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 visible 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 how novel forms of bulk, strongly interacting matter behave, such as the quark-gluon plasma that formed in the early universe.
- **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 performing 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 calculations of the interactions of quarks and gluons described by the theory of QCD using 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 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 U.S. participation in select international collaborations. It provides more than 90 percent of the nuclear science research funding in the U.S., resulting in an average of approximately 90 Ph.D. degrees awarded annually to students for research supported by the program. As documented in the 2015 Nuclear Science Advisory Committee (NSAC) Long Range Plan for Nuclear Science, *Reaching for the Horizon*[a], over 40% of the scientists who receive Ph.D.'s in nuclear science find careers in sectors other than academia and DOE research laboratories, serving national needs in defense, government and industry. NP research is guided by DOE's mission and priorities. It develops the core competencies and expertise needed to achieve the goals of the NP program and trains the next generation of nuclear scientists. 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 advanced instrumentation and world-class facilities used in experiments. The national laboratories provide state-of-the-art resources for targeted detector and accelerator research and development (R&D) for future upgrades and

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[a] "*Reaching for the Horizon: The 2015 Long Range Plan for Nuclear Science*." Nuclear Science Advisory Committee, October 2015 (https://science.energy.gov/~/media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf).

new facilities. This research develops knowledge, technologies, and trained scientists to design and build next-generation NP accelerator facilities. It is also relevant to machines being developed by other domestic and international programs.
The world-class scientific user facilities and associated instrumentation necessary to advance the U.S. nuclear science program 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). In FY 2017, these facilities provide particle beams for an international user community of over 3,000 research scientists. Approximately 30 percent of these researchers are from institutions outside of the U.S. and they 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 such as High Energy Physics (HEP) and Basic Energy Sciences (BES), DOE Offices such as National Nuclear Security Administration (NNSA) and Nuclear Energy (NE), Federal agencies such as the 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 research programs important for their respective missions. The 12 GeV CEBAF Upgrade project will be completed in 2017 and the highly anticipated science program it enables will be initiated. 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). This project started in FY 2014 and it is already over 70% complete.

The 2015 NSAC Long Range Plan (LRP) for Nuclear Science recommended that a high-energy, high-luminosity polarized Electron Ion Collider (EIC) be considered the highest priority for new facility construction following the completion of FRIB. Consistent with that vision, NP developed a strategic plan in 2016 to assess the uniqueness and scientific merit of such a facility via a National Academy of Sciences (NAS) study by an independent panel of external experts. Further, NP convened a panel of experts to carry out a community-based review to identify critical R&D needed to reduce risk and establish the basic feasibility of various machine concepts for an electron-ion collider. EIC related R&D efforts will align with the priorities identified in this report.

Involving students in the development and construction of NP facilities and advanced instrumentation, and 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 that are 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, national defense, 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 2018 Budget Request

The 2018 President's Request funding level of $502,700,000 is a decrease of 18.54% relative to the FY 2016 Enacted level. The FY 2018 Budget Request continues support for high priority efforts and capabilities in nuclear science to optimize scientific productivity within available resources. Critical infrastructure, scientific user facilities, and R&D efforts are prioritized to maintain U.S. leadership in some areas of nuclear science for continuing high priority activities, while the funding decrease requires a reduction in program scope. Support will continue for discovery science research and R&D integration to facilitate the development of important new applications for medicine, commerce and national security. Advances will continue to be enabled by world-class experimental user facilities and Nobel prize-worthy theoretical and experimental nuclear physics research. In addition, the DOE Isotope Program will continue to introduce new medical isotopes to the community for clinical trials and cancer therapy, and modest support is provided for stable isotope enrichment capabilities in the United States to replenish U.S. inventory and reduce foreign dependence on isotopes of strategic importance for the nation.

The Request for *Research* supports university and laboratory researchers so that critical core competencies are preserved and enables high priority theoretical and experimental activities to pursue compelling scientific opportunities at the frontier of nuclear science. Laboratory research activities focus on domestic nuclear science programs and on optimizing existing scientific instrumentation in the nuclear science enterprise in the federal complex. The rescoped university research program is focused on priorities of the restructured nuclear physics program. A reduction in university and laboratory scientists is expected. The FY 2018 Request supports world-class research in multiple scientific thrusts of nuclear science. These include:

- Initial experimental and theoretical exploitation of the new capabilities enabled by the 12 GeV CEBAF Upgrade to unravel the mechanism of quark confinement;
- Discovery research at RHIC, the nation's only remaining collider, to search for a critical point in the phase diagram of QCD matter and further characterize the quark-gluon plasma (QGP) discovered at RHIC that last existed at the beginning of the cosmos;
- Challenging new experiments at ATLAS to study nuclear structure and nuclear reactions occurring under extreme conditions in the cosmos that are conjectured to play a central role in the synthesis of heavy elements;
- High priority, critically needed accelerator R&D to retire potentially "show-stopping" technical challenges to the realization of a possible U.S.-based Electron-Ion Collider (EIC);
- Pioneering R&D in neutrino-less double beta decay to determine whether the neutrino is its own anti-particle, a discovery that could fundamentally change current understanding of the physical universe;
- Forefront isotope R&D to develop new production methods for critical isotopes in high demand for the nation, including isotopes for medicine that could revolutionize therapy for metastasized cancer, and the development of enriched stable isotope production capabilities to reduce the nation's dependence on foreign supplies.

The Request for *Facility Operations* includes funding for the operations of the NP scientific user facilities. A reduction in operations staff is expected. In the short-term, investments in maintaining and/or improving operational reliability and new facility capabilities, such as capital equipment and accelerator improvement projects, are paused, and efforts are redirected to operations of the facility to enable world-class science and the optimization of existing capabilities:

- RHIC operates for 1,470 hours (~10-weeks). The Low Energy RHIC e-Cooler (LEReC) project, an accelerator improvement project that will be soon completed, is implemented in the accelerator, enabling new capability to further increase luminosity in order to carry out a definitive search for a critical point in the phase diagram of QCD matter;
- CEBAF operates for 1,070 hours (~10 weeks) to launch the highly anticipated science program of the newly constructed 12 GeV machine and associated experimental instrumentation;
- ATLAS operates as the world's premiere stable ion beam facility for 2,620 hours (~23 weeks) to enable compelling experiments in nuclear structure and astrophysics;
- Isotope production facilities are supported, with maintenance deferred in the short term, in order to ensure mission readiness for isotope production. These facilities produce isotopes in short supply that are critical to the nation's federal complex, research enterprise and industry. University isotope production capabilities begin to be networked into the DOE Isotope Program for the eventual coordination of regional production of high priority short-lived isotopes. Operation of the Enriched Stable Isotope Prototype Plant (ESIPP) is maintained and poised to begin to replenish U.S. inventory and reduce dependence on foreign suppliers.

The Request for *Construction and Major Items of Equipment (MIEs)* includes:

- Construction of the Facility for Rare Isotope Beams (FRIB), which will provide world-leading capabilities for nuclear structure and nuclear astrophysics, continues; the project has made impressive progress since it started in FY 2014 and it is over 70% complete. The project will be rebaselined to reflect an increased Total Project Cost and schedule delay as a result of a decrease in its funding in FY 2018 relative to the current funding baseline profile.
- The Gamma-Ray Energy Tracking Array (GRETA) MIE, proposed to be initiated in the FY 2017 President's Request, is funded at a reduced level relative to original plans. GRETA will enable provision of advanced, high resolution gamma ray detection capabilities for FRIB;
- The Stable Isotope Production Facility (SIPF) MIE, which is supported at a reduced pace relative to original plans. Proposed to be initiated in the FY 2017 President's Request, SIPF will provide increased domestic capability for production of critically needed enriched stable isotopes, and reduce the nation's dependence on foreign supply.

Nuclear Physics
Funding ($K)

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
Medium Energy Nuclear Physics				
Research	34,411	—	25,316	-9,095
Operations	99,672	—	88,598	-11,074
SBIR/STTR and Other	18,457	—	16,253	-2,204
Total, Medium Energy Nuclear Physics	**152,540**	**—**	**130,167**	**-22,373**
Heavy Ion Nuclear Physics				
Research	36,036	—	20,943	-15,093
Operations	172,088	—	164,738	-7,350
Total, Heavy Ion Nuclear Physics	**208,124**	**—**	**185,681**	**-22,443**
Low Energy Nuclear Physics				
Research	54,263	—	33,233	-21,030
Operations	27,402	—	19,222	-8,180
Total, Low Energy Nuclear Physics	**81,665**	**—**	**52,455**	**-29,210**
Nuclear Theory				
Theory Research	37,616	—	27,749	-9,867
Nuclear Data	8,022	—	5,537	-2,485
Total, Nuclear Theory	**45,638**	**—**	**33,286**	**-12,352**
Isotope Development and Production for Research and Applications				
Research	6,329	—	5,307	-1,022
Operations	15,304	—	15,804	+500
Total, Isotopes[c]	**21,633**	**—**	**21,111**	**-522**
Subtotal, Nuclear Physics	**509,600**	**508,631**	**422,700**	**-86,900**

[a] The FY 2016 Enacted level includes SBIR and STTR and reflects updates through the end of the fiscal year.

[b] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

[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 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
Construction				
06-SC-01, 12 GeV CEBAF Upgrade, TJNAF	7,500	7,486	0	-7,500
14-SC-50, Facility for Rare Isotope Beams	100,000	99,810	80,000	-20,000
Total, Construction	**107,500**	**107,296**	**80,000**	**-27,500**
Total, Nuclear Physics	**617,100**	**615,927**	**502,700**	**-114,400**

SBIR/STTR Funding:

- FY 2016 Transferred: SBIR: $14,040,000; STTR: $2,106,000
- FY 2018 Request: SBIR $12,941,000 and STTR $1,820,000

Nuclear Physics
Explanation of Major Changes ($K)

	FY 2018 vs FY 2016
Medium Energy Nuclear Physics: Funding is provided for operation of the recently upgraded CEBAF accelerator to support 1,070 operating hours and experimental activities in some of the newly upgraded experimental halls to launch the highly anticipated 12 GeV CEBAF 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. 12 GeV researchers from national laboratories and universities implement, commission, and operate new experiments at CEBAF. National laboratory and university research support is reduced and several activities within the Medium Energy program are ended to enable the high priority 12 GeV science program. These include the RHIC Spin program focused on understanding the spin structure of the proton, and the Research and Engineering Center at the Massachusetts Institute of Technology, a University Center of Excellence within the nuclear science portfolio. Funding decreases for mandatory SBIR/STTR for the NP program.	**-22,373**
Heavy Ion Nuclear Physics: Funding for operations of RHIC is provided to enable world-leading research in heavy ion nuclear physics in order to answer fundamental questions about the properties of the quark-gluon plasma discovered there and about the scientific explanation of intriguing new phenomena resulting from that discovery. A 1,470 hour run in FY 2018 will focus on measurements to explore how magnetic fields generated in RHIC collisions, as strong as any in the known universe, influence the properties of the quark-gluon plasma, a state of matter that existed in the infant universe. A collateral goal of the FY 2018 run is the first direct confirmation of the restoration of chiral symmetry - the symmetry of nature responsible for the generation of the mass of the visible universe. U.S. participation in the complementary CERN Large Hadron Collider (LHC) heavy ion program is ended, and national laboratory and university research is reduced. Research efforts focus to support the domestic heavy ion program at RHIC – data taking, analysis and the enhancement of existing scientific instrumentation and infrastructure.	**-22,443**
Low Energy Nuclear Physics: The ATLAS facility continues to provide critical capabilities for nuclear structure and astrophysics research and operates approximately 2,620 hours in FY 2018. Funding decreases, as planned, for disposition activities of the closed down Holifield Radioactive Ion Beam Facility (HRIBF), which are completed in FY 2017. National laboratory and university research support is reduced to support highest priority efforts and core competencies. Research in neutrinoless double beta decay focusses on completing existing experiments such as the CUORE experiment and the Majorana Demonstrator; efforts to develop new candidate technologies for a next generation neutrinoless double beta decay experiment are paused. Operations of two University Centers of Excellence, Texas A&M and The High Intensity Gamma Source (HIGS) at Duke University, are paused. Operations of the 88” Cyclotron at LBNL for an in-house nuclear science program are paused and efforts focus on the implementation of new capabilities for the Super Heavy Element program that aims to discover new elements on the periodic table. The pause in operations will impact the Department of Defense Space radiation Effects Electronics (SEE) testing program. Development of small scientific instrumentation for FRIB is paused to focus efforts on construction of the facility itself. The GRETA MIE, proposed to start in the FY 2017 President’s Request, continues in FY 2018 at a pace determined by available resources to address certain aspects of engineering design and long-lead procurement; 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 is a high resolution gamma array tracking device that will provide a combination of high efficiency, good background suppression, and excellent energy and position resolution in order to fully exploit the opportunities at FRIB for both fast fragmentation and reaccelerated beams.	**-29,210**

	FY 2018 vs FY 2016
Nuclear Theory: Support for theory research efforts at laboratories and universities, as well as for the U.S. Nuclear Data Program and SCIDAC, is reduced. University and laboratory scientists refocus their efforts on activities within the nation's nuclear physics portfolio that are supported in the FY 2018 Request. Investments in Lattice Quantum Chromodynamics Dynamics computing hardware is paused to enable focus on high priority theoretical efforts.	**-12,352**
Isotope Development and Production for Research and Applications: Operations funding provided to support mission readiness for production activities at national laboratory facilities is decreased. Arrangements are continued to position the isotope program to network a suite of university accelerators and reactors for cost-effective, regional production of short-lived isotopes for research and medical applications. The first member of the university network, the University of Washington, began producing astatine-211 for cancer therapy research in FY 2016. Modest funding for operations of the ESIPP is provided to produce small quantities of enriched stable isotopes for research applications. The Stable Isotope Production Facility (SIPF) MIE, proposed to initiate in the FY 2017 President's Request, continues at a pace determined by available resources. When completed, SIPF will produce needed domestic capability for producing enriched stable isotopes for research, defense and industry. Isotope research funding at universities and laboratories is decreased and will focus on the development of new production techniques for high priority isotopes. In particular, effort continues on the production of Ac-225, a promising therapeutic for metastasized cancers, to the levels needed for clinical trials.	**-522**
Construction: Construction funding continues according to a re-baselined profile for the Facility for Rare Isotope Beams in FY 2018. Support for the 12 GeV Upgrade at CEBAF, which is completed in 2017, is ended in accordance with its construction profile.	**-27,500**
Total, Nuclear Physics	**-114,400**

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 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, which recently stood up an Inter-Agency working group including NE, NNSA, the Department of Homeland Security (DHS), and the Domestic Nuclear Detection Office (DNDO), provides evaluated cross-section and decay data relevant to a broad suite of Federal missions and topics such as reactor design (e.g., of interest to the NE and Fusion Energy Sciences [FES] programs), materials under extreme conditions (of interest to the BES and FES programs), and nuclear forensics (NNSA, 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 (NIH, HEP); and research in developing neutron, gamma, and particle beam sources with applications in cargo screening and nuclear forensics (NNSA, DHS, DNDO, 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 that are critical for basic research and applications. It also supports research on the development of new or improved production and separation techniques for 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
First 12 GeV Electrons from the Newly Upgraded Continuous Beam Accelerator Facility (CEBAF). The newly commissioned CEBAF delivered its first 12 GeV electrons on December 14, 2015, to its new experimental Hall D complex, as planned. The successful achievement came as part of the ongoing 12 GeV CEBAF Upgrade project scheduled to be completed in September 2017. Hall D, the new and fourth experimental hall at CEBAF, is the home of the GLUEX detector focused on landmark measurements of exotic, heretofore unseen subatomic particles thought to result from excitations of gluons that interact with the up and down quarks inside protons and neutrons. Observations of such exotic particles will provide unprecedented opportunity to advance understanding of quantum chromodynamics (QCD), the theory of the strong force. Thanks to a recent upgrade to allow simultaneous four-hall operation for science data taking, Hall D will contribute not only to new scientific reach, but record levels of scientific productivity when CEBAF begins full operation.

Heavy Quarks at RHIC Go Tubing in the Quark-Gluon Plasma. One of the earliest signature discoveries at RHIC was that in the Quark-Gluon Plasma (QGP), a form of matter which existed microseconds after the Big Bang, all particles containing light up and down quarks collectively flow together out of the hot, dense region where the QPG is formed. Early predictions suggested the same flow would not be observed for the much more massive charm and beauty quarks because they were too heavy to be pushed along with the flow of the expanding plasma. Surprisingly, however, recent results from RHIC, enabled by record luminosity and new state-of-the-art silicon tracking detectors, show that heavy quarks do indeed flow, although they do not fully keep up with their lighter quark counterparts. These measurements give new insights into the remarkable strength of the collective motion of quarks inside the QGP formed at RHIC, and its transport properties at the instant of formation.

Newcomers Join the Official Table of the Elements. After a rigorous effort to confirm their discovery, the International Union for Pure and Applied Chemistry recently accepted claims for the observation of *four* new elements, with atomic numbers 113, 115, 117, and 118. The discovery of these “superheavies” is particularly exciting as positive indication that a long-postulated “island of stability”, where superheavy elements with lifetimes on the scale of seconds or days, may indeed exist. In recognition of the long standing NP supported U.S. collaboration and contribution to this research at ORNL, one of the new elements (117) has been named Tennessine (Ts), forever changing the Table of the Elements displayed on the walls of classrooms everywhere. Isotopes that enabled this historic research were provided by the DOE Isotope Program.

Important Milestone Reached Deep Under Ground: Final Module Commissioning for the Majorana Demonstrator. One of the most urgent Grand Challenge questions of modern physics is why the neutrino mass is so small, and whether the neutrino is its own anti-particle. A proposed candidate experiment to answer these questions, capable of detecting rare decays predicted to happen for a single nucleus only once every 10^{28} years, is currently undergoing a scaled-down feasibility study named the Majorana Demonstrator (MJD) to demonstrate the sensitivity and background levels that are needed for a larger ton-scale experiment. MJD, an experiment jointly funded by DOE-NP and NSF, is currently being implemented at the Sanford Underground Research Facility in Lead, SD. It comprises two cryostat modules, each containing more than 20 kg of high-purity germanium detectors. Two-thirds of these detectors are made from germanium that has been isotopically enriched to be 87% pure 76Ge. The project recently passed a major milestone as it began commissioning the second and final module of detectors.

Baby Steps Promise Giant Leaps in Nuclear Theory Computing: Inelastic Nuclear Reaction Calculated from First Principles Quantum Chromodynamics. Starting from first principles Quantum Chromodynamics (the theory of the strong force), the Nuclear Physics Lattice QCD (NPLQCD) Collaboration has now calculated for the first time, the rate for the capture of a low-energy neutron by a proton to produce a deuteron and a gamma ray, the $np \rightarrow d\gamma$ radiative capture process. Although one of the simplest, most basic inelastic nuclear reactions, this process has enormous consequences for understanding the process of nucleo-synthesis following the Big Bang which initiated the production of most light nuclei in the cosmos. To accomplish this landmark result, the Collaboration relied heavily on recent advances in high-performance computing (HPC), determining the short-distance two-nucleon interactions with the electromagnetic field and extrapolating the results to the physical pion mass.

Thin Skinned Calcium-48. In order to build a Ca-48 nucleus (20 protons and 28 neutrons) “from the ground up”, an international team led by ORNL used ORNL’s Titan supercomputer was assembled to solve this emergent, strongly correlated, many-body system, and to compute the neutron distribution in the Ca-48 nucleus. Surprisingly, they found that the predicted difference between the radii of the neutron and proton distributions in Ca-48 (called the “neutron skin”) is considerably smaller than previously postulated. These groundbreaking calculations now become the subject of planned experimental measurements at TJNAF. The outcomes will have particular relevance to nuclear astrophysics, as the neutron skin thickness of such nuclei directly impacts the predicted size of neutron stars.

Tri-Laboratory Effort to Develop a Cancer-Fighting Isotope Passes a Major Milestone. Actinium-225 is an alpha-emitting radioisotope that has enormous promise as a therapeutic agent against metastatic and diffuse cancers and infectious diseases. Early studies of pharmaceuticals which incorporate Ac-225 have demonstrated extraordinary efficacy against these types of cancers and certain kinds of infection. The present supply of Ac-225 is extremely limited and barely sufficient to support these early clinical trials. In April of 2015 a collaborative effort was formed among Brookhaven National Laboratory, Los Alamos National Laboratory, and Oak Ridge National Laboratory to develop a new production route using proton accelerators. A recent review of progress determined that the research team is ahead of schedule in developing the targetry, chemistry, and transportation logistics for production of sufficient amounts of Ac-225 to support advanced research and clinical trials. The tri-laboratory team was approved to continue the effort with a focus on optimization of the technologies to create a routine and reliable supply of the isotope to support developing clinical applications.

A New Spin on the Proton. New data from high-energy polarized proton collisions at RHIC (the world’s only polarized proton collider) indicate that gluons —named for their role in binding the up and down quarks inside a proton—play a substantial role in determining the proton spin, a fundamental property which is often overlooked despite its profound influence on the structure of nuclei. The results suggest that the overall contribution from gluons might even be greater than the contribution from valence quarks, which is known to account for only a third of the proton’s spin. By determining the intrinsic contribution from both gluons and quarks, researchers are narrowing in on a final piece of the proton spin puzzle: the contribution from the orbital motion of these elusive constituents. A key factor in recent RHIC runs enabling this landmark progress has been the record luminosity (beam-beam collisions) achieved, which in a single run have exceeded the combined luminosity of all previous RHIC runs combined.

Direct evidence for Nuclei Shaped as a Pear. While most nuclei are either spherical or adopt shapes with symmetric deformations (such as the shape of a football or a doorknob), a few are predicted to have the shape of a pear. These so-called octupole-deformed nuclei come about through the coupling between pairs of nucleons (protons and neutrons) occupying close-lying orbitals within the nucleus, resulting in strong correlations. Now, for the first time, the strength of the octupole, pear-shaped deformation has been quantified in the Barium – Cerium region in Coulomb excitation experiments at ATLAS. Specifically, capability provided by the new Californium Rare Isotope Breeder Upgrade (CARIBU) at ANL allowed the first post acceleration of radioactive ^{144,146}Ba beams. Combined with the enhanced detection capability provided by the upgraded CHICO2 parallel plate avalanche chamber array and the gamma ray tracking provided by the world leading Gamma Ray Energy Tracking In-Beam Nuclear Array detector, these new measurements of the octupole deformation of ^{144}Ba constitute groundbreaking confirmation of the fidelity of nuclear models predicting octupole deformations which can now be extended into other unexplored regions of the nuclear landscape.

Swift Pace of FRIB Construction Allows Early Start of Front-end Commissioning. The FRIB project is the Office of Nuclear Physics' highest priority construction effort. Even though ground breaking of this state-of-the-art, highly complex facility started just back in March 2014, FRIB construction has already surpassed the 70% completion mark as of November 1, 2016. As construction continues, a notable accomplishment has been the production of the first FRIB ion beam with the recently installed Advanced Room Temperature Ion Source (ARTEMIS) electron-cyclotron-resonance (ECR). This ion source was commissioned on the front end of the FRIB linear accelerator (LINAC) 16 months earlier than originally planned by re-sequencing FRIB construction activities, enabling the project to retire associated risk with the front-end ion source and start the installation and commissioning of other front-end components. Over 1,400 scientists eagerly await the physics opportunities that FRIB will provide, and new collaborations to deepen theoretical understanding of FRIB science and develop new detector instrumentation are actively in pursuit.

Building a National Network for Regional Isotope Needs: The DOE Isotope Program has recently established a partnership agreement with the University of Washington (UW) to enable UW to supply astatine-211 (At-211) for pre-clinical research. Operating on a weekly production schedule, the UW processing laboratories and technical staff are able to provide the DOE Isotope Program with regional distribution of highly pure At-211 to western states in the U.S. Addressing a recommendation in the NSAC-Isotope 2015 Long-Range Plan for the DOE Isotope Program, the partnership with UW marks the first of many such potential agreements that could create a network of university-based isotope production centers capable of nationally providing short-lived radionuclides like At-211.

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. Experiments which scatter electrons off of protons, neutrons and nuclei are used to clarify the effects of the quark and gluon spins within nucleons, and the effect of the nuclear medium on the quarks and gluons. The subprogram also supports experimental searches for higher-mass “excited states” and exotic hadrons predicted by QCD, as well as studies of their various production mechanisms and decay properties.

The Medium Energy Nuclear Physics subprogram supports research at and operation of the subprogram’s primary research facility, CEBAF at TJNAF. The subprogram has provided support for spin physics research at RHIC, the only collider in the world that can provide polarized proton beams; however, in FY 2018, Medium Energy funding for RHIC is suspended to support other high priority efforts within the program, such as the launching of the 12 GeV CEBAF program. 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 continues to open up exciting new scientific opportunities, and will secure continued U.S. world leadership in this area of physics. The upgrade construction project will be completed in 2017, and the highly anticipated science program will be launched in FY 2018. 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 microscopic understanding in the 12 GeV energy regime 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 support for CEBAF includes laboratory and university scientific and technical staff needed to conduct high priority data analysis to extract scientific results. No support for capital equipment, Accelerator Improvement Projects, or General Plant Projects is provided to CEBAF in FY 2018. Reduced accelerator R&D efforts at TJNAF focus on high priority activities. Complementary special focus experiments that require different capabilities that have been supported at the High Intensity Gamma Source (HIGS) at Triangle Universities Nuclear Laboratory, Europe, and elsewhere and are paused in FY 2018 to support other high priority efforts within the program. The Research and Engineering Center of the Massachusetts Institute of Technology (MIT) has specialized infrastructure to develop and fabricate advanced instrumentation and accelerator equipment; however, the FY 2018 Request does not include funding to support the Center. The subprogram will instead redirect research efforts to other high priority efforts.

The “SBIR/STTR and Other” category within this subprogram provides funding in accordance with the Small Business Innovation Development Act and subsequent related legislation. The NP funding for the SBIR/STTR Program is technically managed by NP, resulting in commercialization opportunities in markets such as medicine, homeland security, defense, and industry as well as in products and services by U.S. small businesses that benefit NP facilities and researchers. This category 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, and NP contributions to the SC Working Capital Fund.

Research

The Medium Energy Research program, with research groups at TJNAF, BNL, ANL, LANL, and LBNL, and approximately 75 scientists and 60 graduate students at 20 universities, carries out highest priority research programs and conducts experiments at CEBAF; the funding decrease results in an overall reduction in laboratory and university research in the FY 2018 Request. Scientists participate in the development and implementation of advanced instrumentation, including state-of-the-art detectors for experiments that may also have application in areas such as medical imaging instrumentation and homeland security. TJNAF staff research efforts will focus on launching the 12 GeV experimental program, including the implementation of experiments, acquiring data, and performing data analysis at select CEBAF experimental halls (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. The subprogram also supports an active visiting scientist program at TJNAF and bridge positions with regional universities 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. 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. The subprogram will suspend ANL research efforts at Fermilab that were focused on determining the contribution to the proton spin from orbital angular momentum of sea quarks and antiquarks as new research efforts focus on the 12 GeV experimental program. Research groups at BNL and LBNL will play limited roles in the analysis of existing RHIC spin data focused on determining the spin structure of the proton, as this experimental program is ended.

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. Limited accelerator R&D funding in Medium Energy and Heavy Ion subprograms supports research on the most significant technical challenges and risk reduction activities associated with concepts for a possible future electron-ion collider.

Operations

The science user community, including a strong international component, uses CEBAF's polarized electron beam capabilities to study the contributions of quarks and gluons to the properties of hadrons. The subprogram provides Accelerator Operations support for the accelerator physicists at TJNAF that operate CEBAF as well as for maintenance and power costs in the first year of operations subsequent to the completion of the 12 GeV CEBAF Upgrade project in 2017. Reductions in facility staff are expected. Investments in accelerator improvements, including the modernization of the accelerator injector components, GPP investments for infrastructure, and capital equipment for research and facility instrumentation, are suspended. Support for developing advances in superconducting radiofrequency (SRF) technology relevant to improving operations of the existing machine are paused as efforts focus on the initiation of the 12 GeV science program. 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, defense, and homeland security. For example, SRF R&D 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. TJNAF accelerator physicists help train the next generation of accelerator physicists, enabled in part by a close partnership with nearby universities and other institutions with accelerator physics expertise. The subprogram provides Experimental Support for the scientific and technical staff, as well as for critical materials and supplies needed for the implementation, integration, assembly, and operation of the large and complex CEBAF experiments. Four experimental halls, increased from three prior to the 12 GeV upgrade, are now capable of providing new and enhanced capabilities for scientists world-wide.

Medium Energy Nuclear Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Medium Energy Nuclear Physics $152,540,000	**$130,167,000**	**-$22,373,000**
Research $34,411,000	**$25,316,000**	**-$9,095,000**
Researchers focused on the 12 GeV experimental program at TJNAF continued to implement and develop experimental instrumentation and prepare for the new Hall D physics capabilities which were demonstrated 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 continued.	The 12 GeV experimental program will be launched at CEBAF, with experiments and data taking in select experimental halls. 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 analyze select data from the RHIC spin run in FY 2017 that focuses on the spin structure of the proton.	The funding decrease requires a reduction in scope. Research efforts at universities and laboratories are reduced, resulting in a reduction of scientific workforce. Terminations include: support for the MIT Research and Engineering Center; Fermilab Nuclear Physics Experimental program; RHIC Spin Research program. Support will be paused for research capital equipment, shifting focus to the enhancement and implementation of existing instrumentation. The program will phase-out efforts focused on analysis and publication of select data sets.
Operations $99,672,000	**$88,598,000**	**-$11,074,000**
Funding supported 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 was provided for Other Project Costs (within project TPC), as part of the 12 GeV CEBAF Upgrade project profile. The major milestone in FY 2016 was to establish first beams to Halls B and C for commissioning activities.	Operations of the CEBAF facility will be supported in the highly anticipated first year of operations, following the completion of the project in 2017. Funding will support 1,070 operational hours (about 29% utilization) of running for research, tuning, and beam studies. Experiments in select halls will be operated for data taking.	Funding for both accelerator operations and experimental support are reduced, resulting in a reduction of ~6 weeks of operations. Program will suspend funding for capital equipment and accelerator improvement funding and for General Plant Projects. Funding reductions cannot accommodate the return of facility operations staff from the 12 GeV construction project, which will result in a reduction in the number of scientists at CEBAF. Program will reduce funding for accelerator R&D efforts in SRF technology as the focus is on launching the 12 GeV program.
SBIR/STTR and Other $18,457,000	**$16,253,000**	**-$2,204,000**
Funding was 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 SC obligations.	The decrease reflects the mandated set-aside for SBIR/STTR.

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 overarching questions in Nuclear Physics, 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. In the aftermath of collisions at RHIC and at the LHC at CERN, 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, establishing the threshold conditions (minimum nucleus mass and energy) under which the plasma can be formed, and discovering whether a the critical point exists where there is a phase transition between normal nuclear matter and the quark-gluon plasma.

The RHIC facility places heavy ion research at the frontier of discovery in nuclear physics. 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 records in performance for both integrated Au-Au luminosity at full energy and a number of other beam settings. This flexibility and performance enables a groundbreaking science program extending into the next decade to answer outstanding questions about this exotic form of matter. The FY 2017 run will test the present understanding of QCD as applied to the spin structure of the proton and will further clarify the scientific interpretation of recent heavy ion measurements. In FY 2018, RHIC will accelerate selected isotopes to explore exciting new phenomena that have emerged in quark-gluon plasma formation. In FY 2018, researchers at RHIC will implement significant accelerator improvements developed over the past couple of years to increase luminosity, enabling a campaign to search for a critical point in the phase diagram of nuclear matter the following year. Efforts will continue, within available, existing resources, to enhance the capabilities of the STAR detector, and continue limited advanced engineering and design activities for an upgrade of the PHENIX detector to sPHENIX. The subprogram will also support limited short and mid-term accelerator R&D at RHIC in critical areas that may include 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 has been used by about 1,200 DOE, NSF, and foreign agency-supported researchers annually.

Collaboration in the heavy ion program at the LHC at CERN has provided 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 comparing these results to the results at RHIC has led to important new insights. U.S. researchers have been making important scientific contributions to the emerging results from all three LHC experiments. In ALICE and CMS, U.S. researchers have been participating in developing and upgrading instrumentation for future heavy ion campaigns at the LHC. In FY 2018, NP will suspend U.S. participation in the heavy ion program at the LHC as research efforts will shift focus to the domestic heavy ion program at RHIC.

<u>Research</u>

The subprogram will support heavy ion research groups at BNL, LBNL, LANL, and ORNL to participate in experiments at RHIC. A reduction in laboratory and university research staff is anticipated due to reduced funding in the FY 2018 Request and termination of U.S. participation in the LHC heavy ion program.

The university and national laboratory research groups provide scientific personnel and graduate students for taking data within the RHIC heavy ion program; 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 data in alliance with the National Energy Research Scientific Computing Center (NERSC), which is supported by SC's ASCR program.

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. Limited accelerator R&D funding in Medium Energy and Heavy Ion accelerator R&D supports the most critical pre-conceptual Electron Ion Collider (EIC) accelerator R&D based on the priorities identified by the NP community's EIC R&D review. The focus is on the most significant technical challenges and risk reduction activities required toward the possible realization of a U.S. based EIC.

Operations

The Heavy Ion subprogram provides support for the operations and power costs of the RHIC accelerator complex at BNL. In FY 2018, the subprogram suspends support for capital equipment and accelerator improvement projects and efforts will be focused on operating the machine and enhancing capabilities of existing instrumentation and accelerator components. A reduction in facility operations staff is expected. 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. The subprogram will delay support for important improvements to extend STAR capabilities that had been planned for the FY 2019 run and search for the critical point in the phase diagram are delayed, but will continue funding these improvements as funding permits. Within available funding, a small effort will also continue on advanced conceptual engineering and design efforts associated with the planned upgrade of PHENIX to "super PHENIX" or sPHENIX. sPHENIX will enable scientists to study how the strongly interacting QGP liquid arises from the weakly interacting quarks and gluons from which it is formed.

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. Accelerator Improvement Projects have focused 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 implemented in FY 2018, after completion in 2017. RHIC accelerator physicists are providing leadership to the effort to address technical feasibility issues of relevance to a possible next-generation collider, including beam cooling techniques and energy recovery linacs; these activities focus on the highest priority challenges in accelerator R&D as funding is reduced. 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 the DOE Isotope Program 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 as well as electronics.

Heavy Ion Nuclear Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Heavy Ion Nuclear Physics $208,124,000	**$185,681,000**	**-$22,443,000**
Research $36,036,000	**$20,943,000**	**-$15,093,000**
Researchers continued to participate in the collection and analysis of new data from RHIC enabled by the 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 generated 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 provided 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 was also supported.	Researchers continue to participate in the analysis and collection of data from RHIC to explore new phenomena in quark-gluon plasma formation. Limited efforts will continue in ongoing development of instrumentation aimed at future physics campaigns to probe the properties of the QGP. Limited accelerator R&D relevant to NP programmatic needs will also be supported.	The funding decrease requires a reduction in scope at universities and national laboratories associated with implementing the RHIC and LHC science programs. The overall research support is reduced, resulting in a reduction in workforce. Additional reductions include funding for accelerator R&D directed at addressing feasibility to meet technical requirements for a future EIC. Terminations include participation of U.S. scientists in the LHC heavy ion program, including the small-scale ALICE instrumentation upgrades at the LHC; the program will shift focus on the domestic heavy ion program and will not meet U.S. commitments to the LHC heavy ion program.

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Operations $172,088,000	**$164,738,000**	**-$7,350,000**
RHIC operations provided for 2,697 beam hours, which was approximately 20 weeks and equal to 66% 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) was essential to understand results on heavy quark propagation in the quark-gluon plasma discovered at RHIC. The high statistics data completed for Run-16 addresses these phenomena and are required for researchers to interpret the data acquired from the last two years.	RHIC operations of 1,470 hours[a] (about 67% utilization) is focused on a targeted run to confirm the restoration of chiral symmetry - the symmetry of nature responsible for the generation of mass. RHIC staff will continue to develop and install instrumentation, as possible, needed for the upcoming experimental campaigns, including electron cooling. The run in FY 2018 is combined with the run in FY 2019, spanning fiscal year boundaries; the facility operates once over two fiscal years. Accelerator science staff will continue to reduce the highest technical risks associated with operating the complex facility, as well as demonstrating technical feasibility of a possible future electron-ion collider.	Reduction provides support of RHIC operations for 10 weeks. Support for capital equipment and Accelerator Improvement Projects is paused in FY 2018. Reductions in facility operations staff are expected.

[a] Optimal beam hours in FY 2018 available beam time is limited to 2,205 hours to allow for access to install upgrades to the accelerator essential for the FY 2019-20 physics campaign. The run in FY 2018 is combined with the run in FY 2019, spanning fiscal year boundaries; the facility operates once over two fiscal years.

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 indicate 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 at ANL is the only DOE-supported facility providing research opportunities in Nuclear Structure and Nuclear Astrophysics, serving a combined international community of about 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 completed in FY 2017.

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, are supported for data analysis and research efforts, but are not funded for accelerator operations. A third university center, the

Center for Experimental Nuclear Physics and Astrophysics (CENPA) at the University of Washington, is supported to provide unique expertise and capabilities for instrumentation development and leads the Project 8 neutrino mass experiment collaboration. The subprogram will pause funding for operations of the 88-Inch cyclotron at LBNL, which provides beams for a small in-house nuclear science program, which will also, also impact important capabilities in materials irradiation important for external users and other missions.

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 project will continue construction activities at a slower rate than originally planned, which will require a rebaseline in FY 2018. The Gamma-Ray Energy Tracking Array (GRETA) MIE, requested as a new start in the FY 2017 Budget Request, is continued in the FY 2018 Request at a slower pace than planned, and is one of the primary tools that the community and NSAC have identified to leverage the capabilities of FRIB. GRETA will have ten times the gamma-ray resolving power of current generation detectors 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.

<u>Research</u>

The subprogram will support Low Energy research groups at ANL, BNL, LBNL, LANL, LLNL, ORNL, and PNNL, with an expected overall reduction in laboratory and university research staff. Historically, about half of the scientists have conducted nuclear structure and astrophysics research primarily using specialized instrumentation at the ATLAS scientific user facility. The GRETA MIE is pursued at a slower pace than had been proposed in the FY 2017 budget, resulting in a delayed completion at a higher cost. Scientists primarily conduct research in fundamental symmetries, including experiments at the Fundamental Neutron Physics Beamline (FNPB) at the Spallation Neutron Source; ongoing double beta-decay experiments such as the Cryogenic Underground Observatory for Rare Events (CUORE) experiment at Gran Sasso Laboratory in Italy, the Majorana Demonstrator R&D effort at the Sanford Underground Research Facility in Lead, South Dakota, and generic R&D for a xenon-based technology for neutrinoless double beta decay experiments; a measurement of the neutrino mass with the Karlsruhe Tritium Neutrino (KATRIN) experiment at the Karlsruhe Institute of Technology in Karlsruhe, Germany; and limited R&D to measure the neutron electric dipole moment. The subprogram continues to provide support, although reduced, to the university Centers of Excellence to maintain their unique capabilities. In FY 2018, the subprogram will suspend funding for competitive R&D efforts, funded in partnership with the NSF, to retire potentially "show-stopping" questions related to detector technologies relevant for a planned down select for a future ton-scale neutrinoless double beta decay experiment are paused.

<u>Operations</u>

ATLAS provides highly reliable and cost-effective stable and selected radioactive beams and specialized instrumentation for scientists to conduct research on nuclear structure and nuclear astrophysics. The subprogram provides support for the operations, power costs and experimental support of ATLAS. The recently installed Electron Beam Ion Source (EBIS) Accelerator Improvement Project enhances the performance of the CARIBU radioactive beam system for accelerated radioactive ion beams. 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 comes online in FY 2018 to complement a gas filled analyzer completed the prior year.

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 SC mission and international stable and radioactive ion beam facilities.

Low Energy Nuclear Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Low Energy Nuclear Physics $81,665,000	**$52,455,000**	**-$29,210,000**
Research $54,263,000	**$33,233,000**	**-$21,030,000**
University and laboratory nuclear structure and nuclear astrophysics efforts continued 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. Efforts continued with the Majorana Demonstrator to demonstrate technical feasibility of a next generation detector in double beta decay. Support continued 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).	High priority university and laboratory nuclear structure and nuclear astrophysics efforts continue to focus on research at ATLAS. Support will continue on the exploration of the fundamental symmetries of nature through research focused on measuring neutrino masses (KATRIN), the lifetime and decay properties of the neutron, and lepton number violation in neutrinoless double beta decay (CUORE, EXO and the Majorana Demonstrator).	Funding reductions include support for university and national laboratory research, which will result in an anticipated reduction in workforce; MIE funding for GRETA, relative to FY 2017 according to the planned profile, in order to exploit the capabilities of FRIB. The R&D effort aimed at a down-select decision for the next generation neutrinoless double beta decay (0vbb) experiment will be suspended. Operations of the two university Centers of Excellence (HIGS and Texas A&M) accelerator facilities will be paused.
Operations $27,402,000	**$19,222,000**	**-$8,180,000**
Continued operation of ATLAS in a 7 day per week mode was a high priority as demand for ATLAS beam time continues to far exceed availability. FY 2016 funding supported 6,160 hours of beam time, and a program of modest upgrades continued for the only operating DOE-supported scientific user facility in nuclear structure and astrophysics. Support continued for equipment disposition activities at HRIBF.	Operation of ATLAS in a 5 day per week mode will be supported to address the high demand for ATLAS beam time which continues to far exceed availability. ATLAS funding will support 2,620 hours of beam time (~40% of optimal).	Funding will support a reduction of 3,280 operating hours relative to FY 2016. Funding for capital equipment and Accelerator Improvement Projects is not included in FY 2018 Request. Equipment disposition activities at HRIBF are completed in FY 2017.

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 third year of new five-year topical collaborations within the university and national laboratory communities will be supported in FY 2018 to address only the highest 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 has been 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. In FY 2018, LQCD research focuses on using existing capabilities, and the LQCD-ext II effort will be stretched out with a pause of investment in new hardware.

The Nuclear Theory subprogram also supports 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. 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 continued through FY 2016. The new group of SciDAC-4 awards selected in FY 2017 will receive continued support.

Theory Research

The Nuclear Theory subprogram supports the research programs of approximately 105 university scientists and 80 graduate students at 33 universities, as well as nuclear theory groups at seven national laboratories (ANL, BNL, LANL, LBNL, LLNL, ORNL, and TJNAF), for an overall reduction of approximately 27% in laboratory and university research staff. 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, the subprogram will continue to support the new round of 5-year topical collaborations initiated in FY 2016/FY 2017 to bring together theorists to address specific high-priority theoretical challenges is continued, possibly with reduced scope. The four new collaborations that may receive continued support are: the Beam Energy Scan Theory (BEST) Collaboration, the Coordinated Theoretical Approach to Transverse Momentum Dependent Hadron Structure in QCD (TMD) Collaboration, the Nuclear Theory for Double-Beta Decay and Fundamental Symmetries (DBD) Collaboration, and the Fission in R-process Elements (FIRE) Collaboration. The BEST and TMD proposals are intimately related to LQCD, 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 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. FIRE is jointly funded by NP and the NNSA to advance the theory of nuclear fission and explore the role of fission recycling in the creation of atomic nuclei in astrophysical environments. NP will consider how best to optimally support these compelling initiatives within available funding. The subprogram will maintain a new focused effort on FRIB theory initiated in FY 2017, which is critical to 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 2018, 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. The U.S. Nuclear Data Program recently stood up an Inter-Agency working group including NNSA, DHS, NE, DNDO, and other Federal Agencies to provide evaluated cross-section and decay data relevant to a broad suite of Federal missions and topics. Funding may also support efforts on opportunistic measurements to address serious gaps and uncertainties in existing nuclear data archives.

Nuclear Theory

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Nuclear Theory $45,638,000	**$33,286,000**	**-$12,352,000**
Theory Research $37,616,000	**$27,749,000**	**-$9,867,000**
Funding continued to support the highest priority theoretical research at universities and national laboratories for the interpretation of experimental results obtained at NP facilities. Theorists concentrated 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 focused 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 continued to support ongoing SciDAC-3 grants and the LQCD ext-II computing project. Support was provided to initiate the second round of theory topical collaborations.	Funding will continue for high 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 continue to 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 the second year of SciDAC-4 grants and the third year of the theory topical collaborations initiated in FY 2016.	The funding decrease requires a reduction in scope. Decreased funding will reduce support for university and national laboratory research and for the FRIB Theory Alliance. Reductions in workforce are anticipated.
Nuclear Data $8,022,000	**$5,537,000**	**-$2,485,000**
Nuclear data evaluation was the prime nuclear data product, combining experiment with theory and linking basic science with applications. The emphasis in FY 2016 was on the compilation and evaluation of nuclear reaction and nuclear structure data which included 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 2018 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	Decreased funding reduces the level of effort for the Nuclear Data scientists, compilers and evaluators.

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 R&D 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, archeological, and other research. Some examples are:

- strontium-82 for cardiac imaging;
- californium-252 for well logging, homeland security, 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, astatine-211, copper-67, 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 security applications;
- lithium-7 as a coolant reagent for pressurized water nuclear power plants;
- tungsten-188, lutetium-177, strontium-90, and cobalt-60 for cancer therapy; and
- arsenic-73, iron-52, and zinc-65 as tracers in metabolic studies.

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 Department of Agriculture, DHS, NNSA, and DOE SC 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

[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.

isotope production research and availability, and to communicate concerns about potential constrained supplies of important isotopes to the federal 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 (whose activities completed in FY 2017). 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 Commission 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.

The DOE Isotope Program also invests in the nation's future biomedical researchers through support for the Nuclear Chemistry Summer School (NCSS) program. The NCSS consists of an intensive six-week program of formal accredited lectures on the fundamentals of nuclear science, radiochemistry, and their applications in related fields, as well as laboratory practicums focusing on state-of-the-art instrumentation and technology used routinely in basic and applied nuclear science.

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

The subprogram supports research 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. The research program has two primary components. One is support of R&D via competitive funding opportunity announcements open to both universities and laboratories. The other is provision of core R&D funding to national laboratories that possess unique facilities and technical expertise that directly support the mission of the DOE Isotope Program. In both components, peer review is used to assess the quality of the research being performed and its relevance for assuring availability of isotopes that are in short supply and needed for research and applications important to the Nation's science and industry. There is also an emphasis in the R&D program on providing training opportunities to students and post-docs to help assure a vibrant work-force essential to the technologies associated with isotope production. 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. 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.

Operations

The Isotope Program is the 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 (PNNL) 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 establishment of a coordinated network of university based isotope production was a recommendation in the 2015 NSAC Long Range Plan. Still in its infancy, the network is designed to leverage the unique and underutilized facilities available at academic institutions which are generally more suited to low-energy production reactions and can support nationwide availability of short-lived radioisotopes. In this way, both the national laboratories and the universities are able to more efficiently meet domestic isotope production needs.

The DOE Isotope Program has invested funds since 2009 to develop stable isotope separation technology at ORNL, first identified as a high priority by the NSAC Subcommittee on Isotopes in 2009. The R&D effort is coming to a close in early FY 2017 and will result in an Enriched Stable Isotope Prototype Plant (ESIPP) to produce small research quantities of enriched stable isotopes. The prototype demonstration has been established in a facility that can be expanded and the resulting capability developed is completely scalable to produce kilogram quantities of enriched stable isotopes in a cost-effective manner. The FY 2017 appropriation initiates 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 as recommended by the NSAC Subcommittee on Isotopes in 2015. The FY 2018 Request continues funding for SIPF at a slower pace than originally planned, delaying completion at an increased cost. Examples of discovery research efforts which could benefit from the facility are neutrinoless double beta decay experiments in nuclear physics and dark matter experiments in high-energy physics that are interested in kilogram 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, 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 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Isotope Development and Production for Research and Applications $21,633,000	**$21,111,000**	**-$522,000**
Research $6,329,000	**$5,307,000**	**-$1,022,000**
Funding continued to support competitive R&D awards to universities and laboratories, as well as laboratory research groups at LANL, BNL, and ORNL. Development of production techniques for alpha-emitting radionuclides for medical therapy continued to be a priority, and was 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 also lead to new isotope production technologies and effectively engaging and training students and post-docs in nuclear chemistry and radiochemistry.	Funding continues for high priority competitive R&D activities at universities and national laboratories leading to new isotope production technologies. Core support will continue to be provided to national laboratories for the highest priority R&D that enhances isotope production capabilities specifically relevant to the physical resources and expertise available at the laboratories. Arrangements will be made towards the implementation of a university network for short-lived high priority medical isotopes.	Support for national laboratory and university research is reduced.
Operations $15,304,000	**$15,804,000**	**+$500,000**
Support provided for infrastructure and maintenance of facilities, core competencies in isotope production and development, and for the NIDC. The maintenance of aging facilities continued to be a funding priority to maintain isotope production capabilities. Funding for program investments and production of particular isotopes was 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.	Funding will provide support for high priority activities needed for mission readiness of the isotope production facilities and the most critical core competencies in isotope production and development. Funding will also support the highest priority activities of the NIDC. Operations of the enriched stable isotope prototype will be initiated to provide the capability to produce small research quantities of enriched stable isotopes, and modest funding continues for the Stable Isotope Production Facility (SIPF) MIE.	Funding is provided for the Stable Isotope Production Facility (SIPF) MIE at a reduced pace than originally planned. Support for the mission readiness of isotope production facilities is reduced relative to current operations by deferring maintenance and enhancements relevant to isotope production. Support for the NIDC is decreased, impacting effective responses to customer inquiries and isotope business operations. Operations of the new stable isotope production prototype is limited.

Description

Consistent with the 2015 NSAC Long-Range Plan's highest priority, the FY 2018 Request includes funding to capitalize on NP's prior scientific facilities investments. Funding in this subprogram provides for design and construction of scientific research facilities needed to meet overall objectives of the Nuclear Physics program. NP currently has two ongoing projects, for which only one will be receiving construction line item funding in FY 2018.

The 12 GeV CEBAF Upgrade at TJNAF will enable scientists to address one of the mysteries of modern physics—the mechanism of quark confinement. The project will be completed in 2017.

The Facility for Rare Isotope Beams (FRIB) at Michigan State University (MSU) continues construction activities in FY 2018 at a slower pace than originally planned, which will require a rebaseline in FY 2018. The completion date will be delayed and the total cost of the project will increase. 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 1,400 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 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Construction $107,500,000	**$80,000,000**	**-$27,500,000**
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 supported procurements, fabrication, installation, and commissioning of the experimental equipment primarily in Halls B and C; and addressed continuing project risks in order to optimize the successful completion of this project within the current TEC baseline. FY 2016 was the final year of TEC funding for the project as it works towards completion (CD-4B) by the end of FY 2017.	Construction complete. No funding requested in FY 2018.	Construction of the 12 GeV Upgrade to CEBAF will be completed in 2017.
14-SC-50, Facility for Rare Isotope Beams (FRIB) $100,000,000	**$80,000,000**	**-$20,000,000**
Work on conventional facilities continued as well as construction of items such as the linear accelerator (linac) tunnel and the target, linac support, and cryoplant areas. The technical systems were fully underway including efforts such as major procurements, fabrication, and assembly for technical components such as the linac, cryomodules, and experimental systems.	FY 2018 funding will support the construction of the cryogenic plant and distribution system. The funds will also support the procurement, fabrication, assembly, and installation of technical systems within the conventional facilities that are scheduled to be substantially complete in FY 2017. These technical systems include systems such as the linac front end, cryomodules, and experimental systems.	The funding decrease requires the project to re-baseline its profile. The planned completion date will be delayed and the Total Project Cost will increase by approximately $20M.

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.

	FY 2016	FY 2017	FY 2018
Performance Goal (Measure)	**HEP 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)	**HEP Facility Operations - Average achieved operation time of HEP 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)	**HEP Neutrino Model - Carry out series of experiments to test the standard 3-neutrino model of mixing**		
Target	Physics analyses results from data taking will be presented by the NOvA and MicroBooNE experimental collaborations at the FY 2016 summer conferences.	Fermilab switches operations mode over from neutrino beam to antineutrino beam delivery to the NOvA experiment. NOvA accumulates physics data in antineutrino mode.	MicroBooNE data taking will complete final year of phase-1. NOvA will publish the first muon and electron anti-neutrino oscillation results. ICARUS data taking will begin. SBND physics commissioning will continue.
Result	Met	TBD	TBD
Endpoint Target	Similar to quarks, the mixing between neutrinos is postulated to be described by a unitary matrix. Measuring the independent parameters of this matrix in different ways and with adequate precision will demonstrate whether this model of neutrinos is correct. Such a model is needed to correctly extract evidence for CP violation in the neutrino sector.		
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)	**NP Facility Operations - Average achieved operation time of NP user facilities as a percentage of total scheduled annual operation time**		
Target	≥ 80 %	≥ 80 %	≥ 80 %

	FY 2016	FY 2017	FY 2018
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 Nuclear Structure - Conduct fundamental research to discover, explore, and understand all forms of nuclear matter.**		
Target	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.	Perform measurements in experimental halls with CEBAF to enhance our understanding of the QCD structure of nuclei and hadronic matter.
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		

Nuclear Physics
Capital Summary ($K)

	Total	Prior Years	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Capital Operating Expenses Summary						
Capital equipment	n/a	n/a	11,736	—	1,700	-10,036
General plant projects (GPP)	n/a	n/a	2,200	—	0	-2,200
Accelerator improvement projects (AIP)	n/a	n/a	5,552	—	0	-5,552
Total, Capital Operating Expenses	**n/a**	**n/a**	**19,488**	**—**	**1,700**	**-17,788**
Capital Equipment						
Gamma-Ray Energy Tracking Array (GRETA) MIE[b]	52,000–67,000	n/a	0	—	200	+200
Stable Isotope Production Facility (SIPF) MIE[a]	9,500–12,000	n/a	0	—	1,500	+1,500
Total Non-MIE Capital Equipment	n/a	n/a	11,736	—	3,004	-8,732
Total, Capital Equipment	**n/a**	**n/a**	**11,736**	**—**	**4,704**	**-7,032**
General Plant Projects						
General plant projects under $5 million TEC	n/a	n/a	2,200	—	0	-2,200
Accelerator Improvement Projects (AIP)						
RHIC Low Energy Electron Cooling	8,300	5,100	1,900	—	0	-1,900
Other projects under $5 million TEC	n/a	n/a	3,652	—	0	-3,652
Total, Accelerator Improvement Projects	**n/a**	**n/a**	**5,552**	**—**	**0**	**-5,552**

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above; below that level, a dash (-) is shown.

[b] 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. The project will be rebaselined to reflect a delayed schedule and increased TPC as a result of FY 2018 funding less than the baseline. The TPC is expected to increase by ~$20M.

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. In particular, 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 for GRETA 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 2018 Request for GRETA of $200,000 is the second year of Total Estimated Cost (TEC) funding. The Total Project Cost Range will be re-evaluated in FY 2018 to consider changes in the planned funding profile.

Isotope Development and Production for Research and Applications

The *Stable Isotope Production Facility (SIPF).* The DOE Isotope Program has invested funds since 2009 to develop stable isotope separation technology at ORNL, first identified as a high priority by the NSAC Subcommittee on Isotopes in 2009. NP is completing an R&D effort in 2017, which has resulted in a prototype capability to produce small research quantities of enriched stable isotopes. The prototype demonstration has been established in a facility that can be expanded and the resulting capability is completely scalable to produce kilogram 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, ecological and computing applications could also be produced. The FY 2017 appropriation initiates 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. MIE funding provides infrastructure and services, and optimizes the design of centrifuges to isotopes of interest. CD-0 was approved September 2015 with an estimated Total Project Cost of $9,500,000–$10,500,000. CD-1 is planned for 2017. The FY 2018 Request for SIPF of $1,500,000 is the second year of TEC funding. The Total Project Cost Range will be re-evaluated in FY 2018 to consider changes in the planned funding profile.

Nuclear Physics
Construction Projects Summary ($K)

	Total	Prior Years	FY 2016 Enacted	FY 2017 Enacted	FY 2018 Request	FY 2018 vs FY 2016
06-SC-01, 12 GeV CEBAF Upgrade, TJNAF						
TEC	310,500	303,000	7,500	0	0	-7,500
OPC	27,500	22,000	4,500	0	0	-4,500
TPC	338,000	325,000	12,000	0	0	-12,000
14-SC-50, Facility for Rare Isotope Beams						
DOE TPC	635,500[a]	218,000[b]	100,000	100,000	80,000	-20,000
Total, Construction (TPC) All Construction Projects	**n/a**	**n/a**	**112,000**	**100,000**	**80,000**	**-32,000**

Funding Summary ($K)

	FY 2016 Enacted	FY 2017 Annualized CR[c]	FY 2018 Request	FY 2018 vs FY 2016
Research	176,677	—	116,385	-60,292
Scientific User Facilities Operations	289,959	—	269,258	-20,701
Other Facility Operations	24,507	—	19,104	-5,403
Projects				
Major Items of Equipment	0	—	1,700	+1,700
Facility for Rare Isotope Beams	100,000	99,810	80,000	-20,000
12 GeV Upgrade TEC	7,500	7,486	0	-7,500
Total Projects	107,500	—	81,700	-25,800
Other[d]	18,457	—	16,253	-2,204
Total Nuclear Physics	**617,100**	**615,927**	**502,700**	**-114,400**

[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. The project will be rebaselined to reflect a delayed schedule and increased TPC as a result of FY 2018 funding less than the baseline. The TPC is expected to increase by ~$20M.

[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] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above; below that level, a dash (-) is shown.

[d] Includes SBIR/STTR funding.

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 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
TYPE A FACILITIES				
CEBAF (TJNAF)[b]	**$111,287**	**—**	**$96,318**	**-$14,969**
Number of Users	1,530	—	1,300	-230
Achieved operating hours	N/A	N/A	N/A	N/A
Planned operating hours	0	—	1,070	+1,070

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above; below that level, a dash (-) is shown.

[b] During FY 2016, there were no research hours to which the CEBAF facility was held accountable while the 12 GeV upgrade was being commissioned. In FY 2016, approximately 16 weeks of machine development were supported. The user community remained active during the shutdown with instrumentation and equipment implementation for the upgraded facility. 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 pre-ops, that are part of the project TPC. FY 2018 is the first year of operations after project completion; optimal hours increase in FY 2018 as operational experience is gained.

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
TYPE A FACILITIES				
Optimal hours	0	—	3,730	+3,730
Percent optimal hours	N/A	—	28.7%	N/A
Unscheduled downtime hours	N/A	N/A	N/A	N/A
RHIC (BNL)	**$179,152**	**—**	**$169,174**	**-$9,978**
Number of Users	1,200	—	1,020	-180
Achieved operating hours[a]	2,697	N/A	N/A	N/A
Planned operating hours	2,510	—	1,470	-1,040
Optimal hours	4,100	—	2,205[b]	-1,895
Percent optimal hours	65.8%	—	66.7%	+0.9%
Unscheduled downtime hours	0	N/A	N/A	N/A
ATLAS (ANL)	**$22,390**	**—**	**$19,086**	**-$3,304**
Number of Users	320	—	272	-48
Achieved operating hours	6,160	N/A	N/A	N/A
Planned operating hours	5,900	—	2,620	-3,280
Optimal hours[c]	6,200	—	6,600	+400
Percent optimal hours	99.4%	—	39.7%	-59.7%
Unscheduled downtime hours	0	N/A	N/A	N/A
Total Scientific User Facility Operations	**$312,829**	**—**	**$284,578**	**-$28,251**
Number of Users	3,050	—	2,592	-4058
Achieved operating hours	N/A	N/A	N/A	N/A
Planned operating hours	8,410	—	5,160	-3,250
Optimal hours	10,300	—	12,535	+2,235

[a] For achieved operations in FY 2016 RHIC was able to achieve 108% of the planned operating hours in FY 2016 as a result of outstanding performance of the machine. A very effective ramp-up of the luminosity and new techniques to provide increased beam intensity allowed RHIC to exceed the luminosity goal for the highest energy gold-gold setup. Rapid efficient setups enabled deuteron-gold measurements at 4 different energies to meet or exceed all planned goals for the FY 2016 run.

[b] Optimal beam hours in FY 2018 available beam time is limited to 2,205 hours to allow for access to install upgrades to the accelerator essential for the FY 2019-20 physics campaign. The run in FY 2018 is combined with the run in FY 2019, spanning fiscal year boundaries; the facility operates once over two fiscal years.

[c] ATLAS was able to achieve 104% of the planned operating hours in FY 2016 as a result of very high reliability.

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
TYPE A FACILITIES				
Percent of optimal hours[a]	69.5%	—	52.0%	-17.5%
Unscheduled downtime hours	0	N/A	N/A	N/A

Scientific Employment

	FY 2016 Enacted	FY 2017 Annualized CR[b]	FY 2018 Estimate	FY 2018 vs FY 2016
Number of permanent Ph.D.'s (FTEs)	823	—	586	-237
Number of postdoctoral associates (FTEs)	365	—	244	-121
Number of graduate students (FTEs)	523	—	293	-230
Other[c]	1,089	—	989	-100

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

[b]FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above; below that level, a dash (-) is shown.

[c] 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 2017 PDS and does not include a new start for FY 2018. The FY 2018 requested funding change from the original planned profile will result in an increase to the project's current baseline cost and schedule. SC will conduct a re-baseline effort following an FY 2018 appropriation.

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 project's scope since the establishment of the project's baseline. In FY 2018, the requested project funding decreases by $17,200,000 from the baseline profile. Following an FY 2018 appropriations, the project will evaluate all added risks, costs, and schedule changes resulting from this change and develop a new cost and schedule baseline, which will be reviewed and approved according to DOE guidelines.

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
FY 2018	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[b]

[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.

[b] The requested FY 2018 funding is less than the planned baseline profile. This will result in a re-baselining effort that will likely increase the project's cost, schedule, and risks.

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
FY 2018	655,700	24,600	49,700	730,000[b]	-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.
[b] The requested FY 2018 funding is less than the planned baseline profile. This will result in a re-baselining effort that will likely increase the project's cost, schedule, and risks.

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	121,769
FY 2017	100,000	100,000	100,000
FY 2018	80,000	80,000	80,000
FY 2019	75,000	75,000	75,000

[a] The funding profile represents DOE's requested portion, which is less than the current baselined TPC. This will be updated once a re-baseline effort is complete.

[b] Costs through FY 2016 reflect actual costs; costs for FY 2017 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	57,200	57,200	47,200
FY 2021	5,300	5,300	10,300
FY 2022	0	0	5,000
Total, DOE TPC	635,500	635,500	635,500[a]

6. Details of Project Cost Estimate[b]

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Design & Construction			
Management and Support	39,268	40,817	35,400
Conventional Facilities	208,201	191,302	165,300
Accelerator Systems	282,974	258,465	241,400
Experimental Systems	67,175	58,259	55,000
Contingency (DOE Held)	58,132	106,907	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	34,658	34,995	35,500
Contingency (DOE Held)	14,952	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)	73,084	121,522	172,800

[a] Due to the reduced project funding request in FY 2018 from the baseline profile, project costs are expected to increase beyond the current TPC estimate. The completion date may also be impacted.

[b] This section shows a breakdown of the total project cost of $730,000,000 as of 02/28/2017, which includes MSU's cost share. The scope of work is not pre-assigned to DOE or MSU funds.

7. Schedule of Appropriation Requests[a]

($K)

		Prior Years	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	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	73,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2014	TPC	128,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2015 PB[b]	TPC	218,000	100,000	100,000	97,200	75,000	40,000	5,300	0	635,500
FY 2016	TPC	218,000	100,000	100,000	97,200	75,000	40,000	5,300	0	635,500
FY 2017	TPC	218,000	100,000	100,000	97,200	75,000	40,000	5,300	0	635,500
FY 2018	TPC	218,000	100,000	100,000	80,000	75,000	57,200	5,300	0	635,500[c]

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[d]

(Related Funding requirements)

(dollars in thousands)

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

[a] The funding profile represents DOE's portion of the baselined TPC to be provided through federal appropriations.
[b] 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.
[c] Due to the reduced project funding request in FY 2018 from the baseline profile, it is likely that project costs will increase beyond the current TPC estimate.
[d] Per the financial assistance award agreement, MSU is responsible for D&D.
[e] Utilities, maintenance, and repair costs are included within the Operations amounts.
[f] The total operations and maintenance (O&M) is estimated at an average annual cost of approximately $90,000,000 (including escalation) over 20 years.

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.