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 that 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**:

- **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 long-term support for both theoretical and experimental research efforts within the NP portfolio. 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. Quantum computing holds great potential for obtaining solutions to many-body QCD problems that are intractable with today's 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. Nuclear physics uses low-energy, precision nuclear experiments, many enabled by new quantum sensors to search for a deeper understanding of fundamental symmetries and nuclear interactions. Comparing experimental observations and theoretical predictions tests the limits of our understanding of nuclear matter and suggests new directions for experimental and theoretical research.

Highly trained scientists who conceive, plan, execute, and interpret transformative experiments are at the heart of the NP program. NP supports these university and national laboratory scientists and U.S. participation in select international collaborations and provides approximately 93 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 (LRP) 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. DOE's mission and priorities guide NP research, which in turn develop the core competencies and expertise needed to achieve the goals of the NP program and train 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

[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).

national laboratories provide state-of-the-art resources for targeted detector and accelerator research and development (R&D) for future upgrades and new facilities. This research develops knowledge, technologies, and trained scientists to design and build next-generation NP accelerator facilities, and is 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 the NP budget. NP supports three scientific user facilities: 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). Each of these facilities has unique capabilities that advance the scientific thrusts outlined in the LRP. In FY 2019, these facilities will provide particle beams for an international user community of over 2,800 research scientists. In FY 2018, approximately 30 percent of these researchers are from institutions outside of the U.S. and they provide very significant benefits, including leveraging the U.S. program through contributed capital, human capital, and experimental equipment, as well as 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), the National Aeronautics and Space Administration (NASA), and the Department of Defense (DOD), and industries, use NP scientific user facilities and core competencies to carry out research programs important for their respective missions. The 12 GeV CEBAF Upgrade project, completed in FY 2017 on cost and schedule, offers exciting opportunities to researches to study quark structure. 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), according to a new baseline cost and schedule. This project is over 82% complete and will provide exciting new capabilities in nuclear structure and astrophysics to better understand the landscape of the periodic table of elements.

The 2015 NSAC LRP for Nuclear Science recommended a high-energy, high-luminosity polarized Electron-Ion Collider (EIC) as the highest priority for new facility construction following the completion of FRIB. Consistent with that vision, in 2016 NP commissioned a National Academy of Sciences (NAS) study by an independent panel of external experts to assess the uniqueness and scientific merit of such a facility; their report is expected in FY 2018. Further, in 2017 NP commissioned the nuclear physics community to convene a panel of technical experts to carry out a peer review to identify critical R&D needed to reduce risk and establish the basic feasibility of various machine concepts for an EIC. The subsequent 2017 report, Report of the Community Review of EIC Accelerator R&D for the Office of Nuclear Physics[a] (the Jones report), was invaluable in aligning R&D efforts to the highest priority efforts.

Involving students in the development and construction of NP facilities and advanced instrumentation, as well as 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- and 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 other 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 and avoid duplication of efforts.

Highlights of the FY 2019 Budget Request

The FY 2019 Budget Request continues support for the highest priority efforts and capabilities in nuclear science to optimize scientific productivity. Critical infrastructure, scientific user facilities, and R&D efforts are supported to maintain U.S. leadership in nuclear science. The Request will continue support for world-class discovery science research and R&D

[a]https://science.energy.gov/~/media/np/pdf/Reports/Report_of_the_Community_Review_of_EIC_Accelerator_RD_for_the_Office_of_Nuclear_Physics_20170214.pdf

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. The Request also provides funding for nascent quantum information science (QIS) efforts, including quantum computing (QC), for NP experiments and modeling in collaboration with the other SC program offices. This effort includes the development of quantum sensors based on atomic-nuclear interactions and quantum control (coherent control) techniques, the production of stable isotopes for next generation quantum information systems, and the development of quantum computing algorithms.

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 to preserve critical core competencies and enable high priority theoretical and experimental activities to target compelling scientific opportunities at the frontier of nuclear science. The FY 2019 Request supports world-class research in multiple scientific thrusts of nuclear science. These include:

- 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;
- Collaboration in the heavy ion program at the CERN LHC to provide 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;
- Research in QIS to enable precision nuclear physics measurements, quantum simulations with trapped ions, and quantum computing solutions to otherwise intractable QCD problems;
- 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). All current EIC-related R&D efforts within the community funded by NP are now aligned with the priorities identified in the Jones report;
- 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 and produce isotopes for quantum computing.

The Request for *Facility Operations* includes funding for the operations of the NP scientific user facilities. Requested funding directs efforts to operations of the facilities to enable world-class science and the optimization of existing capabilities.

- Funding supports RHIC to operate for 2,795 hours (~19 weeks) in FY 2019. The Request allows for the implementation of the Low Energy RHIC e-Cooler (LEReC) project, an accelerator improvement project, which will enable 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;
- Funding supports CEBAF to operate for 2,035 hours (~19 weeks) in FY 2019. This continues the highly anticipated science program of the newly constructed 12 GeV machine with associated experimental instrumentation;
- ATLAS operates as the world’s premiere stable ion beam facility for 5,300 hours (~34 weeks) to enable compelling experiments in nuclear structure and astrophysics;
- Operations funding will be provided to FRIB to support the operational optimization of accelerator components as they complete fabrication and commissioning on the project, and the transition of associated operational to a facility operations budget;

- Mission readiness is supported at isotope production facilities. These facilities produce isotopes in short supply that are critical to the nation's federal complex, research enterprise and industry. University isotope production capabilities are 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) replenishes U.S. inventory, reduces dependence on foreign suppliers for research quantities of stable isotopes, and produces isotopes for quantum systems.

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

- Construction funding for 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 construction in FY 2014 and it is over 82% complete. Construction funding continues according to the currently baselined profile.
- Support for the Gamma-Ray Energy Tracking Array (GRETA) MIE, will enable provision of advanced, high resolution gamma ray detection capabilities for FRIB, and was initiated in FY 2017. GRETA will be funded at a reduced level relative to the planned profile at CD-1.
- Support for the Stable Isotope Production Facility (SIPF) MIE, initiated in FY 2017, will provide increased domestic capability for production of critically needed enriched stable isotopes, and reduce the nation's dependence on foreign supply. This technically driven funding profile will support completion of the facility in FY 2023.
  Funding is provided to initiate the sPHENIX MIE, which will have enhanced capabilities that will further RHIC's scientific mission by studying high rate jet production. This project will be implemented with funding from within the RHIC facility budget.

Nuclear Physics
Funding ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Medium Energy Nuclear Physics				
Research	35,334	—	33,487	-1,847
Operations	99,990	—	98,541	-1,449
SBIR/STTR and Other	20,783	—	20,347	-436
Total, Medium Energy Nuclear Physics	**156,107**	**—**	**152,375**	**-3,732**
Heavy Ion Nuclear Physics				
Research	38,035	—	34,017	-4,018
Operations	174,538	—	171,598	-2,940
Total, Heavy Ion Nuclear Physics	**212,573**	**—**	**205,615**	**-6,958**
Low Energy Nuclear Physics				
Research	56,669	—	55,060	-1,609
Operations	23,499	—	27,499	+4,000
Total, Low Energy Nuclear Physics	**80,168**	**—**	**82,559**	**+2,391**
Nuclear Theory				
Theory Research	36,725	—	42,075	+5,350
Nuclear Data	7,572	—	7,572	0
Total, Nuclear Theory	**44,297**	**—**	**49,647**	**+5,350**
Isotope Development and Production for Research and Applications				
Research	8,829	—	8,829	0
Operations	20,026	—	25,975	+5,949
Total, Isotopes[b]	**28,855**	**—**	**34,804**	**+5,949**
Subtotal, Nuclear Physics	**522,000**	**520,576**	**525,000**	**+3,000**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown.

[b] 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 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Construction				
14-SC-50, Facility for Rare Isotope Beams	100,000	97,200	75,000	-25,000
Total, Construction	**100,000**	**97,200**	**75,000**	**-25,000**
Total, Nuclear Physics	**622,000**	**617,776**	**600,000**	**-22,000**

SBIR/STTR Funding:

- FY 2017 Enacted: SBIR $15,366,000; and STTR $2,161,000
- FY 2019 Request: SBIR $15,747,000; and STTR $2,300,000

Nuclear Physics
Explanation of Major Changes ($K)

	FY 2019 Request vs FY 2017 Enacted
• **Medium Energy Nuclear Physics**: The Request provides support for the CEBAF accelerator complex, including mission readiness of the four experimental halls, mission readiness of the accelerator, all power and consumables of the site, computing capabilities for data taking and analysis, cryogenics plant, scientific researchers on site and at other laboratories and universities, on site accelerator scientists and technicians, operation of the recently upgraded CEBAF accelerator to support 2,035 operating hours, and experimental activities in some of the newly upgraded experimental halls to pursue the highly anticipated 12 GeV CEBAF physics program. CEBAF facility investments in capital equipment and accelerator improvement projects are deferred. 12 GeV researchers from national laboratories and universities implement, commission, and operate new experiments at CEBAF.	**-3,732**
• **Heavy Ion Nuclear Physics**: The Request supports world-leading research in heavy ion nuclear physics and spin physics. It provides funding for the RHIC accelerator complex including mission readiness and development of the experimental halls and instrumentation, mission readiness of the suite of accelerators, all power and consumables of the site, cryogenics plant, computing capabilities for data taking and analysis, scientific researchers on site and at other laboratories and universities, on site accelerator scientists and technicians, operation of RHIC for a 2,795 hour run, and experimental activities to prepare scientific instrumentation and infrastructure for the scientific program; this includes the initiation of the sPHENIX MIE for studying high rate lets of particles. The FY 2019 run will initiate a high precision scan of the QCD phase diagram and search for the critical point by looking for signs of critical phenomena in event-by-event fluctuations. RHIC facility investments in capital equipment and accelerator improvement projects are deferred. The Request supports U.S. commitments to and U.S. participation in the complementary LHC program, including computing commitments and the implementation of new experimental capabilities for the heavy ion LHC ALICE detector.	**-6,958**
• **Low Energy Nuclear Physics**: The Request supports high priority university and laboratory nuclear structure and nuclear astrophysics efforts to focus on research at the over-subscribed ATLAS facility, which will operate for 5,300 hours. ATLAS facility investments in accelerator and scientific instrumentation capital equipment are deferred. Funding for Fundamental Symmetries research supports ongoing effects in neutrinoless double beta decay domestically and abroad to determine whether the neutrino is its own antiparticle; no funding is requested for R&D towards next-generation experiments. Funding in Fundamental Symmetries also includes a suite of efforts such as the Fundamental Neutron Physics Beamline at the Spallation Neutron Source and its ongoing suite of experiments to study neutron properties. The Request supports operations of the 88-Inch Cyclotron at the Lawrence Berkeley National Lab (LBNL) for an in-house nuclear science program and an electronics irradiation capability for the Department of Defense and NASA. There is an increase planned in FY 2019 for FRIB operations support. Operations of all three experimental University Centers of Excellence, the Texas A&M Cyclotron Facility, the High Intensity Gamma Source (HIGS) at Duke University, and the Center for Experimental Nuclear Physics and Astronomy (CENPA) at the University of Washington are supported. An increase is requested for the GRETA MIE, started in FY 2017, 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.	**+2,391**

	FY 2019 Request vs FY 2017 Enacted
• **Nuclear Theory**: The Request supports high priority theory research efforts at laboratories and universities, and the U.S. Nuclear Data Program. The Request also provides support for a targeted investment in quantum information science and quantum computing, in coordination with other SC programs, including the enhancement of specialized Lattice Quantum Chromodynamics (LQCD) computing hardware that is oriented towards the research directions in quantum devices and quantum computing supported by the QIS effort. Such efforts will include R&D on quantum sensors to enable precision NP measurements, development of quantum sensors based on atomic-nuclear interactions, and development of quantum computing algorithms applied to quantum mechanical systems and NP topical problems. NP-related QIS and QC efforts have direct relevance for this area of interest in general, and can lead to advances that are important for applications in QIS and QC.	**+5,350**
• **Isotope Development and Production for Research and Applications**: The Request provides funding for high priority university and laboratory research in new isotope production techniques; efforts continue to develop Ac-225 and other promising cancer therapeutic isotopes for clinical trials. Operations funding increases to restore mission readiness for production activities at national laboratory facilities. The Request provides an increase in university operations for a network of university accelerators and reactors establishes cost-effective, regional production of short-lived isotopes for research and medical applications, and includes the University of Washington and University of Missouri Research Reactor. A modest increase in staff at the National Isotope Development Center aids in addressing the required workforce needed to market the significantly expanded Isotope Program product portfolio. ESIPP is operated to produce research quantities of enriched stable isotopes for next generation quantum information systems, as part of the QIS and QC enhanced efforts. Funding is increased for the Stable Isotope Production Facility (SIPF) MIE, started in FY 2017.	**+5,949**
• **Construction**: Construction funding continues according to the baselined profile for the Facility for Rare Isotope Beams. Support for the 12 GeV Upgrade at CEBAF completed in 2017.	**-25,000**
Total, Nuclear Physics	**-22,000**

Basic and Applied R&D Coordination
The NP mission supports the pursuit of unique opportunities for R&D integration and coordination with other DOE Program Offices, Federal Agencies, and non-Federal entities. For example, researchers from the High Energy Physics (HEP), NP, and Advanced Scientific Computing Research (ASCR) programs coordinate and leverage forefront computing resources and technical expertise through the Lattice Quantum Chromodynamics (LQCD) and SciDAC projects to determine the properties of as-yet unobserved exotic particles predicted by the theory of QCD, 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 NNSA, the Department of Homeland Security (DHS), and DOE's Office of Nuclear Energy (NE), 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 (National Institutes of Health [NIH], HEP); and research in developing neutron, gamma, and particle beam sources with applications in cargo screening and nuclear forensics (NNSA, DHS, and FBI).

R&D coordination and integration are hallmarks of the NP Isotope Development and Production for Research and Applications subprogram (DOE Isotope Program), which produces commercial and research isotopes in short supply 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, which is used by nuclear power plants as a coolant reagent. The DOE Isotope Program conducts biennial Federal workshops to identify isotope demand and supply across a broad range of Federal agencies (including NIH, NASA, FBI, DOD, DHS, DOT, NSF, NIST, ONDI, DOS, and DOE) to ensure that isotopes are available for the federal complex to accomplish its missions.

Program Accomplishments
RHIC Collisions Create a Vortex of Quark-Gluon Plasma. The Quark-Gluon Plasma (QGP), a hot soup of unbound quarks and gluons discovered in high energy collisions of gold (Au) ions at the RHIC at Brookhaven National Laboratory, is thought to also have existed a few microseconds after the Big Bang. Previous measurements have demonstrated that the QGP is one of the hottest, densest, and least viscous fluids known. New measurements at RHIC have demonstrated that this hot soup of particles is also rapidly swirling, much faster than any other known fluid. The measurements promise to illuminate detailed properties of the hot dense fluid and more precise data in the future may provide a direct measurement of what is predicted to be the strongest magnetic field in the universe.

The 12 GeV Continuous Electron Beam Accelerator Facility (CEBAF) Upgrade Project is completed. The 12 GeV CEBAF Upgrade project has received final approval (CD-4) to start operations. This project, ongoing since March 2004, was completed within its approved cost, schedule, and scope baseline. This formal start of operations promises a watershed in new scientific knowledge on how protons and neutrons collectively act together to yield the properties of nuclei observed in the lab; whether new, predicted, but as-yet unobserved exotic particles, can be found which further elucidate the theory of the strong nuclear force; and whether small violations of nature's fundamental symmetries will be observed which reveal new physics beyond our present understanding.

Facility for Rare Isotope Beams (FRIB) Construction continues. The construction of FRIB to provide unprecedented capability for research on neutron-rich nuclei is NP's highest priority construction project. Even though ground breaking of this state-of-the-art, highly complex facility started a little over three years ago in March 2014, FRIB construction has already surpassed the ~80% completion mark as of July 31, 2017. A notable accomplishment is that beneficial occupancy of the facilities completed as part of the civil construction was achieved in March 2017, ahead of schedule. These facilities can now be used for their intended purposes. That includes early commissioning of the ion source that will "feed" FRIB with the highly charged atoms it will accelerate to create rare isotope beams. Final completion efforts will continue in parallel, including the installation of technical components such as the beamlines, cryogenics systems, and superconducting cryomodules used for particle acceleration. 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 underway.

Building a National University Isotope Production Network for Regional and Unique Isotope Needs. The DOE Isotope Program has recently established a partnership agreement with the University of Missouri Research Reactor (MURR) to enable MURR to supply selenium-75, a biological tracer and research isotope. Addressing a recommendation in the NSAC-Isotope 2015 Long Range Plan for the DOE Isotope Program, the partnership with MURR marks the second agreement (first reactor-based production agreement) established to create a network of university-based isotope production capabilities to promote availability of high priority isotopes. Consideration of additional university sites to the network is underway.

Pioneering the Development of a Novel Isotope for Positron Emission Tomography. Positron Emission Tomography (PET) scans provide physicians with the capability to not only obtain internal images of patients, such as cancer metastases, but also to study organ functionality, such as cardiac blood flow. The variety of studies that can be performed increases with the development of radioactive isotopes with different physical properties (e.g., chemistry, radioactive half-life). Isotope production research at the Brookhaven and Los Alamos National Laboratories has led to the availability of a novel PET isotope, scandium-44, for researchers to develop new PET diagnostics. The research involved developing methods of production of titanium-44, the long half-life parent of scandium-44, and a chemical “generator” from which clinical researchers can extract scandium-44 from the titanium-44. Scandium-44 can be used with existing tumor targeting agents to provide high resolution imaging results over its short half-life, which are crucial to metabolic tracking and therapeutic treatment planning. The generator also offers a convenience in distribution and application as other PET isotopes are typically cyclotron-produced.

Important Milestones Reached Deep Under Ground: First Data From Recently Commissioned Detectors. 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. Several first-generation experiments are attempting to demonstrate their capability to answer these questions by detecting rare decays predicted to happen for a single nucleus only once every 10^{28} years or, for example, for 10^{28} nuclei, once per year. A prototype detector named the Majorana Demonstrator (MJD), an experiment jointly funded by NP and NSF, was recently commissioned at the Sanford Underground Research Facility in Lead, South Dakota to study the feasibility of that technology. The MJD detector demonstrated the best energy resolution of any experiment looking for these rare decays and published its first results on physics beyond the Standard Model. Another experiment, the Cryogenic Underground Observatory for Rare Events detector was also commissioned deep underground at the Laboratori Nazionalie del Gran Sasso in Italy as part of this international scientific quest that could help illuminate the reason for the relatively small amount of anti-matter in our present-day universe. The data these projects will provide is a crucial first step in understanding the deeper nature of the neutrino and its role in the evolution of the cosmos.

A New Measurement of the Neutron Lifetime with Unprecedented Precision. While protons remain stable for at least 10^{34} years, if not bound inside a nucleus, a neutron survives just 15 minutes before it decays into a proton, electron, and an antineutrino. Astrophysicists need to know the precise value of the free neutron lifetime to calculate the rate of nucleosynthesis during the "Big Bang”, and nuclear and particle physicists can use the lifetime to constrain fundamental parameters of the Standard Model. To do so, the lifetime of the neutron needs to be known to better than half a second. Given discrepancies in the world’s data however, the current uncertainty is larger than 8 seconds. NP researchers at Los Alamos National Laboratory used an array of magnets to trap ultra-slow neutrons and count how many survive with time. The experiment determined the lifetime to within one second uncertainty and showed that its ultimate sensitivity would be smaller than half a second. This result adds excitement to the world-wide effort to finally determine with sufficient accuracy how long the neutron lives.

FIONA to take on the periodic table’s heavyweights. A new tool at the DOE’s LBNL will be taking on some of the periodic table’s latest heavyweight champions (a.k.a. “super-heavy nuclei”) to see how their masses measure up to predictions. Nuclear physicists have used the known masses of radioactive decay “daughter atoms” as a framework for determining the masses for these heavier “parent” elements. But determining the mass number of some of the heaviest elements has remained out of reach because it is challenging to produce isolated atoms and to measure them before they rapidly decay. The new "For the Identification of Nuclide A" (FIONA) detector provides an opportunity to measure both the mass numbers, A and the charges, Z of the new super heavy elements at the same time. Commissioning is complete and FIONA will now be used to study decay processes associated with element 115, which was recently named Moscovium by the International Union of Pure and Applied Science along with Nihonium, Oganesson, and Tennesine in honor of important contributions to the discovery of these new elements.

Creating Heavy Nuclei in Mergers of Massive Stellar Objects. Working with an international team, scientists at the LBNL have developed new computer models to explore what happens when a black hole joins with a neutron star – the super-dense remnant of an exploded star. The simulations are intended to help detectors home in on the gravitational-wave signals. One of these studies models the first milliseconds (thousandths of a second) in the merger of a black hole and neutron star, and another details separate simulations that model the formation of a disk of material formed within seconds of the merger, and of the evolution of matter that is ejected in the merger. The studies provide insight into the astrophysical conditions of the possible site where nucleosynthesis happens, and provide predictions for observable consequence of gravitational wave sources.

Nuclear Physics
Medium Energy Nuclear Physics

Description

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

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

Various experimental approaches are used to determine the distribution of up, down, and strange quarks, their antiquarks, and gluons within protons and neutrons, as well as clarifying the role of gluons in confining the quarks and antiquarks within hadrons. Experiments that 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, as well as the spin physics research that is carried out using RHIC at BNL. The subprogram has provided support for spin physics research at RHIC, the only collider in the world that can provide polarized proton beams.

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 was successfully completed on cost and schedule in 2017, and the highly anticipated science program is 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 at RHIC using colliding beams of spin-polarized protons, a capability unique to RHIC, will provide information on the origin of the spin of the proton in a kinematic range complementary to that at CEBAF to extend present knowledge beyond the kinematic boundaries accessible at CEBAF alone. Research support for CEBAF and RHIC includes laboratory and university scientific and technical staff needed to conduct high priority data analysis to extract scientific results. Complementary special focus experiments that require different capabilities are also supported at the High Intensity Gamma Source (HIGS) at Triangle Universities Nuclear Laboratory, Europe, and elsewhere. Efforts are supported at the Research and Engineering Center of the Massachusetts Institute of Technology (MIT), which has specialized infrastructure used to develop and fabricate advanced instrumentation and accelerator equipment.

The "SBIR/STTR and Other" category provides funding in accordance with the Small Business Innovation Development Act and related legislation, resulting in commercialization opportunities in medicine, homeland security, defense, and industry, as well as products and services that benefit NP. This category includes funding to meet other obligations, such as the annual Lawrence Awards and Fermi Awards.

<u>Research</u>

The Medium Energy Research subprogram supports a focused effort of medium energy research groups at TJNAF, BNL, ANL, the Los Alamos National Laboratory (LANL), and the LBNL to carry out the highest priority research programs and conduct experiments at CEBAF, RHIC, and elsewhere. Scientists participate in the development and implementation of select 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 continuing the 12 GeV experimental program, including the implementation of select experiments, acquiring data, and performing data analysis at select CEBAF experimental halls (Halls A, B, C, and D) and RHIC. Scientists conduct targeted research to advance knowledge and to identify and develop the science opportunities and goals for next generation instrumentation and facilities. The subprogram also supports a 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 new experiments in the 12 GeV scientific program, and are engaged in commissioning experiments, 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. Research groups at BNL and LBNL play leading roles in RHIC data analysis critical for determining the spin structure of the proton. Researchers at MIT and at TJNAF are developing high current, polarized electron sources for next generation NP facilities.

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 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 funding for a focused team of accelerator physicists at TJNAF that operate CEBAF, as well as for maintenance and power costs in the second year of operations following the completion of the 12 GeV CEBAF Upgrade project in 2017. The Request defers investments in accelerator improvements aimed at addressing CEBAF reliability, GPP investments for infrastructure, and capital equipment for research and facility instrumentation. Support is provided for the most important efforts in developing advances in superconducting radiofrequency (SRF) technology relevant to improving operations of the existing machine. The core competency in SRF technology plays a crucial role in many DOE projects and facilities outside of nuclear physics (such as the Basic Energy Sciences project LCLS II) and has broad applications in medicine and homeland security. For example, SRF 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 focused Experimental Support for 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.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Medium Energy Nuclear Physics $156,107,000	**$152,375,000**	**-$3,732,000**
Research $35,334,000	**$33,487,000**	**-$1,847,000**
Researchers participated in the early 12 GeV physics program at TJNAF and continued to implement and develop experimental instrumentation. Researchers published in FY 2017 the first 12 GeV GlueX physics result showing that polarization provides powerful new information on meson production. Researchers participated in the high luminosity RHIC spin run to test and confirm the QCD structure of color spin interactions. Analysis of prior 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 Request continues the 12 GeV experimental program at CEBAF, with high priority experiments taking data in 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. This includes support for scientific workforce resident at TJNAF and outside universities and national laboratories that plan the scientific program; develop, implement and maintain scientific instrumentation; participate in the experimental runs to acquire data; analyze data and publish experimental results; and train students in nuclear science. Analysis of prior RHIC polarized proton beam data to learn more about the origin of the proton's spin, and support for short and mid-term accelerator R&D, continues.	Funding supports a focused group of 12 GeV researchers from national laboratories and universities to mount, implement, and operate the highest priority experiments at CEBAF. The Request prioritizes the implementation of the scientific experimental program at TJNAF.
Operations $99,990,000	**$98,541,000**	**-$1,449,000**
Funding supported the required machine development, and its associated incremental power costs, the completion of the 12 GeV CEBAF project on cost and schedule, and beam time for the early physics program in select Halls. Funding was provided for Other Project Costs (within project TPC), as part of the 12 GeV CEBAF Upgrade project profile. CEBAF operated for 2,191 hours or 17 weeks in FY 2017.	Operations of the newly upgraded CEBAF facility will support the continuation of the high priority 12 GeV science program, following the successful completion of the project in 2017. Funding will support 2,035 operational hours of running for research, tuning, and beam studies. Experiments in multiple halls will be operated for data taking.	Accelerator operations and experimental support funding supports ~19 weeks of operations. Funding is not requested for facility capital equipment, accelerator improvement funding, and General Plant Projects. Funding supports a more focused operations staff, power costs, materials, and supplies.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
SBIR/STTR and Other $20,783,000	**$20,347,000**	**-$436,000**
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 Office of Science obligations.	The decrease reflects the mandated set-aside for SBIR/STTR.

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 Large Hadron Collider (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 tested 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 2019, researchers at RHIC will utilize 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. The Request will continue to support efforts, within available, existing resources, to enhance the capabilities of the STAR detector, and initiate an upgrade of the PHENIX detector to sPHENIX with funds previously used to operate the PHENIX detector. In addition, the Request will support modest 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 is typically used by about 1,200 DOE, NSF, and foreign agency-supported researchers annually.

Collaboration in the heavy ion program at the LHC at CERN provides U.S. researchers the opportunity to investigate states of matter under substantially different initial conditions than those provided by RHIC, providing complementary information regarding the matter that existed during the infant universe. Data collected by the ALICE, CMS, and ATLAS detectors confirm that the quark-gluon plasma discovered at RHIC is also seen at the higher energy, and 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.

Research

The subprogram will support heavy ion research groups at BNL, LBNL, LANL, and the Oak Ridge National Laboratory (ORNL) to participate in experiments at RHIC and the LHC. In FY 2019, laboratory and university workforce will be focused on the highest priority efforts at RHIC; research commitments to the LHC program are fully met.

The university and national laboratory research groups provide focused 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 Advanced Scientific Computing Research (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. Accelerator R&D funding in Medium Energy and Heavy Ion accelerator R&D supports the most critical pre-conceptual 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.

<u>Operations</u>
The Heavy Ion subprogram provides support for the operations and power costs of the RHIC accelerator complex at BNL. In FY 2019, the subprogram focuses support on RHIC operations and does not request support for capital equipment and accelerator improvement projects. 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 provide experimental support to the facility, including the development, implementation, and commissioning of scientific equipment associated with the RHIC program. In FY 2019, the only detector operating at RHIC is STAR; the remaining available funding will be used to initiate the proposed upgrade of PHENIX to "super PHENIX" (sPHENIX). sPHENIX will enable scientists to study how the near-perfect QGP liquid, which has the lowest shear viscosity ever observed arises from the strongly interacting quarks and gluons from which it is formed.

Through operations of the RHIC complex, important core competencies have been 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 in prior years 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. 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. 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.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Heavy Ion Nuclear Physics $212,573,000	**$205,615,000**	**-$6,958,000**
Research $38,035,000	**$34,017,000**	**-$4,018,000**
Researchers completed the heavy flavor measurements at RHIC, enabled by the STAR Heavy Flavor Tracker MIE, and continued to analyze data. Researchers completed taking data with the PHENIX detector and performed R&D and conceptual design of the sPHENIX detector. NP 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 and an upgrade to the ALICE instrumentation. Competitive accelerator R&D relevant to NP programmatic needs was also supported.	Researchers will participate in the analysis and collection of data from RHIC to explore new phenomena in quark-gluon plasma formation, with a particular search for signs of critical phenomena in event-by-event fluctuations that could reveal the critical point in the QCD Phase Diagram. Modest scientific efforts will initiate the sPHENIX MIE for the study of high rate particle jets. This includes support for scientific workforce resident at RHIC and outside universities and national laboratories that plan the scientific program; develop, fabricate, implement and maintain scientific instrumentation; participate in the experimental runs to acquire data; analyze data and publish experimental results; and train students in nuclear science. U.S. scientists play a leadership role in the heavy ion efforts at the international ALICE, CMS, and ATLAS LHC experiments, and provide the required funding to the LHC for U.S. commitments for management and operating costs, computing, and contributions towards upgrades of the ALICE detector. Mid- and short-term accelerator R&D relevant to NP programmatic needs will also be supported.	The Request will support a narrowed focus of university and national laboratory RHIC research. U.S. scientists participate in the Nuclear Physics program at the LHC.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Operations $174,538,000	**$171,598,000**	**-$2,940,000**
RHIC operations provided for 2,631 beam hours, which was approximately 21 weeks 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 facility is now operating at 44 times its design luminosity.	RHIC will operate for 2,795 hours and will focus on the beam energy scan with the newly implemented Low Energy electron Cooling to increase luminosity of low energy beams. Funding supports the RHIC accelerator complex (four different particle accelerators not including the RHIC collider rings that are 2.4 miles in circumference), including mission readiness and development of the experimental halls and instrumentation, mission readiness of the suite of accelerators, all power and consumables of the site, cryogenics plant, computing capabilities for data taking and analysis, accelerator scientists, engineers, and technicians, and RHIC operations staff. High priority facility specific accelerator R&D will continue.	Funding will provide for ~19 weeks of operation. The Request does not include support for capital equipment and Accelerator Improvement Projects.

Nuclear Physics
Low Energy Nuclear Physics

Description
The Low Energy Nuclear Physics subprogram focuses on answering the overarching questions associated with 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?

The Fundamental Symmetries portfolio currently addresses these questions through precision studies using neutron beams and decays of nuclei, including neutrinoless double-beta decay. U.S. scientists are world leaders in the global research effort aimed at neutrino science and NP is the steward of neutrinoless double beta decay in the Office of Science. In partnership with the NSF, NP has invested in past, current and future neutrino experiments both domestically and overseas, playing critical roles in international experiments which depend on U.S. leadership for their ultimate success (CUORE, KATRIN). Beams of cold and ultracold neutrons at the Spallation Neutron Source are used to study fundamental properties of neutrons, and R&D towards an experiment for this beamline to measure the electric dipole moment of the neutron, which could shed light on the asymmetry of matter versus antimatter in the universe, is addressing technical feasibility and on the path towards becoming the flagship experiment at this beamline. 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 DOE-supported facility providing research opportunities in Nuclear Structure and Nuclear Astrophysics, serving a combined international community of about 400 scientists. ATLAS is the world's premiere facility for stable beams and 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 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 increasingly 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. In addition to its world-class, standalone scientific program, ATLAS is also an essential training ground for scientists and students as they prepare for the FRIB research program. 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. ANL maintains a target development laboratory in direct support of ongoing low energy research undertaken at ATLAS. In FY 2017, this core competency was strengthened to establish the National Center for Accelerator Target Science, a national asset for the low energy community, including FRIB.

Disposition activities of the ORNL Holifield Radioactive Ion Beam Facility, which ceased operations in FY 2012, are completed in FY 2017.

Accelerator operations are supported at two university Centers of Excellence with specific goals and unique physics programs: the Cyclotron Institute at Texas A&M University (TAMU) and accelerator facilities at the Triangle Universities Nuclear Laboratory (TUNL) at Duke University. A third university center, the Center for Experimental Nuclear Physics and Astrophysics (CENPA) at the University of Washington, provides unique expertise and capabilities for instrumentation development. NP also supports operations of the LBNL 88-Inch Cyclotron to provide beams for a small in-house nuclear science program focused on studying the properties of newly discovered elements on the periodic table, and unique testing capabilities in materials irradiation important for external users and other critical missions, such as the Department of Defense and NASA.

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 Request includes funds to support FRIB operations and retain critical operations staff as accelerator components on the project are completed and efforts transition to operations. The Gamma-Ray Energy Tracking Array (GRETA) MIE, initiated in FY 2017, is continued in the FY 2019 Request. This advanced instrumentation is one of the primary tools that the nuclear science community has 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 focused efforts of Low Energy research groups at ANL, BNL, LBNL, LANL, LLNL, ORNL, and PNNL. About half of the scientists conduct nuclear structure and astrophysics research primarily using specialized instrumentation at the ATLAS scientific user facility, as well as the smaller accelerator facilities at university-based Centers of Excellence. The GRETA MIE continues at a pace slower than planned to provide unprecedented gamma-ray tracking capabilities for the future FRIB facility. GRETA will revolutionize gamma-ray spectroscopy providing more than an order of magnitude increased sensitivity for gamma ray coincidence measurements. The remaining groups primarily conduct research in fundamental symmetries, including experiments at the Fundamental Neutron Physics Beamline (FNPB) at the Spallation Neutron Source; double beta-decay experiments such as the Cryogenic Underground Observatory for Rare Events (CUORE) experiment at Gran Sasso Laboratory in Italy and the Majorana Demonstrator R&D effort at the Sanford Underground Research Facility in Lead, South Dakota; a measurement of the neutrino mass with the Karlsruhe Tritium Neutrino (KATRIN) experiment at the Karlsruhe Institute of Technology in Karlsruhe, Germany; and R&D to measure the neutron electric dipole moment. Support is not requested for next-generation R&D aimed at a ton-scale neutrinoless double beta decay experiment. Support is also provided to the university Centers of Excellence to maintain and nurture their unique capabilities.

<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 operations, power costs, accelerator improvement projects and experimental support of ATLAS. In FY 2019, efforts will be focused on operating the machine, and the Program does not request support for accelerator and scientific instrumentation capital equipment. Recent or to be completed in 2018 accelerator and scientific instrumentation include the Electron Beam Ion Source (EBIS), the cutting edge CARIBU radioactive beam system for accelerated radioactive ion beams, the in-flight radioactive ion separator to increase the intensity of radioactive beams, and a new gas filled analyzer completed in FY 2017.

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

Support is provided to maintain operations support of the 88-Inch Cyclotron. Modest funds are provided to support FRIB operations, which will be initiated in FY 2018. These funds retain critical operations staff as accelerator components are completed on the project and efforts transition to operations.

Nuclear Physics
Low Energy Nuclear Physics

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Low Energy Nuclear Physics $80,168,000	**$82,559,000**	**+$2,391,000**
Research $56,669,000	**$55,060,000**	**-$1,609,000**
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 and EXO to demonstrate technical feasibility of a next generation detector in double beta decay. Support is continued for operations of the GRETINA detector, operations of the KATRIN experiment, operations of the FNPB, operations of CUORE and R&D on setting a world leading limit on the electric dipole moment of the neutron and R&D on the lifetime of the neutron.	The Request supports high priority university and laboratory nuclear structure and nuclear astrophysics efforts to focus on research at ATLAS, the world's premiere stable beam facility, as well as development of the FRIB scientific program. Research and operations continue at the unique university-based Centers of Excellence. Research will continue with the Majorana Demonstrator and EXO to consider performance of different technologies in neutrinoless double beta decay experiments. U.S. participation in the operations of the international KATRIN and CUORE experiments will continue, as does ongoing R&D at the FNPB on the feasibility of setting a world leading limit on the electric dipole moment of the neutron. The Request continues to support the GRETA MIE.	No funding is requested for the R&D effort aimed at developing technology for the next generation neutrinoless double beta decay (0vbb) experiment in partnership with NSF. The GRETA MIE will continue, as will research on the neutron electric dipole moment experiment.
Operations $23,499,000	**$27,499,000**	**+$4,000,000**
Continued operation of ATLAS was a high priority as demand for ATLAS beam time continues to far exceed availability. In FY 2017, ATLAS cost-effectively delivered 5,468 hours or ~34 weeks. The AGFA gas filled analyzer was completed on cost and schedule, and the AIRIS spectrometer is on track for completing as planned in FY 2018. The National Center for Accelerator Target Science, an asset for the entire Low Energy community and leveraged by ATLAS staff, was launched in FY 2017.	The Request supports the operation of ATLAS to address the high demand for ATLAS beam time, which continues to far exceed availability. ATLAS funding at this cost-effective facility will support 5,300 hours of beam time. Funding is also provided to ramp up the operations activities for FRIB.	Funding supports operations of ATLAS for ~34 weeks. Funding supports an increase in FRIB operations and maintenance of operations at the 88-Inch Cyclotron.

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. Currently, Nuclear Theory addresses all three of NP's scientific thrusts and in FY 2019, it will focus on the two remaining thrusts, that of QCD and Nuclear Structure and Astrophysics. 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 fourth year of five-year topical collaborations within the university and national laboratory communities will be supported in FY 2019 within available funds to address only the highest priority topics in nuclear theory that merit a concentrated theoretical effort.

The U.S. Nuclear Data Program (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. The USNDP recently established two university efforts, 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 also recently stood up an Inter-Agency working group including NNSA, DHS, NE, and other Federal Agencies to provide evaluated cross-section and decay data relevant to a broad suite of Federal missions and topics. Plans have been underway for the USNDP to support efforts on opportunistic measurements to address serious gaps and uncertainties in existing nuclear data archives.

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 through FY 2017. It follows the previous joint efforts that address the computational requirements of LQCD research by continuing to provide specialized computing resources for LQCD research. NP requires this type of computing capability in order to conduct simulations that address its science program. In FY 2019, NP will support LQCD computing needs for dedicated computational resources with investments at JLab, and support is augmented from the new SC quantum information science (QIS) initiative to accommodate new developments in quantum devices and quantum computing algorithms.

The Request provides support for NP activities related to QIS and quantum computing (QC), in collaboration with efforts by the other SC research program offices. NP-specific efforts could include R&D on quantum sensors to enable precision NP measurements, development of quantum sensors based on atomic-nuclear interactions, and development of quantum computing algorithms applied to quantum mechanical systems and NP topical problems. NP-related QIS and QC efforts have direct relevance for this area of interest in general, and can lead to advances that are important for applications in QIS and QC in many fields.

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. A new group of SciDAC-4 awards were selected in FY 2017 and continue in FY 2019.

Theory Research

The Nuclear Theory subprogram supports the highest priority research programs of nuclear theory groups at seven national laboratories (ANL, BNL, LANL, LBNL, LLNL, ORNL, and TJNAF). This research has the goals of improving our fundamental understanding of nuclear physics, interpreting the results of experiments carried out under the auspices of the experimental nuclear physics program, and identifying and exploring important new areas of research. 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 5-year topical collaborations initiated in FY 2016/FY 2017 within available funds to bring together theorists to address specific high-priority theoretical challenges. The ongoing topical collaborations will receive continued support in FY 2019: 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 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. 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. The subprogram will continue efforts 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. Efforts related to QIS and QC are initiated to address the needs of the NP program and provide technological and computational advances relevant to other fields.

Nuclear Data

Funding is requested to support the USNDP to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Nuclear Theory $44,297,000	**$49,647,000**	**+$5,350,000**
Theory Research $36,725,000	**$42,075,000**	**+$5,350,000**
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 provide for QIS efforts, including support for QIS research and LQCD computing. Funding will support 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 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 and nuclear structure and reactions 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 RHIC experiments. Funding will also support the third year of support for SciDAC-4 grants and the fourth year for the theory topical collaborations initiated in FY 2016.	Increased funding will be provided for QIS research and LQCD computing aimed at QIS and QC activities. Funding supports the highest priority theoretical research efforts across the Nuclear Physics program, and supports a theoretical collaboration focused on the science at FRIB.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Nuclear Data $7,572,000	**$7,572,000**	**$0**
Nuclear data evaluation was the prime nuclear data product, combining experiment with theory and linking basic science with applications. The emphasis in FY 2017 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.	Funding is requested to support the USNDP to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development. A modest experimental component to address gaps in the existing nuclear data will be considered.	The Request supports the highest priority USNDP efforts at universities and national laboratories.

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;
- actinium-227, 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 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 all federal organizations to develop strategic plans for isotope production and to establish effective communication to better forecast isotope needs and leverage resources. NP conducts biennial workshops, attended by representatives of all Federal agencies that require stable and radioactive isotopes, to provide a comprehensive assessment of national needs for isotope products and services, to inform priorities for investments in research for developing new isotope production and processing techniques, to communicate advances in isotope production research and availability,

[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.

and to communicate concerns about potential constrained supplies of important isotopes to the federal complex. 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 nuclear chemistry and 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.

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 activity 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. 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. 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.

A high priority is a dedicated 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. Research efforts have demonstrated that the accelerator produced actinium-225 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. In coordination with NIH, samples of the isotope produced by the accelerator production approach were evaluated by several different researchers involved in medical applications research to confirm these results. The accelerator route of production has the potential to provide quantities sufficient to support both research trials and ultimately clinical applications in the future.

Research supported for the past couple of years has culminated in the demonstration of reactor-produced actinium-227, representing the world's first source of new material. Actinium-227 decays to radium-223, which is used in new radiopharmaceutical drugs to treat prostate cancer. The provision of actinium-227 by the Isotope Program ensures that prostate cancer patients can have a reliable supply of palliative care drugs.

Operations

The Isotope Program is the steward of the Isotope Production Facility (IPF) at 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, the LANL Plutonium Facility for extracting americium-241 from NNSA plutonium processes, the Low Energy Accelerator Facility (LEAF) at Argonne National Laboratory for the production of the medical isotope copper-67, 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 at the stewarded facilities, such as an alpha-particle cyclotron at the University of Washington where full-scale production of astatine-211 was developed to support research into the use of the isotope in cancer therapy, and the recently added University of Missouri Research Reactor (MURR) where the Isotope Program supported the development of reactor production of selenium-75 for industrial gamma radiography. The establishment of a coordinated network of university-based isotope production was a recommendation in the 2015 NSAC-Isotope Long Range Plan. The network is designed to leverage the unique and often 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. Investments in FY 2019 increase the size of the University Network to more efficiently meet domestic isotope production needs. The suite of facilities that the Isotope Program supports continues to expand, with the above mentioned LANL Plutonium Facility, ANL LEAF, MURR and the University of Washington being the most recent additions.

The DOE Isotope Program has invested funds to develop stable isotope separation technology, first identified as a high priority by the NSAC Subcommittee on Isotopes in 2009. The R&D effort has resulted in an Enriched Stable Isotope Prototype Plant (ESIPP) to produce research quantities of enriched stable isotopes through the use of electromagnetic separation and centrifuge technology. The SIPF MIE was initiated in FY 2017 to establish kilogram production capability to help meet the nation's demand for enriched stable isotopes for basic research, medical, national security and industrial applications as recommended by the NSAC Subcommittee on Isotopes in 2015. The FY 2019 Request supports the SIPF MIE with a technically-driven profile for completion in FY 2023, reducing the nation's dependence for these critical isotopes on a foreign source. Examples of discovery research efforts that could benefit from the facility are foreign neutrinoless double beta decay experiments 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 can also be produced. ESIPP focuses on ruthenium-96 production in FY 2017 and FY 2018 to provide the otherwise unavailable target material to RHIC for its planned physics program. In FY 2019, funding is provided to produce specialty enriched stable isotopes for future QIS-drive technologies.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Isotope Development and Production for Research and Applications $28,855,000	**$34,804,000**	**+$5,949,000**
Research $8,829,000	**$8,829,000**	**$0**
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 will continue 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.	Funding for national laboratory and university research will support the highest priority efforts.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Operations $20,026,000	**$25,975,000**	**+$5,949,000**
Support was 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 NSAC's updated long-range plan for the Isotope Program (completed in FY 2015) and the Federal workshop held in the fall of 2016.	Funding supports mission readiness of the isotope production facilities and the most critical core competencies in isotope production and development, ensuring that isotope orders for cancer therapy and other commitments are reliably met. NIDC activities will support the effective interfaces with the growing stakeholder community. Funding will provide mission readiness of the newly commissioned ESIPP for the production of important enriched stable isotopes for the nation. In FY 2019, funding will also provide to produce stable isotopes for next generation QIS-driven technologies. The SIPF MIE will be supported for completion in FY 2023. Funding will support the addition of several new universities into the National University Isotope Production Network, which will emphasize production of astatine-211 for cancer therapy.	Funding is increased for the SIPF MIE with planned completion in FY 2023. Support for the mission readiness of isotope production facilities will be modestly increased to account for additional production capabilities and competencies needed to meet customer commitments. NIDC workforce is modestly increased to address the growing isotope program portfolio. Funding will provide for production of isotopes critical for QIS research and next-generation quantum computing technologies. Funding will be provided to grow the university production network for production of unique isotopes.

Nuclear Physics
Construction

Description

Consistent with the 2015 NSAC Long-Range Plan's highest priority, the FY 2019 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 2019.

The Facility for Rare Isotope Beams (FRIB) at Michigan State University (MSU) will continue construction activities in FY 2019, with a funding request aligned to the current baseline. The project is proceeding on track within the established project baseline and working towards an "early finish," 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 MSU and was established as a control point in the FY 2014 appropriation. Prior to that time, funding was provided within the Low Energy subprogram.

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 was completed in 2017, on cost and schedule.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Construction $100,000,000	**$75,000,000**	**-$25,000,000**
14-SC-50, Facility for Rare Isotope Beams (FRIB) $100,000,000	**$75,000,000**	**-$25,000,000**
The FY 2017 funding supported conventional construction which resulted in the project achieving Beneficial Occupancy of its buildings in March 2017, approximately ten weeks ahead of schedule. The funds also supported fabrication, assembly, installation and testing of the technical systems including the Front End system, cryomodules, and experimental systems. A technically related achievement in FY 2017 regarding the front end system was that the FRIB project successfully produced its first ion beam from its ARTEMIS electron-cyclotron-resonance (ECR) ion source.	The FY 2019 funding will support the ongoing fabrication, assembly and testing of cryomodules that will also be installed and tested in the newly constructed tunnel. Other technical systems, such as the experimental related systems will also be fabricated, assembled, installed and tested. As the various systems near completion, the linear accelerator commissioning effort will occur to validate their performance according to project requirements.	Funding decreases, as planned, relative to FY 2017. FRIB will proceed on track within the established project baseline.

Nuclear Physics
Performance Measure

In accordance with the GPRA Modernization Act of 2010, the Department sets targets for, and tracks progress toward, achieving performance goals for each program.

	FY 2017	FY 2018	FY 2019
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 %	N/A	< 10 %
Result	Met	N/A	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 %
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	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.	Initiate a search for a Critical Point in the Phase Diagram of Nuclear 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 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Capital Operating Expenses Summary						
Capital equipment	n/a	n/a	13,400	—	9,887	-3,513
General plant projects (GPP)	n/a	n/a	1,000	—	0	-1,000
Accelerator improvement projects (AIP)	n/a	n/a	4,608	—	1,504	-3,104
Total, Capital Operating Expenses	**n/a**	**n/a**	**19,008**	**—**	**11,391**	**-7,617**
Capital Equipment						
Gamma-Ray Energy Tracking Array (GRETA) MIE	52,000–67,000[b]	n/a	500	—	2,500	+2,000
Stable Isotope Production Facility (SIPF) MIE	9,500–10,500	n/a	2,500	—	5,000	+2,500
Super-PHENIX (sPHENIX) MIE[c]	29,000-35,000	n/a	—	—	1,200	+1,200
Total Non-MIE Capital Equipment	n/a	n/a	10,400	—	1,187	-9,213
Total, Capital Equipment	**n/a**	**n/a**	**13,400**	**—**	**9,887**	**-3,513**
General Plant Projects						
General plant projects under $5 million TEC	n/a	2,200	1,000	—	0	-1,000
Accelerator Improvement Projects (AIP)						
RHIC Low Energy Electron Cooling	8,300	7,000	1,300	—	0	-1,300
Other projects under $5 million TEC	n/a	3,652	3,308	—	1,504	-1,804
Total, Accelerator Improvement Projects	**n/a**	**10,652**	**4,608**	**—**	**1,504**	**-3,104**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown.

[b] Total Project Cost range

[c] sPHENIX MIE will be funded through existing operations funding which would typically be used to operate the previous version of the detector, PHENIX; no new funds are required.

Major Items of Equipment Descriptions

Low Energy Nuclear Physics

The *Gamma-Ray Energy Tracking Array (GRETA) detector* directly supports the NP 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 was obtained in September FY 2017. The FY 2019 Request for GRETA of $2,500,000 is the third year of Total Estimated Cost (TEC) funding. The Total Project Cost Range will be re-evaluated in FY 2019 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 completed 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, foreign 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 initiated 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 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 2018. The FY 2019 Request of $5,000,000 represents a technically-driven project implementation.

Heavy Ion Nuclear Physics

The *Super Pioneering High Energy Nuclear Interaction Experiment (sPHENIX)* directly supports the Nuclear Physics mission by using precision, high rate jet measurements to further characterize the quark-gluon plasma (QGP) discovered at RHIC in order to understand the anomalous energy loss observed in the QGP. sPHENIX will enable scientists to study how the near perfect QGP liquid with the lowest shear viscosity ever observed arises from the strongly interacting quarks and gluons from which it is formed. CD-0 was approved September 2016 with an estimated Total Project Cost of $29,000,000 to $35,000,000. CD-1 is planned for 2018. This MIE is funded within the existing funds for RHIC operations. Operating funds that are typically used to maintain and operate the PHENIX detector will be used to upgrade the detector. No new funding is required. sPHENIX adds electron and hadron calorimeters to the existing silicon tracking capabilities and makes use of a recycled solenoid magnet for a cost effective upgrade. The FY 2019 Request for sPHENIX of $1,200,000 is the first year of Total Estimated Cost (TEC) funding.

Nuclear Physics
Construction Projects Summary ($K)

	Total	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
14-SC-50, Facility for Rare Isotope Beams						
DOE TPC	635,500[b]	318,000[c]	100,000	97,200	75,000	-25,000
Total, Construction (TPC) All Construction Projects	**n/a**	**n/a**	**100,000**	**97,200**	**75,000**	**-25,000**

Funding Summary ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[i]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Research	200,015	—	196,587	-3,428
Scientific User Facilities Operations	292,727	—	292,138	-589
Other Facility Operations	21,826	—	25,275	+3,449
Projects				
Major Items of Equipment	4,176	—	8,700	+4,524
Facility for Rare Isotope Beams	100,000	—	75,000	-25,000
Total Projects	104,176	—	83,700	-20,476
Other[d]	3,256	—	2,300	-956
Total Nuclear Physics	**622,000**	**617,776**	**600,000**	**-22,000**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. 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.
[c] A portion of the PY funding was provided within the Low Energy subprogram. The FY 2014 appropriation established FRIB as a control point.
[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 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
TYPE A FACILITIES				
CEBAF (TJNAF)[b]	**$111,076**	**—**	**$108,767**	**-$2,309**
Number of Users	1,597	—	1,600	+3
Achieved operating hours	2,191	—	N/A	N/A
Planned operating hours	2,190	—	2,035	-155

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown.
[b] 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 and FY 2019 as operational experience is gained.

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
TYPE A FACILITIES				
Optimal hours	3,330	—	3,940	+610
Percent optimal hours	65.8%	—	51.6%	-14.2%
Unscheduled downtime hours			N/A	
RHIC (BNL)	**$181,921**	**—**	**$178,162**	**-$3,659**
Number of Users	985	—	985	0
Achieved operating hours	2,631	—	N/A	N/A
Planned operating hours	2,640	—	2,795	+155
Optimal hours	4,100	—	4,100	0
Percent optimal hours	64.2%	—	68.2%	+4.0%
Unscheduled downtime hours			N/A	
ATLAS (ANL)	**$23,946**	**—**	**$17,695**	**-$6,251**
Number of Users	231	—	272	+41
Achieved operating hours	5,468	—	N/A	N/A
Planned operating hours	5,300	—	5,300	0
Optimal hours	6,600	—	6,600	0
Percent optimal hours	82.8%	—	80.3%	-2.5%
Unscheduled downtime hours			N/A	
FRIB (MSU)	**$0**	**—**	**$4,000**	**+$4,000**
Number of Users	—	—	N/A	N/A
Achieved operating hours	—	—	N/A	N/A
Planned operating hours	—	—	N/A	N/A
Optimal hours[a]	—	—	N/A	N/A
Percent optimal hours	—	—	N/A	N/A
Unscheduled downtime hours	—	—	N/A	N/A
Total Scientific User Facility Operations	**$316,943**	**—**	**$291,834**	**-$25,109**

[a] ATLAS was able to achieve 103.2% of the planned operating hours in FY 2017 as a result of very high reliability.

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
TYPE A FACILITIES				
Number of Users	2,813	—	2,857	+44
Achieved operating hours	10,290	—	N/A	N/A
Planned operating hours	10,130	—	10,130	0
Optimal hours	14,030	—	14,640	+610
Percent of optimal hours[a]	66.2%	—	63.3%	-2.9%
Unscheduled downtime hours				

Scientific Employment

	FY 2017 Enacted	FY 2018 Annualized CR[b]	FY 2019 Request	FY 2019 vs FY 2017
Number of permanent Ph.D.'s (FTEs)	802	—	757	-45
Number of postdoctoral associates (FTEs)	355	—	335	-20
Number of graduate students (FTEs)	507	—	481	-26
Other[c]	1,056	—	979	-77

[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] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. 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 2018 PDS and does not include a new start for FY 2019.

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.

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	8/1/2013	8/26/2014	N/A	3Q FY 2022
FY 2019	2/9/2004	9/1/2010	9/1/2010	8/1/2013	8/26/2014	8/1/2013	8/26/2014	N/A	3Q FY 2022

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline

[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 continued through 4Q FY 2017.

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	-94,500	635,500
FY 2019	655,700	24,600	49,700	730,000	-94,500	635,500

4. Project Scope and Justification

Scope

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

As contractually required under the financial assistance award agreement, FRIB is being constructed in accordance with the project management principles in DOE Order 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.

[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.

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 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.

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

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 2017 reflect actual costs; costs for FY 2018 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

6. Details of Project Cost Estimate[a]

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Design & Construction			
Management and Support	37,153	39,268	35,400
Conventional Facilities	208,100	208,201	165,300
Accelerator Systems	289,726	282,974	241,400
Experimental Systems	74,207	67,175	55,000
Contingency (DOE Held)	46,564	58,132	158,650
Total, Design & Construction	655,750	655,750	655,750
Other Costs			
Conceptual Design/Tech R&D/NEPA	24,641	24,640	24,600
Pre-ops/Commissioning/Spares	34,659	34,658	35,500
Contingency (DOE Held)	14,950	14,952	14,150
Total, Other Costs	74,250	74,250	74,250
Total, TPC	TBD	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)	61,514	73,084	172,800

7. Schedule of Appropriation Requests[b]

(Dollars in Thousands)

		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[c]	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

[a] This section shows a breakdown of the total project cost of $730,000,000 as of 11/30/2017, which includes MSU's cost share. The scope of work is not pre-assigned to DOE or MSU funds.
[b] The funding profile represents DOE's portion of the baselined TPC to be provided through federal appropriations.
[c] The Performance Baseline was approved August 1, 2013. The first project data sheet submitted for FRIB was in the FY 2015 Congressional Budget Request. It was established as a control point in the FY 2014 appropriation. Funding for the project prior to that time was provided within the Low Energy subprogram.

(Dollars in Thousands)

		Prior Years	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	Outyears	Total
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
FY 2019	TPC	218,000	100,000	100,000	80,000	75,000	57,200	5,300	0	635,500

8. Related Operations and Maintenance Funding Requirements

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

(Related Funding requirements)

(dollars in thousands)

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

9. D&D Information

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

10. Acquisition Approach

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

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