operating Hours –

- For Past Fiscal Year (PY), the amount of time (in hours) the facility was planned to be available for users.
- For Current Fiscal Year (CY), the amount of time (in hours) the facility is planned to be available for users.
- For the Budget Fiscal Year (BY), based on the proposed budget request the amount of time (in hours) the facility is anticipated to be available for users.

Optimal Hours – The amount of time (in hours) a facility would be available to satisfy the needs of the user community if unconstrained by funding levels.

Percent of Optimal Hours – An indication of utilization effectiveness in the context of available funding; it is not a direct indication of scientific or facility productivity.

- For BY and CY, Planned Operating Hours divided by Optimal Hours (OH) expressed as a percentage
- For PY, Achieved Operating Hours divided by Optimal Hours.

Unscheduled Downtime Hours – The amount of time (in hours) the facility was unavailable to users due to unscheduled events. NOTE: For type "A" facilities, zero Unscheduled Downtime Hours indicates Achieved Operating Hours equals Planned Operating Hours.

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
TYPE A FACILITIES					
CEBAF (TJNAF)[a]	**$108,694**	**$109,512**	**$110,090**	**$114,365**	**+$4,275**
Number of Users	1,235	1,380	1,380	1,380	0
Achieved operating hours	0	0	N/A	N/A	N/A
Planned operating hours	0	0	0	2,890	+2,890
Optimal hours	0	0	0	3,330	+3,330
Percent optimal hours	N/A	N/A	N/A	86.8%	+86.8%
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A

[a] During FY 2015–2016, there are no research hours to which the CEBAF facility will be held accountable while the 12 GeV upgrade is commissioned and reliability is low. In FY 2015, approximately 18 weeks and in FY 2016, approximately 16 weeks of machine development are supported. The user community remained active during the shutdown with instrumentation and equipment implementation for the upgraded facility so they continue to be shown in these years. During FY 2017, the planned operating hours and optimal hours include 330 hours of operations (commissioning) that are supported from 12 GeV CEBAF Upgrade OPC funding, or preops, that are part of the project TPC.

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
TYPE A FACILITIES					
RHIC (BNL)	**$172,579**	**$172,522**	**$179,152**	**$186,764**	**+$7,612**
Number of Users	1,200	1,200	1,200	1,200	0
Achieved operating hours[a]	3,389	3,389	N/A	N/A	N/A
Planned operating hours	2,770	2,770	2,490	3,040	+550
Optimal hours	4,100	4,100	4,100	4,100	0
Percent optimal hours	82.7%	82.7%	60.7%	74.1%	+13.4%
Unscheduled downtime hours	0	0	N/A	NA	NA
ATLAS (ANL)[b]	**$21,892**	**$21,892**	**$22,390**	**$23,390**	**+$1,000**
Number of Users	400	420	420	420	0
Achieved operating hours[c]	6,686	6,686	N/A	NA	N/A
Planned operating hours	5,900	5,900	5,900	5,900	0
Optimal hours	6,200	6,200	6,200	6,600	+400
Percent optimal hours	107.8%	107.8%	95.2%	89.4%	-5.8%
Unscheduled downtime hours	0	0	N/A	NA	NA
Total Scientific User Facility Operations	**$302,926**	**$303,926**	**$311,632**	**$324,519**	**+$12,887**
Number of Users	3,000	3,000	3,000	3,000	0
Achieved operating hours	10,075	10,075	N/A	N/A	N/A
Planned operating hours	8,670	8,670	8,390	11,830	+3,440
Optimal hours	10,300	10,300	10,300	14,030	+3,730
Percent of optimal hours[d]	85.5%	85.5%	64.6%	79.7%	+15.1%
Unscheduled downtime hours	0	0	N/A	N/A	NA

[a] While the length of the RHIC run was just slightly longer than planned (22.4 weeks vs. 22 weeks planned), RHIC was able to achieve 122% of the planned operating hours in FY 2015 as a result of outstanding performance and record reliability of the machine (87.5% vs. 82.5% planned). The high machine reliability, excellent performance of machine upgrades and of both detectors, and a very effective ramp-up of the luminosity allowed RHIC to exceed the luminosity goals for the two scheduled modes in FY 2015, p+p and p+Au.

[b] The optimal hours at ATLAS in FY 2015–2017 vary due to planned downtime for installation of upgrades.

[c] ATLAS was able to achieve 113% of the planned operating hours in FY 2015 as a result of postponing planned maintenance and installation of equipment in order to maximize the time and benefits of the reaccelerated CARIBU beam campaign with GRETINA.

[d] For total facilities only, this is a "funding weighted" calculation FOR ONLY TYPE A facilities: $\frac{\sum_1^n[(\%OH\ for\ facility\ n)\times(funding\ for\ facility\ n\ operations)]}{Total\ funding\ for\ all\ Type\ A\ facility\ operations}$

Scientific Employment

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Estimate	FY 2017 vs. FY 2016
Number of permanent Ph.D.'s (FTEs)	844	844	820	825	+5
Number of postdoctoral associates (FTEs)	344	344	330	330	0
Number of graduate students (FTEs)	522	522	510	530	+20
Other[a]	1,050	1,050	1,035	1,035	0

[a] Includes technicians, engineers, computer professionals, and other support staff.

14-SC-50, Facility for Rare Isotope Beams (FRIB)
Michigan State University (MSU), East Lansing, MI
Project is for a Cooperative Agreement

1. Significant Changes and Summary

Significant Changes

This Project Data Sheet (PDS) is an update of the FY 2016 PDS and does not include a new start for FY 2017. There are no significant changes.

Summary

The most recent approved Critical Decision (CD) for the Facility for Rare Isotope Beams (FRIB) project is CD-3B, Approve Start of Construction of the Accelerator and Experimental Systems, which was approved on August 26, 2014, with a DOE Total Project Cost (TPC) of $635,500,000, and a scheduled CD-4 by 3Q FY 2022. Michigan State University (MSU) is providing an additional cost share of $94,500,000, bringing the total project cost to $730,000,000. Start of civil construction officially began in March 2014, and technical construction began in August 2014. Since the start of the civil and technical construction, multiple independent project assessments have determined the project is proceeding on track within the established project baseline. There are no changes in the scope, cost, and schedule since the establishment of the project's baseline.

FRIB is funded through a cooperative agreement financial assistance award with MSU per 10 CFR 600, and the project is required by this agreement to follow the principles of the DOE Order 413.3B. Funding tables contained in sections 3, 5, and 6 of this PDS differ slightly in how the baseline is presented from a traditional PDS for a federal capital asset construction project in that they include the MSU cost share. The table in section 7, Schedule of Appropriation Requests, displays only DOE funding.

A Federal Project Director with certification level 4 has been assigned to this project and approves this PDS.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3A	CD-3B	D&D Complete	CD-4
FY 2011	2/9/2004		4Q FY 2010	TBD	TBD	TBD	TBD	N/A	FY 2017–2019
FY 2012	2/9/2004		9/1/2010	4Q FY 2012	TBD	TBD	TBD	N/A	FY 2018–2020
FY 2013	2/9/2004		9/1/2010	TBD	TBD	TBD	TBD	N/A	TBD
FY 2014	2/9/2004		9/1/2010	3Q FY 2013	TBD	3Q FY 2013	TBD	N/A	TBD
FY 2015	2/9/2004		9/1/2010	8/1/2013	4Q FY 2014	8/1/2013	4Q FY 2014	N/A	3Q FY 2022
FY 2016	2/9/2004	9/1/2010	9/1/2010	8/1/2013	8/26/2014[a]	8/1/2013	8/26/2014	N/A	3Q FY 2022
FY 2017	2/9/2004	9/1/2010	9/1/2010	8/1/2013	8/26/2014[a]	8/1/2013	8/26/2014	N/A	3Q FY 2022

[a] This date represents when the design was substantially complete to allow the start of technical construction (CD-3B). A limited amount of design effort will continue through 4Q FY 2017.

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

3. Project Cost History[a]

(dollars in thousands)

	Design/ Construction	R&D/Conceptual Design/NEPA	Pre-Operations	Total TPC	Less MSU Cost Share	DOE TPC
FY 2015	655,700	24,600	49,700	730,000	-94,500	635,500
FY 2016	655,700	24,600	49,700	730,000	-94,500	635,500
FY 2017	655,700	24,600	49,700	730,000	-94,500	635,500

4. Project Scope and Justification

Scope
FRIB scope includes the design, construction, fabrication, assembly, testing, and commissioning of the civil and technical scope that will enable high intensity primary beams of stable isotopes to be accelerated up to a minimum energy of 200 MeV per nucleon by a superconducting linear accelerator (linac) capable of delivering 400 kW of beam power at full energy. The scope also includes the capability for secondary beams of rare isotopes to be produced "in-flight" and separated from unwanted fragments by magnetic analysis. In support of these capabilities, the civil construction portion includes a structure of approximately 220,000 square feet that will house the linac tunnel, target high bay area, linac support area, and cryoplant area. The technical scope includes a 2K/4.5K cryogenics plant, linac front end, cryomodules, and experimental systems.

CD-4 Key Performance Parameters

System	Parameter	Performance Criteria
Accelerator System	Accelerate heavy-ion beam	Measure FRIB driver linac Argon-36 beam with energy larger than 200 MeV per nucleon and a beam current larger than 20 pico nano amps (pnA).
Experimental Systems	Produce a fast rare isotope beam of Selenium-84	Detect and identify Selenium-84 isotopes in FRIB fragment separator focal plane
	Stop a fast rare isotope beam in gas and reaccelerate a rare isotope beam	Measure reaccelerated rare isotope beam energy larger than 3 MeV per nucleon
Conventional Facilities	Linac tunnel	Beneficial occupancy of subterranean tunnel structure of approximately 500 feet path length (minimum) to house FRIB driver linear accelerator
	Cryogenic helium liquefier plant—building and equipment	Beneficial occupancy of the cryogenic helium liquefier plant building and installation of the helium liquefier plant complete
	Target area	Beneficial occupancy of target area and one beam line installed and ready for commissioning

[a] Because this project is funded with operating dollars through a financial assistance award, its baseline is categorized through a work breakdown structure (WBS), which is slightly different from typical federal capital assets. Note that the project's WBS totals $730,000,000 including MSU's cost share. The WBS scope is not pre-assigned to DOE or MSU funds.

As contractually required under the financial assistance award agreement, FRIB is being conducted in accordance with the project management principles in DOE O 413.3B, Program and Project Management for the Acquisition of Capital Assets, and all appropriate project management requirements have been met.

Justification

The science which underlies the FRIB mission is a core competency of nuclear physics: understanding how protons and neutrons combine to form various nuclear species; understanding how long chains of different nuclear species survive; and understanding how one nuclear species decays into another and what is emitted when that happens. Forefront knowledge and capability in this competency is essential, both for U.S. leadership in this scientific discipline and to provide the knowledge and workforce needed for numerous activities and applications relevant to national security and economic competitiveness.

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

FRIB is optimized to produce large quantities of a wide variety of rare isotopes by breaking stable nuclei into rare isotopes. High intensity primary beams of stable isotopes are produced in Electron Cyclotron Resonator (ECR) ion sources and accelerated up to a minimum energy of 200 MeV per nucleon by a superconducting linear accelerator capable of delivering 400 kW of beam power at full energy. Secondary beams of rare isotopes are produced "in-flight" and separated from unwanted fragments by magnetic analysis. These rare isotope beams are delivered to experimental areas or stopped in a suite of ion-stopping stations where they can be extracted and used for experiments at low energy, or reaccelerated for astrophysical experiments or for nuclear structure experiments. The project includes the necessary infrastructure and support facilities for operations and the 1,000-person user community.

5. Financial Schedule[a]

	(dollars in thousands)		
	Appropriations	Obligations	Costs[b]
DOE Total Project Cost (TPC)			
FY 2009	7,000	7,000	4,164
FY 2010	12,000	12,000	13,283
FY 2011	10,000	10,000	11,553
FY 2012	22,000	22,000	18,919
FY 2013	22,000	22,000	20,677
FY 2014[c]	55,000	55,000	48,369
FY 2015	90,000	90,000	79,266
FY 2016	100,000	100,000	113,000
FY 2017	100,000	100,000	102,000
FY 2018	97,200	97,200	98,200
FY 2019	75,000	75,000	76,000

[a] The funding profile represents DOE's portion of the baselined TPC to be provided through federal appropriations.
[b] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.
[c] The first project data sheet submitted for FRIB was in the FY 2015 Congressional Budget Request. It was established as a control point in the FY 2014 appropriation. Funding for the project in FY 2013 and prior years was provided within the Low Energy subprogram.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[b]
FY 2020	40,000	40,000	41,000
FY 2021	5,300	5,300	6,300
FY 2022	0	0	2,769
Total, DOE TPC	635,500	635,500	635,500

6. Details of Project Cost Estimate[a]

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Design & Construction			
Management and Support	40,817	41,340	35,400
Conventional Facilities	191,302	165,720	165,300
Accelerator Systems	258,465	244,837	241,400
Experimental Systems	58,259	54,916	55,000
Contingency (DOE Held)	106,907	148,937	158,650
Total, Design & Construction	655,750	655,750	655,750
Other Costs			
Conceptual Design/Tech R&D/NEPA	24,640	24,640	24,600
Pre-ops/Commissioning/Spares	34,995	34,995	35,500
Contingency (DOE Held)	14,615	14,615	14,150
Total, Other Costs	74,250	74,250	74,250
Total, TPC	730,000	730,000	730,000
Less MSU Cost Share	-94,500	-94,500	-94,500
Total, DOE TPC	635,500	635,500	635,500
Total, Contingency (DOE Held)	121,522	163,552	172,800

7. Schedule of Appropriation Requests[b]

(dollars in thousands)

		Prior Years	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	Outyears	Total
FY 2011	TPC	29,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2012	TPC	59,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2013	TPC	51,000	22,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2014	TPC	51,000	22,000	55,000	TBD	TBD	TBD	TBD	TBD	TBD
FY 2015 PB[c]	TPC	51,000	22,000	55,000	90,000	100,000	100,000	97,200	120,300	635,500
FY 2016	TPC	51,000	22,000	55,000	90,000	100,000	100,000	97,200	120,300	635,500
FY 2017	TPC	51,000	22,000	55,000	90,000	100,000	100,000	97,200	120,300	635,500

[a] This section shows a breakdown of the total project cost of $730,000,000, which includes MSU's cost share. The scope of work is not pre-assigned to DOE or MSU funds.

[b] The funding profile represents DOE's portion of the baselined TPC to be provided through federal appropriations.

[c] The Performance Baseline was approved August 1, 2013. The first project data sheet submitted for FRIB was in the FY 2015 Congressional Budget Request. It was established as a control point in the FY 2014 appropriation. Funding for the project prior to that time was provided within the Low Energy subprogram.

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	3Q FY 2022
Expected Useful Life (number of years)	20
Expected Future Start of D&D of this capital asset	NA[a]

(Related Funding requirements)

(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations[b]	90,000	90,000	1,800,000[c]	1,800,000

9. D&D Information

The FRIB project is being constructed at MSU under a cooperative agreement financial assistance award. The one-for-one requirement, which requires the demolition of a square foot of space for every square foot added, is not applicable, since this is not a federal capital acquisition.

10. Acquisition Approach

FRIB project activities will be accomplished following all procurement requirements, which include using fixed-priced competitive contracts with selection based on best value. MSU has contracted for the services of an architect-engineer firm for the design of the conventional facilities. The Driver Linac and Experimental System components will be self-performed by the MSU design staff with assistance from outside vendors and from DOE national laboratories that possess specific areas of unique expertise unavailable from commercial sources. Integration of the conventional facilities with the Driver Linac and Experimental Systems will be accomplished by the MSU FRIB Project Team.

[a] Per the financial assistance award agreement, MSU is responsible for D&D.
[b] Utilities, maintenance, and repair costs are included within the Operations amounts.
[c] The total operations and maintenance (O&M) is estimated at an average annual cost of approximately $90,000,000 (including escalation) over 20 years.