Department of Energy Laboratory Plan –TJNAF

May 1, 2015 - Draft

I. Mission and Overview

The Thomas Jefferson National Accelerator Facility (TJNAF), located in Newport News, Virginia, is a laboratory operated by Jefferson Science Associates, LLC for the Department of Energy's (DOE) Office of Science (SC). The primary mission of the laboratory is to explore the fundamental nature of confined states of quarks and gluons, including the nucleons that comprise the mass of the visible universe. TJNAF also is a world-leader in the development of the superconducting radio-frequency (SRF) technology utilized for the Continuous Electron Beam Accelerator Facility (CEBAF). This technology is the basis for an increasing array of applications at TJNAF, other DOE labs, and in the international scientific community. The expertise developed in building and operating CEBAF and its experimental equipment has facilitated an upgrade that doubled the maximum beam energy (to 12 GeV (billion electron volts)) and provided a unique facility for nuclear physics research that will ensure continued world leadership in this field for several decades. The upgraded facility is in the commissioning phase and will begin research operations in the near future. TJNAF's present core capabilities are: experimental, theoretical and computational Nuclear Physics; Accelerator Science; Applied Nuclear Science and Technology; and Large Scale User Facilities/Advanced Instrumentation.

The Lab has an international scientific user community of 1,380 researchers whose work has resulted in scientific data from 178 full and 10 partial experiments, 365 Physics Letters and Physical Review Letters publications and 1,205 publications in other refereed journals to-date at the end of FY 2014. Collectively, there have been more than 98,000 citations for work done at TJNAF.

Research at TJNAF and CEBAF also contributes to thesis research material for about one-third of all U.S. Ph.D.s awarded annually in Nuclear Physics (26 in FY 2014; 504 to-date; and 200 more in progress). The Lab's outstanding science education programs for K-12 students, undergraduates and teachers build critical knowledge and skills in the physical sciences that are needed to solve many of the nation's future challenges.

II. Lab-at-a-Glance

Location: Newport News, Virginia

Type: Program-Dedicated, Single-purpose lab

Contract Operator: Jefferson Science Associates, LLC (JSA)

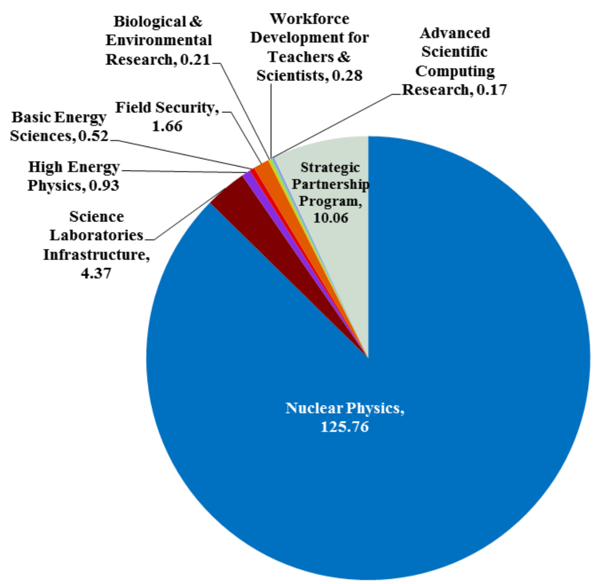
Responsible Site Office: Thomas Jefferson Site Office

Website: http://www.jlab.org

Physical Assets:
- 169 acres and 72 buildings and 9 trailers
- 890,015 GSF in buildings
- Replacement Plant Value (RPV): $384M
- 0 GSF in Excess Facilities
- 76,151 GSF in Leased Facilities

Human Capital (period ending 9/30/14):
- 673 FTEs
- 26 Joint faculty
- 24 Postdoctoral Researchers
- 4 Undergraduate and 34 Graduate students
- 1,380 Facility Users
- 1,230 Visiting Scientists

FY 2014 Funding by Source: *(Cost Data in $M)*



FY2014 Total Lab Operating Costs (excl. Recovery Act): $144.0
FY2014 Total DOE Costs: $133.9
FY2014 SPP (Non-DOE/Non-DHS): $10.1
FY2014 SPP as % Total Lab Operating Costs: 7.0%
FY2014 Total DHS costs: $0.0
Recovery Act Costed from DOE Sources in FY2014: $1.9

III. Core Capabilities

The following core capabilities distinguish TJNAF and provide a basis for effective teaming and partnering with other DOE laboratories, universities, and private sector partners in pursuit of the laboratory mission. These distinguishing core capabilities provide a window into the mission focus and unique contributions and strengths of TJNAF and its role within the Office of Science laboratory complex. Descriptions of these facilities can be found at the website noted in the Lab-at-a-Glance section of this Plan.

Each of the laboratory's core capabilities involves a substantial combination of facilities and/or teams of people and/or equipment, has a unique and/or world-leading component, and serves DOE/DHS missions and national needs. Specifically, TJNAF's four major core capabilities meeting these criteria are described below in detail:

1. **Nuclear Physics** (funded by DOE Office of Science (SC)– Nuclear Physics (NP))

   Experimental Nuclear Physics
   TJNAF is a unique world-leading user facility for studies of the structure of nuclear and hadronic matter using continuous beams of high-energy, polarized electrons. The Continuous Electron Beam Accelerator Facility (CEBAF) electron beam can be simultaneously delivered to the experimental halls at different energies. Up to May 2012, the beam energy delivered was up to 6 GeV, and there were three experimental halls – A, B and C. Each experimental hall was instrumented with specialized experimental equipment designed to exploit the CEBAF beam. The detector and data acquisition capabilities at TJNAF, when coupled with the high-energy electron beams, provide the highest luminosity (10^{39}/eN/cm^2/s) capability in the world. The TJNAF staff designs, constructs, and operates the complete set of equipment to enable this world-class experimental nuclear physics program. With between 1,200 and 1,400 users annually, TJNAF supports one of the largest nuclear physics user communities in the world.

   The experimental nuclear physics program at TJNAF provides unique access to fundamental aspects of hadronic structure, the structure of complex nuclei, hadron formation from colored states, and tests of the standard model of nuclear and particle physics. Thus, the nuclear physics program at TJNAF should be viewed as an integral component of the field of nuclear physics, with important contributions to all major thrusts identified in the 2007 NSAC Long Range Plan, and also the Intensity Frontier of particle physics.

   TJNAF's completed 6 GeV program utilizing CEBAF has given the United States leadership in addressing the structure and interactions of nucleons and nuclei in terms of the quarks and gluons of Quantum Chromo Dynamics (QCD). That research program, when analysis is completed, will enable the TJNAF to complete 8 of the 13 OMB/SC milestones for progress in Hadronic Physics. The Nuclear Physics community in the U.S. has acknowledged this leadership and its potential, and indeed the 2007 NSAC Long Range Plan recommended completion of a doubling of the energy reach of CEBAF, the 12 GeV Upgrade, as its highest priority. Later NSAC Subcommittees and Decadal Plans reaffirmed this priority. The science program at 12 GeV represents the realization of major scientific opportunities associated with this priority NSAC recommendation and will enable completion of the two OMB/SC milestones that are part of the initial research program.

   The last decade has seen the development of new theoretical and experimental tools designed to address the nature of confinement and the structure of hadrons comprised of light quarks and gluons in a quantitative way. Together, these will allow both the spectrum and the structure of hadrons to be elucidated in unprecedented detail. New program directions include higher-resolution maps of the nucleon's charge and magnetization distributions and a measurement of the electron's weak charge. New phenomenological tools have been developed that produce multidimensional images of hadrons with great promise to reveal the dynamics of the key underlying degrees of freedom. Recent lattice QCD calculations predict the existence of new exotic hybrid mesons that can be discovered with the new experiments GlueX and CLAS12. The 12 GeV Upgrade of CEBAF will enable a new experimental program with substantial discovery potential to address these and other important topics in nuclear and hadron physics.

As in all scientific fields, the advancement of experimental nuclear physics requires the development of new experimental tools and techniques. The staff and users of TJNAF have demonstrated exceptional capability to realize scientific progress through new instrumentation and methods. Large acceptance spectrometer systems capable of operation at high luminosity have opened new opportunities to explore the structure of nucleons and test our knowledge of QCD. This program will continue into the future with the upgraded instrumentation associated with the 12 GeV Upgrade project. Another major area of expertise that has been developed is the measurement of exceptionally small parity-violating asymmetries with high precision. This method has enabled major advances in hadronic structure, the structure of heavy nuclei (through measurement of the neutron distribution radius), and precision tests of the standard model of particle physics. Again, these advances have led to new proposals in all these areas during the upcoming era of 12 GeV operation of CEBAF.

The construction of the 12 GeV CEBAF nears completion. The accelerator commissioning has been completed and has been declared ready for operations. Hall A has seen its first continuous wave (CW) beam delivered and is ready to initiate its science program. Accelerated beam to Hall D, the newest and fourth experimental hall, was commissioned in the Fall of 2014, and Hall D continues detector commissioning towards its science program. Construction of experimental facilities in Halls B and C remains ongoing, with their initial commissioning following in 2016. The increased complexity of the accelerator and experimental equipment, including the introduction of Hall D, with its discovery-class program to search for exotic hadronic states of QCD, represent a substantial expansion of the scale of the operations.

Theoretical & Computational Nuclear Physics

A comprehensive theoretical effort and leadership across nuclear physics is the mission of the TJNAF Theory Center. The research program is an essential part of the national strategy for understanding the structure of hadronic matter and the worldwide effort to explore the nature of quark and gluon confinement. This contributes to thirteen current OMB/SC milestones for hadronic physics. This broad program encompasses investigations of the hadron spectrum, hadron structure and hadron dynamics using a range of state-of-the art theoretical, phenomenological and computational approaches. These cover *ab initio* calculations both in the continuum and on the lattice of the properties of light nuclei, analyses of the nucleon-nucleon interaction, predictions for and analyses of the structure of the nucleon and its excitations, the determination of the spectrum of mesons with emphasis on their underlying quark and gluon structure, and explorations of the internal landscape of hadrons in terms of momentum, spin and spatial distributions. This internal dynamics is investigated in parallel studies using the methods of both lattice and perturbative QCD. A recent emphasis here has been on the issue of how to define and then compute the internal orbital motion of quarks and gluons. A particular strength of the theory group is the capability to meld the appropriate theoretical tools with cutting edge computational technology.

The synthesis of the latest technology with innovative theoretical tools is particularly notable in the area of High Performance Computing. TJNAF deploys cost-optimized computing for Lattice QCD calculations as a national facility for the U.S. lattice gauge theory community. Such computing capitalizes on the DOE's investment in leadership-class computing to facilitate the calculations needed to advance the understanding of nuclear and high-energy physics. To make best use of these facilities, innovative development of novel software tools (Chroma) has allowed the calculation of observables of direct relevance to the TJNAF experimental program from the spectroscopy of baryons and mesons, including exotics, to form factors and generalized parton distributions. When combined with the power and speed of the dedicated Graphical Processing Unit (GPU) infrastructure, results of unrivaled precision for the hadron spectrum have been produced. Computational techniques in Lattice QCD now promise to provide insightful and quantitative predictions that can be meaningfully confronted with and elucidated by forthcoming experimental data. Moreover, the relation between nuclear structure at short distance scales and the underlying dynamics of quarks can be uncovered. An increasingly important part of this lattice effort is the computation of hadronic scattering amplitudes, with emphasis on providing the decay couplings of well-established mesons as a benchmark for extension to hybrid states, where the decay couplings will aid the experimental search of GlueX and CLAS12. One third of the Theory Center members is also engaged in phenomenological studies of the physics to be accessed at a future Electron Ion Collider, and are major contributors to the whitepaper that sets out its physics case. In all aspects, the Theory Center works closely with the experimental community, whether in performing crucial radiative corrections for parity-violating experiments, or in studies to constrain transverse momentum-dependent and generalized parton distribution functions from the full kinematic range of results that TJNAF will produce.

A key component in support of the 12 GeV experimental program is the Theory Center's *JLab Physics Analysis Center (JPAC)*. The *JPAC* project draws on world theoretical expertise in developing appropriate phenomenological tools and computational framework required for extracting the details of quark and gluon dynamics from experimental data of unprecedented precision and scope. Definitive answers to the basic questions of "do there exist hadrons for which the excitation of gluons is essential to their quantum numbers" and "what is the detailed internal flavor, momentum, angular momentum and spatial distribution of nucleons" require continuing engagement and collaboration between experimentalists and theorists both at TJNAF, at US universities and the wider hadron physics community.

This program addresses scientific milestones HP 3, 4, 5, 6, 7, 8, 9, 10, 11, 14 and 15 identified as essential for progress in hadronic physics.

The Nuclear Physics Core Capability serves DOE Scientific Discovery and Innovation (SC) mission numbers 2, 4, 22, 24, 26, 27, 28, 30, 33, 34, 35 and 36 from "Enclosure 1: List of DOE/NNSA/DHS Missions."

2. **Accelerator Science** (funded by DOE SC – Nuclear Physics, High Energy Physics, Work for Others (Department of Defense (DOD) – Office of Naval Research (ONR))

The focus of TJNAF's Accelerator Science is on superconducting, high current, continuous wave, multi-pass linear accelerators (linacs), including energy recovering linacs. Past achievements and future plans involve the lab's expertise in low emittance electron injectors, SRF niobium-based accelerating technology, and advanced electron-ion collider design. This broad suite of capabilities is complemented by world-class expertise in accelerator design and modeling.

Injector R&D

TJNAF has extensive expertise in high current photoemission sources, especially polarized sources. Over the past years, the polarization delivered to the CEBAF users has progressed from 35% (bulk gallium arsenide), 70% (strained gallium arsenide) to 89% (multi-layer strained gallium arsenide). In addition to measurements by the experiment, the polarization is measured at the injector with a Mott polarimeter, whose precision has been pushed to the limit with dedicated R&D. A new, higher voltage DC gun has been built (200kV) anticipating the need for improved beam quality for future parity violation experiments at 12 GeV CEBAF, and a photogun capable of operation at 350 kV is being developed for nuclear physics experiments at LERF. Recent photogun development was partially funded by the International Linear Collider (ILC). TJNAF electron sources and injectors have produced in continuous wave operation, electron beams with currents of 180 µA and 89% polarization for CEBAF and unpolarized beams of 9 mA for the ERL. For future high-current unpolarized beam applications, photoguns will soon rely on alkali-antimonide photocathodes that exhibit longer operating lifetime compared to gallium arsenide photocathodes.

SRF R&D

The SRF Institute at TJNAF can be a cost-effective R&D partner for all Office of Science projects requiring SRF expertise because of its experience and facilities. Past and current partnerships include jointly funded R&D and digital RF controls with the Rare Isotope Accelerator (RIA) (the predecessor of the Facility for Rare Isotope Beams (FRIB)), high-current cavities funded by ONR, crab cavities funded by the Advanced Photon Source (APS), and R&D on high Q_0 cavities for future accelerator technologies funded by BES. The application of this know-how is currently being applied to projects across the DOE-SC complex.

TJNAF also carries out forefront SRF R&D including high gradient research (which led to the development of processing procedures that were applied to the 12 GeV cavities) and thin film research aimed at low frequency cavities where the cost of niobium is high.

More recently, the focus has shifted to high Q_0, which reduces the cryogenic losses in SRF cavities. TJNAF is producing very high Q_0 cavity results with the use of Nitrogen doping of traditional solid niobium cavities. Current work continues exploring process refinements and extending the process to various types of cavities. Additionally, TJNAF is studying the possibility of reacting tin on the internal surfaces of Niobium cavities to create a film of Nb_3Sn (a technique initially pioneered at TJNAF). This study, initially funded by BES, is now being continued on NP program funds. The initial results are encouraging and could lead to superconducting cavities with significantly lower cryogenic losses than the niobium cavities that are the state of the art today. TJNAF is also engaged in understanding the impact of these very high Q0 cavities on the requirements for cryostat and component designs in cryomodules.

TJNAF is also pursuing a program to adapt commercial plasma processing to superconducting cavities. The goal is to develop a procedure that would enable *in situ* processing of cryomodules installed in CEBAF to maintain the gradient needed for high-energy operations.

TJNAF is also studying new materials, notably large-grain niobium, which improves the Q_0 while reducing the material costs. Studies of niobium with increased tantalum content (reduced purification) are also demonstrating promise of higher Q_0 at lower cost. These two effects are not mutually exclusive and together provide a low-cost strategy to reach the performance required by CW accelerators at a more affordable cost.

Advanced Electron Ion Collider (EIC) Design

The Accelerator Division, in partnership with the Physics Division and collaborators at other national laboratories, has been developing a design concept for a Medium Energy Electron Ion Collider (MEIC). A pre-conceptual design report for an MEIC was published in 2012, which fulfills the energy and luminosity requirements of the EIC physics White Paper. The MEIC design team, composed of TJNAF personnel and strategic national and international collaborators, is now working towards a Conceptual Design Report (CDR) in 3-4 years and has produced a first cost estimate, which was submitted to the NSAC Subcommittee on EIC cost. The MEIC is a collider that uses the existing 12 GeV CEBAF as an injector for the electron ring. The ion ring requires a brand new ion complex to produce, accelerate and collide the ions with the electrons. The injector complex consists of a source, ion linac, pre-booster, booster and collider ring. The Booster, electron ring and ion ring are stacked in a common figure-8 tunnel. The innovative figure-8 design allows proton and light-ion polarization in excess of 70%. The optics for the main accelerator components has been designed, and the focus now has turned to studying the correction systems and planning the R&D to validate key needed technologies. The most critical R&D item is high-energy bunched-beam electron cooling, and we plan to establish feasibility of this novel technology with a series of studies, simulations and targeted experiments that leverage our competence and capabilities and those of our collaborators. TJNAF is also focusing our TJNAF accelerator R&D towards the MEIC. The challenge in the next few years will be to identify the resources needed to successfully complete a CDR consistent with the Critical Decision timeline for an EIC Project.

The Accelerator Science Core Capability serves DOE Scientific Discovery and Innovation mission numbers 25, 26, and 30 from “Enclosure 1: List of DOE/NNSA/DHS Missions.”

3. Applied Nuclear Science and Technology

Accelerator Technology - (funded by DOE SC – Nuclear Physics, Basic Energy Sciences, High Energy Physics, DOD ONR, Commonwealth of Virginia, and Industry)

As a result of the development, construction, and operation of CEBAF, TJNAF has developed world-leading expertise in superconducting RF linear accelerators, high intensity electron sources, beam dynamics and instrumentation, and other related technologies. These capabilities have been leveraged to develop new technologies relevant to other disciplines beyond nuclear physics as well as applications to areas of national security.

Using SRF technology based on CEBAF, TJNAF has constructed and operated an advanced Free Electron Laser (FEL). The development of this machine enabled TJNAF to pioneer new Energy Recovery Linac (ERL) technology. In the ERL, the electron beam is re-cycled back through the accelerator out of phase with the accelerating field so the beam energy is returned to the SRF cavities. This power, which would normally be dumped, can represent 90% of the beam power in a high power linear accelerator. TJNAF was the pioneer in developing this technology and the TJNAF FEL remains the highest power system extant. A number of other laboratories are adopting this technology, and ERL technology is likely to become an important contribution to sustainability initiatives at DOE labs.

Up until recently, the FEL was primarily funded by the Office of Naval Research (ONR) in support of its program to develop a high average power laser for shipboard defense against cruise missiles. This IR laser has demonstrated up to 14 kW of CW average power, making it the most powerful free electron laser in the world. The coherent pulses of light have been used for other research on such varied topics as the development of a treatment for adult acne, energy loss in semiconductors due to interstitial hydrogen, terahertz imaging for homeland security purposes, and a search for dark matter. Under separate United States Air Force (AF) funding, an ultraviolet (UV) FEL system has provided

20 microjoule pulses of 300 nm light at 4.7 MHz repetition rates in 120 fs pulse length trains. The harmonics of that UV FEL at 10 to 13 eV provide fully coherent beams with higher average brightness by a factor of 100 than any 3rd generation storage ring and have the added capability to provide ultra-short pulses to address systems dynamically. TJNAF has demonstrated world-leading capability in UV laser development with this FEL technology. Funds were obtained from the Commonwealth of Virginia to upgrade the beam energy by refurbishing one of the cryomodules. This cryomodule has been completed, met specifications in the test cave, been installed in the FEL, and awaits funding for commissioning.

Unfortunately, the Office of Naval Research has canceled its Free Electron Laser program and the TJNAF FEL was not operational in FY14. As a result, TJNAF is engaging in an effort to develop a new plan for the future use of this valuable asset.(It is interesting to note that a similar new facility is under construction at Mainz, Germany for nuclear physics experiments and Cornell University is developing plans for a similar facility in the US.) In the interim, the Lab is using the term LERF (Low Energy Recirculator Facility) to refer to this facility, as some of the future uses would not utilize the equipment as a free electron laser. The present range of the discussion includes future nuclear physics experiments (DarkLight is one example, with construction already partially funded by an NSF MRI grant), characterization of materials using low energy positrons, R&D on production of medical isotopes using the (gamma, n) reaction, and experiments using THz radiation. There is also substantial potential for facilitation of commercial development of free electron laser technology, and TJNAF is pursuing this option as well. TJNAF is developing a plan for future utilization of this facility which is of maximum benefit to the mission of the laboratory and of the nation.

Presently, TJNAF is applying its accelerator technology to collaborate with four other national laboratories to realize the Linac Coherent Light Source II, at the Stanford Linear Accelerator Center (LCLS II at SLAC). Representing a major upgrade in international X-ray Free Electron Laser capabilities for study of atomic interactions, condensed matter physics, warm dense plasmas, and biological physics, the system will provide CW intense coherent 50 fs long photon pulses at up to 5 keV in energy with repetition rates up to 1 MHz. The heart of this facility is a state-of-the-art SRF linac replacing the first 1/3 of the SLAC copper linac providing 4 orders of magnitude improvement in average laser beam intensity. Expertise at TJNAF will be a great asset to facilitate successful construction, installation, and operation of this first SRF-based linac at SLAC. TJNAF will be responsible for construction and installation of half (2 GeV) of the superconducting accelerator as well as the cryogenic refrigerator. The system will utilize an entirely new nitrogen surface processing to raise the cavity quality factor above 2×10^{10} for substantial savings in electrical power and refrigeration required. Cavities will be fabricated by industry based on the successful XFEL production model but assembly and testing of the cryomodules will be performed by TJNAF and FNAL before installation at SLAC. Once operational, beams from both the existing LCLS accelerator and the new superconducting accelerator will be able to drive two advanced undulators providing exceptional experimental flexibility and doubling the number of users that can utilize the facility simultaneously. The project is looking this year for approval from DOE to award approximately $180M of long lead procurements to advance the FY20 scheduled date for first light.

Another SRF application under consideration is the development of an EUV (Extreme Ultraviolet) FEL for semiconductor lithography. There is increasing industrial interest in this technology, and TJNAF is pursuing the possibility of strategic partnerships with industry to perform the physics and engineering design of an FEL suitable for such an application.

Radiation Detection and 2D and 3D Imaging in Nuclear, Biomedical and other applications (funded by DOE SC – Nuclear Physics and Biological and Environmental Research, Commonwealth of Virginia, Southeastern Universities Research Assoc., and LDRD)

The TJNAF Radiation Detector and Imaging Group develops, constructs and tests a variety of novel high performance (high resolution and high sensitivity) 2D and 3D radioisotope imaging systems. These include single photon, emission computed tomography (SPECT), positron emission tomography (PET), x-ray computed tomography (CT) and optical/infrared imaging. These are used for a broad variety of applications (beyond nuclear physics research) including: medical preclinical and clinical application, studies of biological function in plants and small animals including motion tracking and imaging; and the potential for non-destructive evaluation and homeland security applications.

A new compact detector technology called a silicon photomultiplier (SiPM) is a focus at TJNAF. The devices are used for nuclear and particle physics detector systems because of their immunity to magnetic fields. Their low profile in terms of compactness and low-voltage requirements gives them tremendous potential as photo-sensors for biomedical applications. A hand-held camera based on these SiPMs was designed and used as an imaging aid to cancer surgeons during surgical procedures. Folding in feedback gained from the surgeons, this hand-held camera is now being improved through both the addition of real-time position tracking - to provide SPECT images for the surgeon - and the utilization of wireless data communication to eliminate cables.

Through a Strategic Partnership Program (SPP) with the Southeastern Universities Research Association (SURA), funding from a Commonwealth of Virginia grant provided support for work on a novel gamma-ray collimation technique to facilitate radioisotope-based, high-sensitivity Breast Specific Gamma Imaging (BSGI). The new methodology would reduce the required injected dose to the patient. This SPP agreement also included collaboration with Dilon Technologies and the University of Florida to optimize this technology.

TJNAF is using nuclear physics detector technology to develop optimized systems for radioisotope imaging. TJNAF's Radiation Detector and Imaging Group has developed and advanced a SPECT-CT system that has been used in brain studies on awake, unrestrained mice and is being upgraded to improve its utilization and accommodate rats. Results of an imaging study using the new system showed it can obtain detailed functional brain images of a conscious mouse moving freely and for the first time, documented the effects of a particular anesthesia on the absorption patterns of a brain specific imaging compound on anesthetized vs. awake mice.

TJNAF has also built PhytoPET, a PET imaging methodology for plant research. The use of PET radioisotopes and the PhytoPET system is used to conduct photosynthesis and sugar transport (carbohydrate translocation) studies in plants under different conditions. TJNAF is now further developing these radioisotope imaging techniques to provide a novel tool for plant biologists to explore the interaction of microbes in soil and the roots of plants. For instance, global climatic changes lead to increased episodes of extreme events associated with temperature and precipitation, which affects the water availability for plant growth and, in turn, the preferential water flow along roots and the resultant nutrient cycling in the rhizosphere (soil-root interface). The PhytoPET technology has attracted interest from biologists involved in global climate change, agricultural, bio-fuel and carbon sequestration research.

To further educate biologists on such potential studies, TJNAF and Duke University conducted a workshop on "Visualization with Short-Lived Isotopes Gets to the Root of Plant Environment Transfer" at the 2014 Ecological Society of America (ESA) Annual Meeting. The ESA has more than 10,000 members with various sections related to, *e.g.*, plant ecophysiology, microbial ecology, soil ecology, and applied ecology. The goals of the workshop were: (1) to inform ecologists researching plant and/or microbes' function in different environments about the use of new tools being developed for radioisotope tracers based on advanced technology; and (2) to foster interactions between potential users of these new technologies and their developers. The workshop had over twenty-five participants and included presentations from TJNAF, Duke University, Brookhaven National Laboratory, Oak Ridge National Laboratory, Washington University in St. Louis, and Lawrence Berkeley National Laboratory.

There are other potential developments associated with the detector technology used in the nuclear physics experiments. In the past, such technology at the laboratory has led to a successfully marketed breast cancer imaging device. Should such opportunities arise in the future under the SPP or CRADA rubric, TJNAF would entertain them, provided the scale was appropriate and the perspective retained.

The Applied Nuclear Science and Technology Core Capability serves DOE Scientific Discovery and Innovation mission numbers 9, 14, 26, and 30 from “Enclosure 1: List of DOE/NNSA/DHS Missions.”

4. Large Scale User Facilities/Advanced Instrumentation

Experimental Nuclear Physics (funded by DOE SC – Nuclear Physics)
TJNAF is the world’s leading user facility for studies of the quark structure of matter using continuous beams of high-energy, polarized electrons. CEBAF is housed in a 7/8 mile racetrack and was built to deliver precise electron beams to three experimental End Stations or Halls simultaneously. Hall A houses two high-resolution magnetic spectrometers of some 100 feet length and a plethora of auxiliary detector systems. Hall B has been the home of the CEBAF large-acceptance spectrometer (CLAS) with multiple detector systems and some 40,000 readout channels. Hall C boasts an 80 feet long high-momentum magnetic spectrometer and has house many unique large-installation experiments. Maintenance, operations and improvements of the accelerator beam enclosure and beam quality, and the cavernous experimental Halls and the multiple devices in them, are conducted by the TJNAF staff, to facilitate user experiments.

The expertise developed in building and operating CEBAF has led to an upgrade that doubled the maximum beam energy (to 12 GeV) and provided a unique facility for nuclear physics research that will ensure continued world leadership in this field for several decades. The $338M project, known as the 12 GeV CEBAF Upgrade, received Critical Decision 0 (CD-0) approval in March 2004 and started construction (CD-3 approval) in September 2008. This upgrade has added one new experimental facility, Hall D, dedicated to the operation of a hermetic large-acceptance detector for photon-beam experiments, known as GlueX. The upgrade work still in progress will add a new magnetic spectrometer in Hall C, and convert the Hall B apparatus to allow for the higher-energy and higher luminosity operations. Unique opportunities exist in Hall A with the existing equipment, with the new Super BigBite Spectrometer (SBS) under construction and possibly, with additional dedicated apparatus for one-of-a-kind experiments, such as the foreseen MOLLER apparatus to measure the weak charge of the electron and provide a fundamental precision test of the Standard Model. Approval of CD-4A (Approve Accelerator Project Completion and the Start of Operations) was received in summer 2014, approximately five months ahead of schedule.

To enable the experimental program, TJNAF staff is a world leader in the development and operation of high-power cryogenic target systems, and highly-polarized gaseous and solid-state target systems, such as polarized ^{3}He, H and D solid-state polarized target systems, and frozen-spin H and HD-Ice targets. Many of these targets have demonstrated world record performance. In addition, to facilitate a modern and efficient data acquisition system, TJNAF staff have designed and developed an ultra-fast fully pipelined electronics system, with components finding their way into other user facilities such as Brookhaven National Laboratory.. This development of advanced data acquisition instrumentation allows for spin-offs such as that described in the bio-medical applications above.

CEBAF Operations

As mentioned, CEBAF has been recently upgraded to provide electron beam with energy up to 12 GeV, a factor three over the original 4 GeV CEBAF design. In addition to the increase in beam energy, the maximum number of simultaneous experiments that CEBAF can support has been increased from three to four. The experimental program is very flexible and dynamic. The simultaneous execution of experiments requires that CEBAF be capable of delivering beam with a large dynamic range in beam currents (nA → 100s of μA) or bunch charge (0.004fC → 0.4pC). Additionally, the experimental user can request beam energies that correspond to 1, 2, 3, 4, 5 or 5.5 pass re–circulation. The electron beam is polarized and spin alignment can be optimized for a single user.

Presently, CEBAF is transitioning from the 12 GeV commissioning effort into the "initial years" Physics program. Up to this point, an opportunistic Physics program has been supported during periods when the accelerator commissioning efforts allowed. Extensive superconducting radio frequency (SRF) cavity maintenance is planned for the summer of 2015. After this maintenance, the first beam operations at full design energy, 12 GeV at 5.5 passes, are planned for the fall of 2015.

With 418 installed SRF cavities, CEBAF operations represent a significant fraction of the world SRF operating cavity-hour data set. Some of the CEBAF SRF cavities have been operating for more than 20 years. The CEBAF data set and operational experience is a valued resource for new or existing SRF based accelerators.

Additional research and development activities include beam diagnostics, emphasizing non-invasive techniques to monitor and maintain delivery of beams with up to a 1MW of beam power. CEBAF operations also support and enable R&D in Accelerator Physics at the Center for Injector and Sources, Center for Advanced Studies of Accelerators (CASA), SRF Institute and efforts from the Engineering and Physics Divisions.

TJNAF staff has developed a substantial ability to conceive and design large accelerator facilities, building upon 6 GeV CEBAF operations and augmented with the ongoing 12 GeV Upgrade. With the completion of the 12 GeV Upgrade, TJNAF will continue its role of the world's premier experimental QCD facility. The ability to use the TJNAF LERF as an accelerator R&D test-bed for energy-recovery linacs, and techniques required to establish cooling of proton/ion beams, for example, provides a mutual beneficial cross-fertilization between the TJNAF LERF and Nuclear Physics.

Accelerator Technology (funded by DOE SC – BES, DOD – ONR)

SRF Accelerator Construction

TJNAF has developed state-of-the-art instrumentation for the design, development, fabrication, chemical processing, and testing of superconducting RF cavities. This complete concept-to-delivery capability is among the best in the world. All of these capabilities have been essential to the development, deployment, commissioning and operation of the 12 GeV CEBAF Upgrade. The addition of TJNAF's Technology and Engineering Development Facility (TEDF), now completed, provides 100,000 additional square feet that have enhanced and co-located all SRF operational elements and provides additional experimental assembly space. It also provides configurable space that can be adapted to work on different kinds of SRF cavities as TJNAF's portfolio of projects expands. Essential to the SRF program at TJNAF is a five-year plan to progressively update the SRF processing tools to optimally match to the building infrastructure, improve processing and achieve a safer and ergonomically better work environment.

These facilities will be used to assemble the cryomodules for the LCLS-II project, and modifications are ongoing to optimize the facilities for a different style of cryomodule.

Cryogenics

Over the last two decades, TJNAF has developed a unique capability in large scale cryogenic system design and operation that is an important resource for the US national laboratory complex.. The TJNAF cryogenics group has been instrumental in the design of many construction projects requiring large scale cryogenics: (SLAC (LCLS-II), Michigan State University (FRIB), Oak Ridge National Lab (SNS), TJNAF (12 GeV Upgrade), and NASA) as well as improving the cryogenic efficiency of existing systems (Brookhaven National Laboratory). In the process, many inventions have been patented, and one has been licensed by Linde (one of two companies that build cryogenic systems) for worldwide applications on new and existing cryogenic plants. This work has also resulted in many Master's theses to ensure the continuity of this expertise in the coming decades. This know-how is being applied to TJNAF as well as other projects discussed below.

TJNAF's cryogenics group's highly-skilled staff operates and improves the laboratory's three large 2K cryogenic plants (Central Helium Liquefier (CHL) 1 & 2 and the Cryogenic Test Facility (CTF)) that support CEBAF operations and SRF production. The overall refrigerator count has increased to five operational plants (adding ESR1 and Hall D) as the 12 GeV Upgrade comes on-line. The large 2K plants utilize patented cryogenic cycles developed by TJNAF that increase efficiencies by up to 30% more than what was traditionally available from industry. Extensive operational experience has allowed the group to develop controls technologies and techniques that permit year round, unattended operations that drastically decrease staffing needs traditionally required for operations of this magnitude. Additionally, stepwise improvements have been made on the mechanical systems, primarily the warm compressors, which significantly extend their lifetimes between major maintenance cycles and decrease input power needs. The combination of cycle and mechanical improvements has decreased the input power requirements for equivalent refrigeration at 2K by 1.4MW for CHL2 compared to CHL1.

The 12 GeV Upgrade has benefitted from improvements that were first demonstrated at NASA's Johnson Space Center where both the cycle technology and improvements on the warm compressor system were applied to a 12.5kW refrigerator at 20K for a space effects chamber to test the James Webb telescope. Prior to this, the cycle technologies were applied to other DOE facilities, notably to the Relativistic Heavy Ion Collider (RHIC) at Brookhaven.

The group is presently responsible for designing, specifying, procuring and commissioning the CHL for FRIB, based on the successful CHL2 designed for the 12 GeV Upgrade. Additionally, responsibilities for specifying and procuring the LCLS-II refrigerator have been undertaken by the group.

Nationally, this group is the premier source of cryogenic engineering and design for large helium refrigerators, filling a void in commercially available services. TJNAF's cryogenics group is consulted when project needs for a large helium refrigerator system arise (>2kW @ 4K or equivalent capacity) to ensure effective design results and highly efficient operation.

The Large Scale User Facilities/Advanced Instrumentation Core Capability serves DOE Scientific Discovery and Innovation mission numbers 24, 26 and 30 from Enclosure 1: List of DOE/DHS Missions.

IV. Science Strategy for the Future/Major Initiatives

Science in the 21st Century is making enormous advances on several fronts in physics, chemistry, biology and other subjects through the research capabilities provided by advanced accelerator facilities and their operation as international user facilities. TJNAF possesses key capabilities and competencies in accelerator science and in the application of the modern accelerator technologies. Continued development of these capabilities is one of the major initiatives integral to this strategic plan. In addition to providing world leading facilities and expertise to meet the identified needs of the nuclear physics research community, TJNAF has identified collaborative roles that it can play in the provision of facilities elsewhere associated with the Office of Science (e.g., Basic Energy Sciences and High Energy Physics) and other agencies.

The nuclear physics program being pursued by more than 1,300 users and staff has been dominated by a series of key experiments using CEBAF operating at energies up to 6 GeV. The motivation and interpretation of these experimental studies is underpinned by theoretical studies using state-of-the-art calculational techniques in QCD both on the lattice and in the continuum, as well as precision photon-Z boson radiative corrections to experiments like Qweak. A major goal of the laboratory is to successfully complete the 12 GeV Upgrade Project. This project is currently under construction and will be commissioned in 2014-2016. This will allow a unique 3D map of the valence quarks and extend the earlier studies to comprehensively describe the valence quark momentum and spin distributions in nucleons and nuclei. New opportunities to discover heretofore unobserved hadron states predicted by quantum chromodynamics will become available. Higher precision measurements of the weak couplings of elementary particles will be accessible through measurements of parity violating asymmetries. Lepton scattering has proven to be and continues to be a powerful tool in the elucidation of the structure of the subatomic world, and a future electron-ion collider with high luminosity could provide new opportunities to explore hadronic structure in a region dominated by the quark-antiquark sea and by gluons.

Details on each of the components of TJNAF's scientific strategy and major initiatives follow.

1. Nuclear Physics

a) 12 GeV CEBAF Upgrade Project (Funded by DOE SC – Nuclear Physics)

- ***The vision:*** The 12 GeV CEBAF Upgrade Project is an upgrade to the CEBAF accelerator and to the associated experimental facilities, which will enable CEBAF's world-wide user community to expand its research horizons, and will allow breakthrough programs to be launched in three key areas:
  - The experimental investigation of the powerful gluon fields believed to be responsible for quark confinement; understanding confinement is essential for understanding the structure of nuclear matter and is one of the major gaps in our understanding of QCD; CEBAF is unique among planned or existing facilities in its ability to address these issues;
  - The exploration of the quark and gluon structure of the proton, the neutron, and atomic nuclei through study of the newly developed field of nucleon tomography; and
  - The search for new physics beyond the Standard Model of nuclear and particle physics.

The 12 GeV CEBAF Upgrade directly addresses the major scientific opportunities identified in both the 2002 and the 2007 Long Range Plans, in which the Nuclear Science Advisory Committee (NSAC) recommended the 12 GeV CEBAF Upgrade as its highest priority for the Nuclear Physics program. It directly supports the Nuclear Physics mission and addresses the objective to measure properties of the proton, neutron, and atomic nuclei, which, in concert with theoretical calculations, will provide an improved quantitative understanding of their quark and gluon substructure.

The full scope of the 12 GeV CEBAF Upgrade project includes upgrading the electron energy of the main accelerator from 6 GeV (Giga- or billion electron volts) to 12 GeV, constructing a new experimental area (Hall D), and enhancing the capabilities in the existing experimental halls to support the most compelling nuclear physics research.

Required Resources: In the baseline plan, CD-4B (Approve Experimental Equipment Project Completion) is expected by September 2017. The project received CD-2 Approval on November 9, 2007, and received CD-3 Approval for the start of construction on September 15, 2008. Funding began in FY 2004; $320M has been received as of February 28, 2015 and $313M has been costed or committed. The baseline funding profile extends through FY 2017. The baseline Total Project Cost is $338 million; the Total Estimated Cost (TEC) is $310.5 million, and Other Project Cost (OPC) is $27.5 million. This funding is complemented by support from the Commonwealth of Virginia, the National Science Foundation and International Funding Agencies.

- ***Significant Accomplishments:*** The documentation package for Critical Decision 4A was prepared in consultation with the Federal Project Director and Federal Program Manager. This package included demonstration of all key performance parameters for the accelerator and civil project scope, as well as the Transition to Operations Plan and the Lessons Learned document, and was posted in June 2014 for review by DOE. An ESAAB was held in July 2014 resulting in approval of CD-4A (Accelerator Project Complete and Start of Operations), five months ahead of schedule.

Hall D beam commissioning took place in November 2014. The Key Performance Parameter (Detector operational: events recorded with a >2 nA electron beam at > 10 GeV beam energy at 5.5 passes) was met and approved by DOE in December 2014.

Significant progress has been made on all seven new superconducting spectrometer magnets. The Q1 magnet has been delivered to Jefferson Lab, installed on the Hall C carriage, then successfully cooled and powered to operating currents. The HB magnet is also on-site, installed in Hall C, and undergoing acceptance tests. The remaining five magnets are under construction, with five (of six) coils for the Hall B Torus on-site having passed QA tests.

An Independent Project Review (IPR) of the 12 GeV Upgrade Project was conducted on March 12, 2015 by the DOE-SC Office of Project Assessment; the review committee noted the excellent progress made on the Hall D commissioning, superconducting magnets, and detector portions of the project. Accelerator and Hall D are 100% complete. Civil construction is 97% complete. Construction in Halls B and C are 80% complete. Installation of the Torus magnet has begun in Hall B, as well as detector and magnet installation in Hall C.

b) Experimental Nuclear Physics Program (Funded by DOE SC – Nuclear Physics)

- ***The Vision:*** The ongoing research program at CEBAF is an essential part of the national and global program in nuclear physics spanning the study of hadronic physics, the physics of complex nuclei, the hadronization of colored constituents, and precision tests of the standard model of particle physics. With the 12 GeV Upgrade, TJNAF will provide many new opportunities for scientific advancement and discovery in these fields.

  During the last few years, the TJNAF Program Advisory Committee (PAC) has considered experimental proposals from its user community for the upgraded facility. Interest in the 12 GeV science program has been tremendous, and there are presently 70 approved proposals, each with a scientific rating and recommended allocation of beam time. This set of approved experiments will require more than six years of operation at near-full efficiency, extending scientific productivity well into the 2020's. The PAC continues to meet on an annual basis to consider new proposals. In 2014, the PAC had an additional meeting to provide lab management with insights on the approved experiments with the highest overall science impact, feedback to be folded into the scheduling process. A brief overview of the approved science program is presented in the following.

  Hadronic Physics
  As envisioned in the original documentation for the 12 GeV Upgrade, the implementation of a new meson spectroscopy program in the mass range up to 3.5 GeV will offer a dramatic new window into the role of gluon self-interactions and the nature of confinement. Previous models of undiscovered mesons with exotic quantum numbers are now complemented by robust Lattice QCD calculations (performed by TJNAF theorists and collaborators) that indeed predict these states within the mass range of the GlueX experiment in Hall D. *The prospects for discovering these mesons at TJNAF have increased dramatically in the last few years.* In addition, the detailed spectroscopic information from experiment, coupled with the guidance of new Lattice QCD results, truly offers an exciting and unique opportunity to explore mechanisms of confinement.

  The study of the internal landscape of the nucleons is now undergoing a renaissance. Driven by the inadequacies of previous treatments and recent experimental data, TJNAF is now moving beyond the simple one dimensional parton distribution functions of the past. The pioneering efforts of HERMES and COMPASS, together with the 6 GeV TJNAF, have demonstrated the feasibility of studying Transverse Momentum Dependent (TMD) distributions as well as Deeply Virtual Compton Scattering (DVCS) measurements that offer access to Generalized Parton Distributions (GPD). Indeed recent measurements using the 6 GeV CEBAF have demonstrated that high quality CW polarized electron beams with a combination of large acceptance and precision detectors are a powerful tool to attack these new observables. We can now be confident that the extended kinematic range and new experimental hardware associated with the TJNAF 12 GeV Upgrade will provide access to these novel distributions and reveal new aspects of nucleon structure. *It is quite possible that much of the remaining nucleon spin will be found to be in the orbital motion of the valence quarks at TJNAF.*

  Physics of Nuclei
  The description of complex nuclei at a fundamental level must include correlations among the nucleons beyond the simple mean field model. Indeed, these correlations are essential to understand the details of nuclear structure evident in the spectra of all nuclei. In a recent discovery, these correlations were shown to be associated with the distributions of quarks in

nuclei. *This provides the first indication of a deep connection between the role of nucleon-nucleon interactions and the quark structure of many nucleon systems.*

The spatial distribution of protons in nuclei is closely related to the charge distribution, which is accurately determined in elastic electron scattering experiments. However, the neutron distribution has been much more difficult to study experimentally. The sensitivity of the parity-violating electron nucleus interaction to the distribution of neutrons in the nucleus offers a unique method to address this fundamental but elusive quantity. This distribution of neutrons, relative to the proton distribution, is a direct consequence of the symmetry energy term in the equation of state of nuclear matter. In addition to being a basic property of all nuclear systems, this symmetry energy governs the properties of neutron stars, such as the radius.

From Color to Hadrons

Many aspects of QCD involve the internal color degrees of freedom of systems which must then be studied by detecting the colorless particles that result from hadronization of these objects. For example, the quark-gluon plasma (QGP) is studied at RHIC through detection of the hadrons that emerge from the hot droplet of QGP. This basic process can be better studied in controlled experiments with lepton beams, where a single quark – at TJNAF a light quark – is ejected by the scattering process and the space-time evolution of this quantum state can be studied by varying the kinematics and nuclear environment.

Beyond the Standard Model

Over the last few years we have seen a remarkable growth in the proposed program to test the Standard Model of electroweak interactions using the facilities at TJNAF. Indeed, the lab now envisions a powerful program to provide higher precision tests of the Standard Model and learn about the unseen forces that were present at the dawn of the universe. These experiments push the technology at TJNAF to the limits, and recent success with the Qweak experiment clearly points the way to a more ambitious program in the future. The unique quality of the electron beams also enables a sensitive search for light neutral vector bosons that could explain the muon g-2 anomaly as well as offer connections to theories of cosmological dark matter. *The facilities at TJNAF provide exceptional opportunities for discovery of new phenomena beyond the Standard Model.*

International Context

One should note that there are complementary efforts on the international scene that provide a broader context for the TJNAF program. COMPASS at CERN continues with large acceptance at much lower luminosity, but also has reach to higher center-of-mass energies. COMPASS can generally provide similar information to CEBAF with lower statistical precision at lower Bjorken x. (COMPASS has received approval for several years of further running at CERN.) Mainz has a 2 GeV CW microtron facility, with excellent CW polarized electron beams. (This facility received last year renewed multiyear funding from the German government.)

Hadron beam facilities that provide relevant experimental capabilities are also coming on line. JPARC in Japan will explore strange nuclear systems with high intensity Kaon beams. TJNAF is seeing a strong interest in collaboration on meson spectroscopy from GSI and other German institutes.

Thus, TJNAF is a unique and integral component of a worldwide program in experimental nuclear physics. There is indeed a large and active international community studying QCD, confinement, and precision tests of the Standard Model. TJNAF is clearly providing the U.S. nuclear physics program with a leadership role in this vibrant international community, and with the successful upgrade, will be a flagship for this diverse scientific program for many years to come.

- ***Resources Required*:** TJNAF is now ready for accelerator operations. Experimental Hall A and Hall D, with the new GlueX apparatus, are ready to initiate their science program. Completion of construction and subsequent installation of 12 GeV equipment associated with the Upgrade project in experimental Halls B and C remains ongoing. In the next two years, the focus will be on machine development towards robust 12 GeV accelerator operations for the envisioned science program, on completion of Halls B and C and subsequent pre-operations, and start of science in all Halls. Completion of 12 GeV Upgrade project funding coupled with robust operations budgets will be essential to realizing the scientific potential of the 12 GeV CEBAF. With the advent of the 12 GeV operations, the goal is to operate the facility at close to the optimal level of 37 weeks per year with, on average, experiments in three of the four halls taking data at any given time. This corresponds to a present experiment backlog of about six years, assuming full funding for maximum productivity of the facility. In addition, capital equipment funds are required to: fund the SBS in Hall A, particle identification detection systems for Halls B and D; a beam line upgrade in Hall B to maximize the allowable luminosity, a neutral-particle facility in Hall C; and, high-power cryogenic target and polarized ^{3}He target infrastructure for Halls A and C. Similarly, accelerator improvement project funds would be required to allow for full flexibility of beam and energy operations to all Halls. Accelerator improvement projects already underway include dogleg magnet modifications and a full energy injector region. There are also a number of exciting initiatives being proposed by the user community which would significantly enhance the 12 GeV research capabilities and which will require that the laboratory secure additional equipment funds, including potential international resources. These initiatives include the MOLLER apparatus, and the SoLID system. The MOLLER apparatus completed a successful DOE science review in fall 2014 and is now ramping up for a CD-1 review. A position paper for the SoLID system was finalized, and a Director's Review was held in February 2015.

- ***Significant Accomplishments:*** Some recent accomplishments of the experimental program yielding significant results include:

  <u>Protons Hog the Momentum in Neutron-Rich Nuclei</u> – At a momentum greater than the Fermi momentum, the fraction of proton-neutron pairs dominates in atomic nuclei. TJNAF recently found that *even in neutron-rich heavy nuclei proton-neutron pairs dominate* over proton-proton and by inference neutron-neutron pairs. The implication of this pairing is that, even if there are far more neutrons than protons in nuclei, the proton momentum above the Fermi momentum is near-identical to that of the neutron – the momentum is shared. This is confirmed in nuclear theory calculations for light nuclei, and results in an *on average higher proton than neutron momentum*, as indeed had also been suggested for neutron-rich nuclei. This is completely unlike the effects for non-interacting Fermions in a mean field, where one would expect the neutrons to occupy higher-momentum states, obeying Pauli's exclusion principle. In contrast, the protons in neutron-rich systems carry higher-average momentum than the neutrons. This result has implications for the equations of state of neutron stars and, for instance, atomic interactions in ultra-cold atomic gases. The results were published in Science 346, 614 (2014).

  <u>Probing Color Forces</u> – Polarizabilities determine the dynamical response of bound systems – be they molecules, atoms or nucleons – to external fields. It is the property of matter that describes the relative tendency of the internal structure to be distorted by the field. Nucleons can have an electric polarizability, a magnetic polarizability, but also a spin polarizability. TJNAF researchers have determined the so-called "d2" moment of a polarized neutron embedded in ^{3}He

which is connected to a spin polarizability, but may be more appropriately seen as the effect of a Lorentz color force on the neutron, proportional to the sum of transverse electric and magnetic color fields the quarks inside the neutrons experience. This net effect is similar as the "chromodynamic lensing" a struck quark experiences from color forces, as it exits the nucleon before converting into a confined system. The results agree with state-of-the-art calculations from advanced computing and models. The results also imply that the neutron electric and magnetic color forces are nearly equal in magnitude but opposite in sign. The results are published in Physical Review Letters 113, 022002 (2014).

Exploring Proton Structure with Electrons and Positrons: Resolving the Proton Form Factor Puzzle – The proton electric form factor describes the spatial extended distribution of the fractionally-charged quarks inside the proton. One of the major findings of the TJNAF 4- and 6-GeV science program has been the discovery that the proton's charge distributions differs from its magnetization distribution. However, results from measurements using spin degrees of freedom differed from the more conventional scattering probability measurement (Rosenbluth-separation) technique. The discrepancy was considered to have arisen from corrections due to two-photon exchange terms impacting the conventional technique far more than the spin technique. A direct comparison of electron and positron scattering could directly resolve this. An experiment at TJNAF did exactly this. A mixed electron and positron beam was created, and the scattered electrons or positrons were detected, in combination with the struck recoiling proton. The ratio of the scattering probabilities agrees with expectations based on two-photon exchange effects, solving the noted discrepancy. Complementary experiments at VEPP-3 in Novosibirsk and OLYMPUS at DESY, using sequential positron and electron beams, expect results shortly. The TJNAF results are published in Physical Review Letters 114, 062003 (2015).

The EIC Science with Light Ions: Towards Nuclear Binding – The ability of the EIC to collide electrons and light nuclei, with 2 to 12 nucleons, whose nuclear structure is experimentally well studied and well described by existing models, will allow us to *study* the nucleon-nucleon force at short distances, but from the point of view of quarks and gluons. The recent discovery at TJNAF of the intriguing correlation between the quark motions inside the nucleus and the nucleon-nucleon force at short distance dramatically enhances such studies at the EIC. Detection of spectators (those nuclear fragments which do not participate in the DIS process) from a nucleus can identify the active nucleon and studies the nuclear binding effects and what role the partons play in them. TJNAF scientists have shown the potential to access neutron spin structure with polarized deuterons and spectator tagging at an Electron-Ion Collider. It was shown that the free neutron structure could be obtained by extrapolating the measured spectator proton recoil momentum to the on-shell point. The method eliminates nuclear modifications and can be extended to polarized scattering, as well as to semi-inclusive and exclusive final states. Recent emphasis is now on measurements at spectator proton recoil momentum well above the deuteron's Fermi motion, to study the role of partons in nuclear binding.

c) **Theoretical and Computational Nuclear Physics Program** (Funded by DOE SC – Nuclear Physics, and Advanced Scientific Computing Research)

- ***The Vision*:** TJNAF's world class program in nuclear theory has been enabled by close integration of theoretical and computational methodologies with emerging computing technology. The SciDAC program has facilitated the combining of capacity computing on leadership class machines, such as that at ORNL, with the capability for fast processing by GPUs, by supporting critical software developments. Success in creating software suitable for heterogeneous computing is a hallmark of the TJNAF effort in lattice QCD. The optimization of acceleration devices that combine CPUs and GPUs is the current technology linking TJNAF with innovative hardware companies. Importantly, this has the potential to produce benefits transcending the boundaries of lattice QCD across nuclear physics and into other areas of computational science from biology to oceanography. Consequently, it is timely to pursue the development of a regional center for universities within Virginia (as well as more widely within Southeastern Universities Research Association or SURA), together with commercial and defense enterprises, in which TJNAF facilitates disseminating and sharing expertise. The creation of a viable computational science program beyond nuclear physics will require close ties to other SURA institutions to achieve credibility and critical mass in a range of research areas. Close links with key hardware companies ensure that TJNAF can provide important contributions in this march to the exascale.

- ***Resources Required*:** Local funding may be sought, for instance through the Commonwealth of Virginia, for such a program. Such developments will in turn ensure the nuclear physics program maintains its cutting edge. The largest award to-date of 250 million core hours on the Oak Ridge Leadership Class Facility will enable the computation within lattice QCD of the decays of hybrid states relevant to the TJNAF 12 GeV program to be performed.

- ***Significant Accomplishments:*** Pioneering calculations of hadronic scattering phase-shifts have been performed on the lattice, for resonant channels. The first was purely elastic I=1 $\pi\pi$ scattering and generated the ρ-resonance. Next were the first computation of inelastic scattering with $K\pi$ and $K\eta$ coupled-channels, which produced realistic results for K*-resonances up to spin 2. This bodes well for the next generation of hadron scattering calculations for which a range of coupled final states are essential. Moreover, transition form-factors have now become a target for computation, with the establishment of a formalism relating finite volume matrix elements to real hadron scattering. As part of the on-going program of Quantum Monte Carlo calculations of the properties of light nuclei, extensive results in very good agreement with experiment for the electromagnetic moments and transitions in $A \leq 9$ nuclei have been published. This has set the stage for the publication of a review of Quantum Monte Carlo methods for nuclear physics surveying these accomplishments. A major study of how the spin structure of the neutron is made possible by using polarized deuterons and spectator proton tagging has been published, with more promising results to follow. New limits on the intrinsic charm in the nucleon set by global analyses of parton distributions, and on the anti-down-anti-up asymmetry in the proton in chiral effective theory have both been published in Physical Review Letters.

2. **Electron Ion Collider (EIC)** (Funded by DOE SC – Nuclear Physics)

- ***The Vision***: The Nuclear Physics community in the U.S. has identified an electron ion collider as a major new opportunity for the field. Indeed, the 2007 NSAC Long Range Plan stated, "An Electron-Ion Collider (EIC) with polarized beams has been embraced by the U.S. nuclear science community as embodying the vision for reaching the next QCD frontier. EIC would provide unique capabilities for the study of QCD well beyond those available at existing facilities worldwide and complementary to those planned for the next generation of accelerators in Europe and Asia." Such a facility would continue the TJNAF's program of studying the fundamental structure of nuclear matter into a regime where the dynamics is governed by a plethora of soft quarks, antiquarks and gluons.

  The scientific case for an EIC was endorsed by the 2010 NAS Decadal Report, which stated, "An upgrade to an existing accelerator facility that enables the colliding of nuclei and electrons at forefront energies would be unique for studying new aspects of quantum chromodynamics. In particular, such an upgrade would yield new information on the role of gluons in protons and nuclei."

A new NSAC Long Range Plan process started in 2014 and is now in its final stages with a final meeting planned for April 2015 and the final document due to the DOE's Office of Nuclear Physics (ONP) in summer 2015. The hope of the EIC community is to have the EIC endorsed as the highest priority new construction project in ONP.

Over the last few years, there has been considerable progress in developing the physics case for such a facility. In spring 2010, five workshops were organized by the TJNAF user community. This was followed up in fall 2010 by a 10-week program at the Institute for Nuclear Theory in Seattle entitled "Gluons and the quark sea at high energies: distributions, polarization tomography". A 550-page report on this INT/BNL/TJNAF program has been produced. The experience of the TJNAF community in developing the physics program of the 12 GeV Upgrade facility proved a great asset in establishing the value of high luminosity over a wide kinematic range to facilitate the capability of 3D imaging of the partons. An electron ion collider with high luminosity ~10^{34}/cm^2/s at a center-of-mass energy of 20-70 GeV was shown to be the pre-requisite to access the region from intermediate down to low Bjorken x where the sea of gluons and quark-antiquark pairs dominate. These parameters are now agreed upon as the goals for an EIC facility and have provided the basis for developing the machine design. Two major physics goals of this facility can be broadly stated as:

- Map the spin and spatial structure of quarks and gluons in nucleons.
- Discover the collective effects of gluons in nuclei.

In addition, an EIC could help scientists to understand the conversion of color charge to hadrons, providing insight into parton propagation through matter and fragmentation, and ultimately discovering how structure came about from quarks and (gluon) energy in the early universe. Lastly, studies are ongoing to test the Standard Model and its possible extensions at an EIC. The physics motivation for the EIC has been a subject of substantial effort in the community and a steering committee, with many TJNAF users involved, has published a white paper entitled "Electron Ion Collider: The Next QCD Frontier, Understanding the glue that binds us all".

The TJNAF concept for an Electron Ion Collider, the MEIC, has been developed over the last few years by a collaboration of the Physics and Accelerator Divisions. An initial report on the science requirements and a conceptual design of a polarized MEIC was published in 2012.

Optimization of the MEIC continued in 2013 and 2014 and a significant effort went into the preparation of the recent NSAC/LRP EIC Cost review held in January 2015, where the MEIC technical design and initial cost estimate was reviewed to inform the Long Range Plan.
The MEIC design has been optimized to maximize performance and minimize costs. The resulting baseline, with relatively compact collider rings, can deliver high luminosity up to ~10^{34}cm^{-2}s^{-1} at a center-of-mass energy range from 15 up to 65 GeV. It offers an electron energy up to 10 GeV, a proton energy up to 100 GeV, and corresponding energies per nucleon for heavy ions (up to A ~ 200) with the same magnetic rigidity. As mentioned, this design choice balances the scope of the science program, collider capabilities, accelerator technology innovation and total project cost.

The essential new elements of the MEIC facility at TJNAF are an electron storage ring and an entirely new, modern ion acceleration and storage complex that share a figure-8 ring of ~2.2km. For the high-current electron collider ring, the upgraded 12 GeV CEBAF SRF linac will serve as a full-energy injector.

The electron ring is based on the PEP-II HER collider lattice design and a significant amount of PEP-II components would be reused, namely the HER dipole and quadrupoles, the vacuum chambers and a significant fraction of the SRF system. The electron transfer lines reuse a significant number of the PEP-II LRF magnets. The ion complex for MEIC consists of sources for polarized light ions and unpolarized light to heavy ions, an SRF ion linac with proton energies up to 280 MeV, and 8 GeV figure-8 booster synchrotron, and a medium-energy collider ring with energies up to 100 GeV. The ion collider ring design is based on cost-effective super-ferric magnet technology. The booster ring, electron collider ring, and ion collider ring are designed as a "figure 8", optimized for at spin preservation and an effective way to allow for polarized ^{2}H beams. The collider provides two interaction points, capable of hosting both a large acceptance detector and a high luminosity detector.

The MEIC design is based on proven technology with low technical risk. Some pre-project R&D is necessary to validate the technical choices. The main components are prototyping of super-ferric magnets and the design and development of the SRF cavity and crab cavities for the collider rings. On-project R&D is focused on value engineering to reduce cost and technical risk.

A WBS project has been developed to support the cost estimate, operating costs have been identified, and a preliminary project budget profile has been worked out.

The near and medium term focus for the MEIC is to further optimize cost and performance in the specific areas of the ion injector, electron cooling and machine layout. We are aiming towards a full CDR in a 2-3 years' timeframe to be ready for CD1 and project down selection.

TJNAF and Brookhaven National Lab (BNL) have chartered a joint advisory committee (EICAC). TJNAF is collaborating with BNL and both a national and international group of scientists in further developing the scientific motivation as well as accelerator R&D. TJNAF users and staff have developed and contribute to several generic detector R&D proposals of relevance to a future electron-ion collider. In particular, TJNAF users from Germany, France and Italy have joined these efforts and recently submitted an EU funding proposal to further develop EIC science and simulation efforts. Eventually, the magnitude of the project may make broad international participation a prerequisite, and a competitive situation with regard to site choice of an electron-ion collider may emerge. TJNAF expects to play a role independent of location, because of its experience and expertise in SRF technology, high current polarized electron sources and energy recovery, which will benefit any future electron-ion collider design including LHeC at CERN. Within TJNAF, the MEIC facility is a natural next step beyond the 12 GeV Upgrade to allow TJNAF to continue in a world leading role as premier Nuclear Science and QCD facility.

Ongoing design efforts are aimed at developing and substantiating a staged construction approach to MEIC to reduce the initial cost and risk. Siting and environmental studies have started with Commonwealth of Virginia funds, and a request for additional Commonwealth of Virginia funds was approved. Site shielding studies have started.

- ***Resources Required:*** An MEIC organization has been created at TJNAF to coordinate and consolidate efforts in the areas of design, R&D, engineering and project management under a common budget code. Resources for pre-project R&D have been identified, and TJNAF is working on resource allocations that include Accelerator R&D funds, LDRD and DOE NP awards for EIC R&D. Additional funds of 4.6 M$ have been awarded by the Commonwealth of Virginia. TJNAF has already established collaborations with ANL, National Superconducting

Cyclotron Laboratory (NSCL), Fermi National Laboratory (FNAL), Brookhaven National Lab (BNL), and Texas A&M University as well as overseas institutes such as FZ- Jülich to support development of the ion injector complex, and with SLAC on the Interaction Region design, the reuse of PEP-II components and non-linear studies. TJNAF is pursuing a partnership with IMP/Lanzhou (China) for an experimental demonstration of electron cooling with pulsed beams. TJNAF collaboration with GSI and other institutes (Saclay, INFN, Mainz) is facilitating detector R&D.

Significant Accomplishments: The MEIC design group has delivered a baseline design that fulfills the performance requirements set by the community's white paper and minimizes technical risks through innovative but solid design choices. A cost estimate has been developed that has been reviewed by a cognizant external committee and offers the opportunity of further cost and performance optimization.

3. **Accelerator Technology** (funded by – DOE SC Nuclear Physics, and Industry)

- ***The Vision*****:** In addition to improving performance and reliability of CEBAF and developing the MEIC design, further development is being directed towards specific future applications that will enable the Laboratory to position itself to make major contributions to new projects in the US and around the world. Also, in the coming years, TJNAF expects to transfer its current technology to US industry (e.g. AES, Niowave, Sciaky).

- ***Resources Required*****:** The planned R&D activities will be conducted in part by using the SRF Institute's evolving set of R&D facilities, including the present Cavity Forming Facility, Cavity Processing Facility, Vertical Cavity Testing Facility, Cavity Assembly Facilities, Cryomodule Assembly Facilities, and Horizontal Test Facilities. The Technology and Engineering Development Facility (TEDF), a Science Laboratory Infrastructure (SLI) project, is now complete. TEDF includes a 70,000-square-foot, stand-alone building situated between the Test Lab and Jefferson Avenue, a 30,000-square-foot addition to the Test Lab, and rehabilitation of the Test Lab. The Old Dominion University Center for Accelerator Science, initiated in 2008 in collaboration with TJNAF, continues to be a useful resource.

  TJNAF has developed a plan to upgrade the current Injector Test Facility to provide capability for testing and developing integrated injector components including DC, RF, and SRF photocathode guns, capture and booster SRF cavities and beam diagnostics. The facility will be built up from the previous generation of CEBAF components that were excessed as part of the 12 GeV Project.

  Future DOE projects will require new high brightness, high current injectors, and the facility will enable TJNAF to continue to lead in this area. However, in addition to injector technology development, test beams will be provided for detector development; the HDIce target will be the first to benefit from this new capability.

- ***Significant Accomplishments:*** The repair and upgrade of the accelerator components that were not included in the 12 GeV Project were coordinated lab-wide in a structured process. The commissioning of the 12 GeV accelerator has proceeded through a careful hot-checkout process that received considerable praise at the summer 2014 DOE review of the 12 GeV Project. This included 42 cryomodules that were carefully re-commissioned after being warmed up for only the second time in the history of the lab. At this time, all of the 12 GeV Project accelerator commissioning goals have been met on schedule.

TJNAF completed a beginning-to-end design of the MEIC, and published a report on the science requirements and conceptual design for a polarized MEIC.

TJNAF developed a proposal for accelerator R&D to implement and verify all techniques required for the MEIC electron cooler design at TJNAF's LERF, and is studying opportunities to test high-current energy recovery at KEK/Japan and electron cooling tests at Lanzhou/China.

4. Laboratory Directed Research and Development (LDRD)
(funded by – DOE SC Nuclear Physics)

- ***The Vision*:** The goal of the newly-instituted LDRD program at TJNAF is to encourage innovation, creativity, originality and quality to maintain the Laboratory's research activities and staff at the forefront of science and technology. Areas eligible for LDRD support include: advanced study of new hypotheses, new concepts and innovative approaches to scientific or technical problems; experiments directed towards "proof-of-principle" or early determination of the utility of new scientific ideas, technical concepts or devices; and conception and preliminary technical analysis of experimental facilities or devices.

- ***Resources Required*:** The Laboratory has recently initiated an LDRD program. For FY 2014, three projects were funded totaling $372K, with awards ranging from $62K to $164K. For FY 2015, the three FY 2014 projects are continuing and three new ones were added, bringing the total funding to $776K. This is designed to be a sustainable program.

- ***Significant Accomplishments:*** FY 2014 was the first year of TJNAF's LDRD program, so there are no final accomplishments to report (all three of those projects are continuing for a second year). However, it is already clear that the program will be a real asset to the laboratory, and partial and significant progress has been made by each of the initial projects: the *Physics potential of polarized light ions with EIC@JLab*; *A Wireless, Hand-Held Data Acquisition System for Imaging Detector*; and *A Fast RF Kicker for the MEIC Electron Cooler*. For the three new projects begun in FY 2015, the Lab is, at this point, in the initial phases of moving them forward, and it would be premature to discuss any results.

V. Strategic Partnership Projects (SPP)

<u>Baseline SPP Program</u>

Low Energy Recirculator Facility (LERF)
At TJNAF, one of the core capabilities is in the area of accelerator science, and in particular superconducting radiofrequency acceleration. The Lab's preeminent expertise in this area has enabled a line of research that builds upon the requirements of the Office of Science nuclear physics program but has impact in a much broader array of applications. The ERL decelerates the electron beam, recovering the energy of the beam into the radiofrequency cavities and the electrons are dumped at 10 MeV, simplifying operations dramatically. This success has spawned major ERL machine construction efforts in Japan at KEK, Cornell in the US, and in Berlin, Germany at Helmholtz-Zentrum Berlin fur Materialien und Energie.

To increase the capability of this system, the Commonwealth of Virginia provided $3M to upgrade the TJNAF FEL buncher and cryomodule during FYs 2013 and 2014. Though technically an SPP, these improvements will also benefit future use of the machine for nuclear physics research and other applications.

Facility for Rare Isotope Beams at Michigan State University (FRIB at MSU)
The cryogenics group at TJNAF has taken responsibility for designing, specifying, procuring and commissioning the Central Helium Liquefier (CHL) for FRIB, based on the successful CHL2 designed for the 12 GeV Upgrade at TJNAF.

The mechanical engineering group is providing detailed engineering/design services for four styles of cryomodules where conceptual design models and assemblies developed by FRIB staff will be developed into complete engineering packages ready for fabrication. This effort details the packaging of the FRIB designed cold masses in the necessary support structures to complete a cryomodule design.

TJNAF has the capability for further substantial participation in the FRIB project to leverage its expertise and production capability to provide assembled and qualified SRF components. This would utilize the substantial infrastructure realized from the SLI ARRA investment at TJNAF. Such participation would be based on the very successful model used for TJNAF construction for the SNS at Oak Ridge National Laboratory (ORNL), enhanced by the new production capability available due to the SLI investment by the Office of Science.

The CERN ERL Test Facility
An emerging international endeavor includes a collaboration of TJNAF and CERN for the design and construction of two prototype 802 MHz cryomodules for ERL operation. The collaboration aims at building two prototype cryomodules each containing four, 5-cell elliptical cavities for operation at 801.58 MHz at 2 K. They will also serve as prototypes for the future CERN ERL Test Facility. This facility is a prerequisite for advancing the CERN Large Hadron Electron Collider (LHeC) at CERN, which is based on an ERL design carried out by TJNAF staff.

Table 1. Strategic Partnership Projects Funding (BA in $M)

Sponsors	FY 2014 Actual Funding Received	FY 2015 Estimated Funding Level	FY 2016 Request
DOD	0.3	0.2	0.0
NRC	-	-	-
DHHS/NIH	-	-	-
All Other Federal Work	-	-	-
Non-Federal Work	2.8	8.2	3.3
Total SPP	**3.1**	**8.4**	**3.3**
Lab Operating	131.4	133.2	146.1
SPP as % of Lab Operating	**2.4%**	**6.3%**	**2.3%**
DHS	-	-	-
SPP + DHS as % of Lab Operating	**2.4%**	**6.3%**	**2.3%**

Note: Table 1 does not include funding for work performed for other DOE facilities or for CRADAs

The SPP program continues to be synergistic with TJNAF’s mission to pursue scientific frontiers aligned with the priorities of the Office of Science. While there is a potential risk of competition between the SPP program and the DOE program for top class accelerator physicists and SRF engineering skills, the TJNAF experience has been very positive. The combination of R&D projects supported by DOE and by SPP provides a dynamic and stimulating environment that enables the Lab to attract and retain top-quality people in the accelerator field.

SPP Strategy for the Future

TJNAF plans to continue its participation with and fulfill its commitments to the FRIB project in the coming years. In addition, TJNAF will seek participation in other projects that help to develop TJNAF's core accelerator competencies. What is important for the strategy is that TJNAF maintains an appropriate perspective with regards to its core mission, the provision of nuclear physics user facilities for Office of Science programs. If the balance is right, all the programs stand to win.

TJNAF envisages a total SPP program not exceeding 5% on average.

VI. Infrastructure/Mission Readiness

Overview of Site Facilities and Infrastructure

Thomas Jefferson National Accelerator Facility is located on a 169 acre federal reservation. North of the DOE-owned land is an eight acre parcel referred to as the Virginia Associated Research Campus (VARC) which is owned by the Commonwealth of Virginia and leased to SURA which, in turn, sub-leases five acres of this property for $1 dollar per year to DOE for use in support of the Lab. SURA owns 37 acres adjacent to the TJNAF site, where it operates a 42-room Residence Facility at no cost to DOE.

TJNAF consists of 72 DOE-owned buildings (874,745 SF), and nine real-property trailers (15,270 SF) totaling 890,015 SF, plus roads and utilities. Additionally, the Lab leases office and shop buildings (37,643 SF) from the Commonwealth of Virginia, office and lab space (26,869 SF) from the City of Newport News located in the Applied Research Center (ARC) adjacent to the TJNAF campus, two leased trailers (1,884 SF), and 9,755 SF of off-site leased storage space totaling 76,151 SF of leased space. The Lab will continue efforts to consolidate leased and trailer office space with the elimination of 7,629 SF of trailers/buildings in FY 2015 and 4,920 SF of trailers in FY 2016. At the close of FY 2014, approximately 728 (part and full time) Staff, 26 Joint Appointments, 24 Postdoctoral Researchers, 4 Undergraduate, and 34 Graduate Students were occupying site facilities. Each day, TJNAF hosts on average, 100 users from the United States and around the world.

In FY 2013, the Technology and Engineering Development Facility project was completed providing the Lab a new 74,000 SF Technology and Engineering Development (TED) Building, a 47,000 SF Test Lab Addition, as well as a renovated Test Lab, (a 50 year-old previous NASA facility), funded by the Science Lab Infrastructure (SLI) program. This project resolved a large amount of the technical and administrative space shortage. The major remaining space shortage is specialty technical and storage space. Currently, there are 61 aged shipping containers (19,240 SF) used for storage. Site electrical distribution and cooling towers have reached the end of their service life. Communications, computing, air conditioning and power, and the Cryogenics Test Facility serving the Test Lab have reached their capacity and need to be expanded to meet the Lab's mission. The Utilities Infrastructure Modernization (UIM) project fully-funded in FY14, will correct these utility deficiencies. The UIM project was awarded CD-3C on February 20, 2015.

Table 1 shows the results of recent Lab Operations Board (LOB) sponsored condition assessment. The Lab has completed the condition assessment of all facilities. A total of 92 of the 115 facilities assessed were found to be adequate, 18 sub-standard and 5 inadequate. All 10 trailers were found to be either substandard or inadequate. Of the 29 Other Structures and Facilities (OSF) assessed, 21 were found to be adequate, with 5 substandard, and 3 inadequate. A total of 7,380 SF of facilities are currently underutilized and plans are being developed to repurpose or excess this space. There are currently no excess facilities at the Lab and none are expected within the next 10 years.

Table 1 – Facility Assessments and Excess Facilities

	Adequate		Substandard		Inadequate	
	Count	**SF**	**Count**	**SF**	**Count**	**SF**
Other Structures and Facilities (OSFs)	21	N/A	5	N/A	1	N/A
Mission Unique Facilities	36	292,847	1	34,861	0	0
Non-Mission Unique Facilities	35	330,772	12	291,743	4	10,964
Number and square footage of excess facilities	0	0				
Square footage of underutilized space in non-excess facilities.	0	7,380				

Campus Strategy

The objectives for the 2025 TJNAF Lab Campus plan are:

- Construct and upgrade facilities and utilities to fully support mission objectives.
- Replace substandard temporary and leased space with permanent facilities.
- Increase energy efficiency and support DOE sustainability goals and requirements.
- Accommodate a Medium Energy Ion Collider (MEIC).

Infrastructure investments over the last ten years have provided more than 264,000 SF of new facilities (Experimental Hall D, Technology and Engineering Development Building, CEBAF Center Wing F, General Purpose Building, and Experimental Staging Building). Through these projects, the campus has been transformed into a walking-campus, with many sustainability features incorporated. Current critical infrastructure gaps shown below have been identified through the latest Lab condition assessment. These gaps need to be closed to enable a fully mission-capable campus.

Infrastructure Gaps

Infrastructure Component	Gaps and Impacts
Cryogenics	Hall and CTF cryogenics are unreliable due to age of equipment
Office and meeting and collaboration space	Temporary / leased office space for scientists, engineers, and support staff is substandard or inadequate Lack of modern meeting capabilities negatively impacts collaboration
Experimental equipment assembly	Layout of existing experimental equipment assembly space is not functional and is not fully utilized for its intended purpose due to storage and other functions occupying the space
Shipping, Receiving, and Warehouse	Temporary / leased storage space is substandard or inadequate Shipping and receiving functions currently occupy space which was intended for experimental equipment assembly
Sustainability	Numerous facilities are currently inefficient and do not meet HPSB or sustainability guiding principles
Site Utilities	Fire protection potable water, sanitary sewer, and storm water systems all lack capacity to support operations

Prioritized Infrastructure Needs

- **Cryogenics** (GPP Cross-cut) - The Lab's highest priority is to upgrade its cryogenic infrastructure to ensure reliability and capacity for future mission needs. Operation of the Cryogenics Test Facility (CTF) is critical to support testing for the cryomodule cavity components produced by the Superconducting Radio Frequency (SRF) Institute for Jefferson Lab, other Labs in the Office of Science complex as well as SPP. Installation of a new 4K cold box, and controls under the UIM project will provide additional CTF 4K capacity. Additional investments are needed to increase 2K capacity and overhaul/replace aging equipment related to 2K operations. A separate and unrelated issue of reliability of the 40+ year old End Station Refrigerator (ESR) plant serving three of the four experimental halls exists due to the lack of critical spare parts that are no longer manufactured or available. The replacement of the ESR will consist of a refurbished and installed surplus 4K refrigerator from the Superconducting Super Collider (SSC) project with the associated distribution system, utilities and controls. Construction of a building to house this equipment is complete. Engineering, design, equipment lead time and installation will take two to three years.

- **Electrical Distribution and Communications** (SLI) – Existing electrical distribution (primary and secondary) for the accelerator have reached the end of their service life. The aluminum conductors are inadequate to meet accelerator electrical requirements. Subsurface communications systems have insufficient capacity to meet existing and future needs. The UIM project currently underway will correct both of these identified gaps. Estimated completion for these elements is in FY 2016.

- **Computer Center Efficiency Upgrade and Consolidation** (SLI and Lab GPP) – Computer Center cooling and power improvements are now underway under the UIM project and will provide needed data center utility capacity to support lab computing needs. HVAC improvements will under the UIM project will reduce the Power Utilization Efficiency to assist in meeting DOE Computer Center power efficiency goals. A Lab funded GPP project with consolidate the Lab computer and data centers. Estimated completion is in FY 2016.

- **EHS&Q Offices -** (Lab GPP) – Construction of 12,000 SF of energy efficient office and technical space to house the EHS&Q Division will consolidate they staff currently residing throughout the Lab in a combination of overcrowded, aging trailers and leased space. Estimated completion is in FY 2016.

- **CEBAF Center Office Addition** (SLI) – The majority of the Lab's administrative functions are currently located in the (34,739 SF) Support Services Center, formerly known as the VARC, constructed in 1965 and leased from the Commonwealth of Virginia. The condition of the structure is substandard and over $5M in recapitalization is needed. Given the age and functionality of the building, expenditures at this level are not warranted. The State is considering repurposing the land for development of a tech park. Additional offices and support functions are located (occupied 26,869 SF) in the Applied Research Center leased from the City of Newport News Virginia. The current lease expires September 30, 2017. This building is also rated as substandard and needs a sustainability renovation to reduce energy consumption towards DOE goals. These functions would fit well within an office addition to CEBAF Center. The Lab also lacks adequate meeting space to host numerous Lab collaborations and conferences which currently have to be held in rented facilities off site. Inclusion of meeting space along with office space is the proposed SLI project. The scope includes a 70,000 SF office addition. Construction will meet high performance building standards. The preliminary cost and time estimate for this element of work is $35M and three years including design. The project will eliminate 60,000 SF of leased space while providing the needed meeting space to support ongoing programs.

- **CEBAF Center Renovation** (Lab GPP/Maintenance) – The condition of the 1988 original structure has been rated as substandard. The mechanical system in this portion of the building has exceeded its service life and has experienced multiple failures. Replacement of major pieces of HVAC equipment is required in the near future. Replacement of the HVAC system will require vacating the portion of the building under renovation and removal and replacement of the ceilings. Lab staff is currently overflowing into common areas such as corridors, storage rooms, and copy areas creating egress issues and safety concerns. Reconfiguration of the affected spaces is needed to alleviate many of these conditions. Renovation will meet high performance building standards. The renovation will be executed one wing per year plus the atrium/auditorium in the fourth year using a combination of Lab GPP and facility maintenance funds.

- **Shipping and Receiving Warehouse/Facility Operations** (Lab GPP)- Existing high bay and technical space in the Experimental Equipment Lab (EEL) is not fully utilized due to its required use for storing materials and equipment and for conducting shipping and receiving activities. Construction of a shipping, receiving and modern warehouse would allow improved use of the much needed high bay and technical space and allow elimination of 61 shipping containers for storage. Completion of this project is needed to create necessary swing space for the renovation of the EEL and to provide long term experimental setup and support space. The facility will also house the facilities maintenance shops currently in the (2,904 SF) Forestry Building leased from the Commonwealth of Virginia. The current lease expires September 30, 2017. This building is in substandard condition and needs to be replaced. The project will be constructed in phases based on Lab annual GPP funding. The facilities operations and maintenance shop will be the first phase.

- **Cryo Building Renovation** (Lab GPP/Maintenance) - The Cryogenics Engineering group is currently housed in a dilapidated, overcrowded, pre-engineered building. The building condition and functionality was determined as substandard during the recent condition assessment. The building will be renovated to correct condition and functionality issues. The project is needed to provide adequate work space for the cryogenics engineers.

- **Experimental Equipment Lab Renovation** (GPP Cross-cut)- Renovation of the Experimental Equipment Lab building is needed to increase the functionality and utilization of the high bay space as well as to correct inadequate mechanical systems, improve efficiency of the building envelop and correct code deficiencies. The scope of the work will require vacating large portions of the buildings during the periods of construction. Functions will be temporarily relocated to the newly constructed Shipping and Receiving Warehouse to minimize the impact on operations.

- **Potable Water Upgrade for Fire Protection** (Lab GPP) – Installation of Reduced Pressure Zone Backflow preventers at the potable water utility connections and installation of a potable water pressure pump to increase on-site water pressure to meet building fire protection requirements.

- **Machine Shop Expansion** (Lab GPP) – Construction of an addition to allow expansion of the existing machine shop to accommodate additional equipment and allow consolidation.

- **Water Reuse System** (Lab GPP) – Installation of roof rain water collection system and storage tank for use in cooling towers and for limited irrigation to reduce potable use to assist in meeting water sustainability goals.

- **CEBAF Center Wing D** (Lab GPP) – Construction of a 14,000 SF office addition to provide additional space to alleviate over utilization of the existing space and increased availability of small meeting spaces in support of collaborations. Construction will meet high performance building standards.

- **Site Storm Water Management** (Lab GPP) – Installation of a storm water retention pond to meet regulatory requirements.

The $29.9M FY 2014 UIM project will, among other things, resolve the above process cooling gaps with the replacement of aging cooling towers and electrical distribution and communication through the replacement of electric cabling and the installation of additional data cabling and equipment. The UIM project will eliminate more than $2.7M of deferred maintenance. The remaining gaps can be closed through a combination of SLI, SLI-GPP, and NP-GPP funding totaling $85.3M over the next ten years. These projects will eliminate more than $3.7M of deferred maintenance. Additional estimated funding of $2.5M is expected through a Utilities Energy Savings Contract to implement energy conservation measures.

The hall flood control gap identified in last year's plan is being resolved using operations funding for replace existing rollup doors with flood rated doors and improvement of existing hall water removal.

Enclosure 2 shows the investments needed to implement this Campus Plan. The plan consists of a mix of SLI, infrastructure crosscut, NP- GPP, and alternative financing. NP-GPP funding levels shown were based on the annual NP budget guidance. It is not anticipated there will be any inadequate facilities at the end of the period.

The fully executed campus plan supports:

- 4 Experimental Halls fully operational
- 4-Hall multiplicity
- 35 weeks of research
- CEBAF reliability >85%
- Partner/lead on major SRF-based accelerator construction projects
- Ability to exploit/leverage capabilities of the Low Energy Recirculator Facility (LERF) (Isotopes, Dark Light, Industry and University-led research)

Site Sustainability Plan Summary

TJNAF has achieved significant progress and remains on-target to meet or exceed the set of diverse sustainability goals for Energy Utilization Intensity reduction, Renewable Energy, Scope 1 Greenhouse Gas (GHG) emissions (Fugitive and Fleet Petroleum management), and High Performance Sustainable Building (HPSB) Guiding Principle compliance for existing facilities. Strategies have been identified and are under development to achieve both Water Intensity and Scope 2 and 3 GHG reduction goals, and the Data Center Power Utilization Effectiveness (PUE) target defined in the DOE Strategic Sustainability Performance Plan (SSPP). A new Executive Order (EO 13693) "Planning for Sustainability in the Next Decade" was recently announced, and specific implementation plans and DOE goals are to be determined in the next several weeks. Generally, EO 13693 increases the primary sustainability goal targets and extends compliance deadlines to 2025.

In FY 2015, Jefferson Lab advanced a Utility Energy Services Contract (UESC) program to finance energy and water efficiency projects, and continue to progress towards achieving its sustainability goals. To date, a, preliminary study and statement of work identifying specific projects for the next phase of the program (Feasibility Study) have been completed. The selected utility, AGL Energy Services, the parent company for Virginia Natural Gas, estimates a four (4) month performance period from task order award to finalize the feasibility study. UESC sustainability initiatives are focused on projects to reduce Energy Utilization Intensity (i.e.: lighting system upgrades), domestic water reduction (i.e.: low flow fixtures) in several administrative facilities, industrial water (i.e.: Ultra-Pure Water reuse), central chilled water efficiency improvements, and water harvesting (rain water capture/reuse). When implemented, the planned UESC projects will contribute especially to achieving energy and water reduction goal categories, and compliance with HPSB Guiding Principles goals for targeted facilities.

As a High Energy Mission Specific Facility (HEMSF), TJNAF is currently engaged in significant expansion of scientific and support facilities, which will result in significantly increased electrical and thermal energy requirements. Consequently, achievement of the SSPP Scope 2 emission reduction target (purchased electricity) represents a significant challenge.

Major reduction of Scope 2 GHG emissions from purchased electricity requires implementation of a combined set of strategies, including:

- Alternative Financing (UESC) of energy reduction strategies and potential on-site and / or regionally located low GHG electricity generation sources.

- Utilities in the Jefferson Lab eGrid service region achieving renewable portfolio standard targets to provide reduced GHG emissions per Megawatt Hour of electric generation by 2020.
- Renewable Energy Credits and/or Green Power Purchasing Agreement.

Further, as the Lab's scientific mission continues to expand, thermal energy (cooling tower water) requirements for accelerator operations are projected to significantly increase. Similar to the projected electricity increases from 12 GeV operations, the Lab's water requirements are estimated to double from the FY 2007 baseline of 50 MGal. Approximately 75% of Jefferson Lab's annual consumption of potable water is primarily consumed in cooling tower operations (evaporation/blow down).

Multiple alternative water reduction strategies are under consideration. Water intensity (annual gallons per gross square foot) reduction plans are designed to provide alternative water sources. Strategies include; (A) Ultra-Pure Water (UPW) system discharge, capture and reuse, (B) rain water harvesting (on and off-site), (C) installation of a ground water infiltration pond, and (D) HVAC condensate capture. Off-site sources of potential non-potable water supply include rain water harvested from adjacent Jefferson Lab property (new Tech Center currently under construction) and a proposed green power / water harvesting project at the Newport News Airport. A combination of these strategies and domestic water reductions (low flow fixtures) is required for Jefferson Lab to achieve the challenging new EO water intensity reduction goal of 36% by 2025.

Sustainability Initiatives Investments

Table 2 summarizes the quantity and type of investment funding provided and planned to achieve sustainability energy and water reduction goals. To date, UESC funding of the preliminary study was provided by AGL Energy Services. The next phase of the UESC (Feasibility Study) will be funded by Jefferson Lab in FY 2015. Annual purchase of Renewable Energy Credits (RECs) will continue to satisfy DOE's renewable energy goal. The quantity of annual REC purchases will increase significantly in future years as one of the combined strategies to achieve new and increased GHG reduction goals to be established in EO 13693.

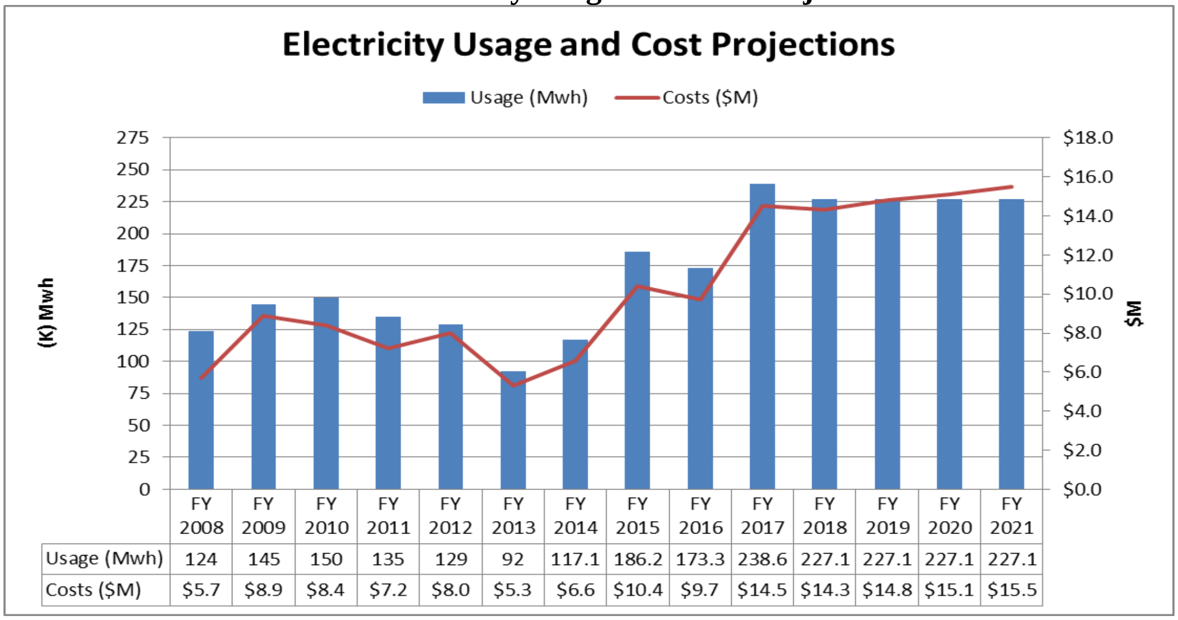
Table 2 Summary of Sustainability Funding

Summary of Sustainability Project Funding ($K)				
Category	**FY14 Actual**	**FY15 Planned**	**FY16 Projected**	**FY17 Projected**
Sustainability Projects (do not list specific projects)	64.0	117.5	152.2	75.0
UESC Contract Payments (if applicable)	0	0	0	250.0
Renewable Energy Credits (REC) Costs	9.6	18.6	27.3	33.8
Total	**73.6**	**136.1**	**179.5**	**333.8**

Electricity Usage and Cost Projections

Chart 1 shows TJNAF's historical electricity usage in (K) Megawatt Hours and costs (Actual year $Million), and future projected electricity usage and cost. Projections based on 23 weeks of accelerator operation using two Central Helium Liquefiers (CHLs) in FY 2015, 16 weeks in FY 2016 and ~30 weeks per year of operation in subsequent years through FY 2021.

Chart 1 Electricity Usage and Cost Projections



VII. Human Resources

Recent History

TJNAF's primary focus for the past several years has been the construction of the 12 GeV Upgrade Project. Over the next two years, as milestones are met, the Lab is transitioning to resuming the research program. The skill mix to meet the demands and requirements of the 12 GeV Upgrade Project will be transitioning to operations and to LCLS-II scope of work during its critical ramp-up period. Recruitment outreach has continued to ensure critical skill sets in the areas of cryogenics and SRF technology are maintained.

Functional Area	FY 2012	FY 2013	FY 2014
Scientists	137	136	128
Engineers	199	196	186
Post Docs	13	7	13
Research Support	298	285	249
Graduate Students	2	2	1
Under Graduate Students	8	4	8
Operations/Admin Support	162	156	143

Future Challenges and Actions

The optimal staffing profile continues to be comprised primarily of scientists, engineers, and technicians in order to meet mission requirements. The technical and scientific staff will possess unique skills in nuclear physics, cryogenics, and skilled trades related to accelerator design and construction. The Lab's plan ensures the expertise and skills mix needed to deliver the science program is supported while controlling overhead.

As the 12 GeV Upgrade Project nears completion of its construction phase, the Lab focus shifts to commissioning and operations. The expertise needed for commissioning and operations is similar as required for construction; therefore, the Lab's current skill mix provides the resources needed for these efforts.

A key initiative of the Lab is the Electron Ion Collider (EIC). The Lab has developed a preliminary EIC concept to include planning and R&D for the fundamental technical requirements associated with the EIC project. The Lab would require a gradual ramp-up of scientists and engineers to support this effort.

The Lab is currently supporting the LCLS-II project at SLAC. A 5-year project, LCLS-II will require about 35 FTEs. The Lab will be responsible for construction and installation of the superconducting accelerator and the cryogenic refrigerator for the LCLS-II. The specialized cryogenics and SRF skills associated with this work will require the Lab to hire a select group of staff to support the project.

Another key area the Lab is supporting is the Facility for Rare Isotope Beams at Michigan State University (FRIB at MSU). The Lab is responsible for designing and commissioning the Cryoplant Central Helium Liquefier (CHL) based on the 12GeV Upgrade CHL design. A combined skill set of cryogenics, electrical engineers and technicians will be required to meet the project scope.

A factor that influences skill gaps is retirement. Currently, 25% of the workforce is eligible for retirement. About two thirds of retirement eligible employees are scientists, engineers, and senior technical specialists. There is also a projected loss in senior operations/administrative management positions due to retirement eligibility in the next few years. JSA is currently engaged in succession planning and developmental efforts to mitigate possible skill erosion.

Anticipated budgetary constraints may impact attraction and retention of key talent. The Lab continues to employ the following strategies to mitigate the loss of vital skills and institutional knowledge:

- Succession planning.
- Technical and leadership training.
- Cross training.
- Targeted recruiting to maintain the necessary skill mix.
- Enhanced diversity outreach efforts.

An essential part of our approach is proactive recruiting for unique and critical skill sets, particularly in engineering and technical specialties. To assist in this effort, TJNAF employs diversity outreach efforts to broaden the talent pool for a more diverse workforce. In 2013, the Lab established a Diversity and Inclusion (D&I) Council to increase awareness and education on the impact and value of a diverse populace. The Council members completed an intensive training program and are now poised to disseminate their knowledge to others in the Lab community with an emphasis on STEM outreach with minorities and females. These activities complement other outreach efforts focused on underrepresented groups in partnership with the national lab community. Finally, TJNAF has developed a succession planning strategy for scientists and engineers to prepare them for more senior positions. This approach includes a talent pipeline that starts with our student Co-Op and intern STEM programs. Supervisors complete the Lab's core management development curriculum which is capped by select participation among high potentials, along with FNAL and Argonne, in the University of Chicago's Strategic Laboratory Leadership Program (SLLP). The Lab selects up-to five top candidates each year; the majority being scientists and engineers.

The JSA benefits program is a vital component of the total compensation package. A competitive program is critical for the attraction and retention of the world class workforce necessary for the Lab to achieve its nuclear research mission. The Lab is committed to maintaining quality benefits while containing costs. In FY 2015, the Lab has implemented a modification to the defined contribution retirement plan that will reduce costs in future years while continuing to offer competitive benefits.

Medical benefits are an area of focus due to increasing costs and the requirements of the Health Care Reform Act. The Lab will continue to evaluate the medical benefits annually, modifying the plans to reduce costs and meet regulatory requirements. The Lab is currently developing a modification to its retiree medical plan. A medical exchange for Medicare eligible retirees will be implemented in FY 2016 and will substantially reduce future costs while continuing to offer a quality benefit.

VIII. Cost of Doing Business

TJNAF's approved metrics and performance indicators provide an excellent understanding and means of tracking the cost of doing business. This information is presented to Thomas Jefferson Site Office annually. TJNAF also provides annually, Institutional Cost Reports to the DOE, as do other Labs in the complex to provide DOE with cost of doing business metrics. There is a clear vision of the scientific future, staffing and infrastructure needs. Over the next six years, TJNAF will experience steady yet manageable cost growth. Although power demand will double by 2017, with the completion of the 12 GeV Upgrade, TJNAF continues to benefit from special status from the Commonwealth of Virginia which results in extremely low electricity rates from Dominion Virginia Power. TJNAF will continue modernization of Lab facilities which will control increases in indirect costs through reductions in deferred maintenance and increased energy efficiency. Staffing needs are managed and understood into 2021 with detailed plans by skill type. Bottoms up activity based planning and budgeting allows the Lab to understand and control overheads. The percentage of overhead costs has been relatively constant averaging ~21% of total cost for the past 5 years. Fringe rates have remained consistently low at averaging ~32% for the past five years. Overall, benefits are in-line with national comparators and are expected to remain so.

<u>Metrics</u>

Table 1 provides detailed information regarding TJNAF's overhead and staffing trends since 2012. In section 1.b. of Table 1, the decrease in direct FTEs from FY 2013 to FY 2014 is attributable to the ramp-down of 12 GeV Upgrade work and to a workforce restructuring (including voluntary and involuntary reductions in force), which also resulted in a decrease of indirect FTEs.

Table 1. Laboratory Overhead Trends - TJNAF (Cost Data in $K)*

	FY 2012	FY 2013	FY 2014	FY 2015 Est.	FY 2016 Est.
1a. Direct FTE Ratio –*Staff (Excludes Temporary Employees)*					
Numerator: Direct FTEs [1] for permanent staff, which represent time charged to client funded work [2], including capital but excluding LDRD	506	506	514	535	533
Supplemental Data: Indirect FTE's for permanent staff (all non-direct FTE's, to include LDRD and organizational burden [4])	169	170	155	157	154
Denominator: Total FTE's (subtotal of direct and indirect FTE's)	675	675	669	693	687
Direct FTE Ratio (%): Direct FTE's/Total FTE's	75%	75%	77%	77%	78%
1b. Direct Ratio – *Total (Includes Temporary Employees)*					
Numerator: Same as preceding metric + Limited Term Employees (LTE), Post Doc, and Staff Augmentation Direct FTEs [1]	606	582	547	562	560
Supplemental Data: Indirect FTE's for total staff (to include LDRD and organizational burden [4]) including Temporary Employees (LTE, Post Doc, Staff Augmentation)	182	178	163	167	163
Denominator: Total FTE's (subtotal of direct and indirect FTEs)	788	760	710	729	723
Direct FTE Ratio (%): Total Direct FTE's / Total FTE's	77%	77%	77%	77%	77%
2a. Total Overhead/Total Lab Cost					
Numerator: Total overhead cost, which includes institutional overhead, LDRD and organizational burden [4] to the extent this overhead is allocated to client funded work [2].	$36,230	$36,116	$33,524	$39,629	$40,929
Denominator: Total lab cost includes all cost charged to client funded work [2] (operating and capital). Includes subcontracts and procurements [4] and line item construction costs.	$182,380	$169,356	$146,303	$173,677	$179,898
Total Overhead/Total Lab Cost (%):	19.9%	21.3%	22.9%	22.8%	22.8%
2b. Total Overhead/Total Lab Operating Cost					
Numerator: same as preceding metric	$36,230	$36,116	$33,524	$39,629	$40,929
Denominator: same as preceding metric, but exclude line item construction costs.	$108,416	$110,246	$111,444	$143,840	$149,734
Total Overhead/Total Lab Operating Cost (%):	33.4%	32.8%	30.1%	27.6%	27.3%
2c. Total Overhead/Total Internal Lab Operating Cost					
Numerator: same as preceding metric	$36,230	$36,116	$33,524	$39,629	$40,929
Denominator: Same as preceding metric, but exclude subcontracts and procurements [4] charged to client funded work [2].	$94,359	$99,037	$100,625	$119,453	$123,731
Total Overhead/Total Internal Lab Operating Cost (%):	38.4%	36.5%	33.3%	33.2%	33.1%
3. Fringe Rate					
Numerator: Total cost of employee benefits (including statutory benefits), not including paid absences.	$19,486	$20,088	$22,163	$21,312	$22,744
Denominator: Total base salary cost.	$65,716	$65,842	$63,407	$64,743	$66,518
Fringe Rate (%):	30%	31%	35%	33%	34%
4. Labor Multiplier on a DOE Operating Funded Project					
Base Salary of $100K: Includes leave/absence costs.	$100K	$100K	$100K	$100K	N/A
Fully Burdened Salary Cost: Multiply the $100K base salary by the fringe benefit (excluding leave), overhead (use an average for all scientific divisions), G&A, LDRD, IGPP/IGPE, fee, and etcetera, rates based on your laboratory's burdening methodology for a DOE operating funded project. Do not include composite rates, such as special rates for large construction projects. Use final indirect rates for FY 2012, FY 2013, and FY 2014, current forward pricing rates for FY 2015 and do not provide a projection for FY 2016. *When complete, this calculation will equal the same number used in the Budget Officers' Conference Metrics section 3.a "Burdened Labor (DOE)". Please be sure to confirm the data with your laboratory budget officer.*	$194.6	$199.2	$196.2	$195.4	N/A
Labor Multiplier: Divide fully burdened salary cost by $100.0K	1.95	1.99	1.96	1.94	N/A
5a. Fully Burdened Person Year – Staff *(Excludes Temporary Employees)*					
Numerator: Total Original Cost Transactions ($K) from Institutional Cost Report [5] (ICR) Exhibit 1 – Original Cost Reporting, excluding Other Procurements, Subcontracts, and Taxes	$94,359	$99,037	$100,625	$119,453	$123,731
Denominator: Staff Direct FTEs (as reported in Metric 1a)	506	506	514	535	533
Fully Burdened Person Year ($K) Staff Direct:	$186.5	$195.8	$195.7	$223.2	$232.2
5b. Fully Burdened Person Year – Total *(Includes Temporary Employees)*					
Numerator: Same as preceding metrics	$94,359	$99,037	$100,625	$119,453	$123,731
Denominator: Total Direct FTEs (as reported in Metric 1b)	606	582	547	562	560
Fully Burdened Person Year ($K) Total Direct:	$155.7	$170.0	$183.9	$212.5	$221.0

1. An FTE is calculated as actual hours charged divided by the expected hours to be charged by a normal employee during a year. Direct FTEs reported in metric 1a should agree with Budget Officers' Conference Metrics Section 2 "Regular Staff" plus "Bargaining Unit".

2. "Client funded work" refers to "direct charges"/"direct funded work."

3. Metric 1b includes LTE, Post Doc, and Staff Aug. Direct FTEs and should agree with Budget Officers' Metrics Section 2 "Subtotal-Direct FTEs"

4. Organizational burden" refers to an overhead pool that accumulates the cost of managing and operating an organization or group of organizations and is usually allocated on a rate established specifically for recovering the cost of the organization and/or grouping. It includes space charges.

5. From annual Institutional Cost Report submission to DOE, Exhibit 1 – Original Cost. Exclude "Other Procurements" (note that this amount does not include utilities and lease cost), "Subcontracts" and "Taxes" as reported on Exhibit 1.

** FYs 2012-2014 data reflect actual costs. FY 2015 and FY 2016 are estimates (adjusted for escalation using a factor that is appropriate to the individual laboratory). Do not provide FY 2016 projected data for item 4. Labor Multiplier.*

Major Cost Drivers, Decisions and Trade-offs

Salaries and Fringe Benefits
A detailed staffing plan by skill mix exists through 2021. Salaries comprise approximately 60% of the Lab's total operating budget. Salary increases and pay adjustments have been consistent with modest cost of living increases. However, the increases have been below the national compensation market trends, and may have an effect on recruitment and retention.

TJNAF has a defined contribution plan provided by TIAA-CREF. The plan provides consultation services to employees at no charge, and the Lab does not pay administrative fees associated with the management of the plan. The Lab modified the plan in CY 2015 which will result in lower costs to DOE in future years.

In anticipation of projected cost increases in medical benefits, the Lab routinely assesses it programs to manage fringe rates. TJNAF is monitoring the Patient Protection and Affordable Care Act (PPACA), or Affordable Care Act (ACA), for impacts to the Lab's medical benefits costs and requirements for compliance in accordance with the ACA. As part of the annual renewal process, the Lab reviews each of its medical plans and examines various options and cost to employees. Increases in coinsurance and co-payment charges are considered, taking into account the effect on premium rates versus the out-of-pocket costs for employees. In recent years, such increases have been implemented to control costs to DOE. The Lab is currently developing a new retiree medical plan to be implemented in FY 2016. The plan will offer a medical exchange program for Medicare eligible retirees. The new plan will provide significant cost savings to DOE.

Site Power and Utilities
Power demand will double in the 12 GeV era from ~19MW to ~40MW. Operational reconfiguration and efficiencies, adjusting total running weeks and, when necessary, modifying run schedules to take advantage of the power bill structure will help mitigate the cost increases. TJNAF has negotiated lower rates with Dominion Power through a beneficial State Rate which at approximately 6 cents per kWh, is far lower than the standard industrial or federal electric rate structure.

The Lab plans to meet Federal sustainability Green House gas reduction goals using a combination of efficiency improvements to reduce use and purchase green energy and renewable energy credits.

TJNAF utilized alternate financing in 2002 to replace aging HVAC equipment and lighting upgrades to reduce energy consumption saving in excess of $225,000 per year. TJNAF implemented innovative helium process technology (Ganni Cycle) that reduced electric demand and costs by trimming the equipment operation based on actual cryogenic requirements. CHL2 uses this technology and other operational efficiencies to operate at reduced levels both during beam operations and during periods when the accelerator beam is not scheduled to be delivered. Construction and operation of cooling towers has been modified to reduce the number of cooling towers as well as the use of variable frequency drives to operate the system. This will save both energy and operating costs by reducing duplication of equipment as well as maintenance.

TJNAF has implemented on-site power load management practices using power draw monitoring to manage electrical demand charges for all system operations. TJNAF is also participating in an electrical load curtailment program at the electrical grid level for electrical load management through Energy Connect (a company providing load management solutions), which resulted in payments to TJNAF of $189,948 in FY 2010, $379,895 in FY 2011, ~$5,486 in FY 2012, and ~$87,600 in FY 2014 (to-date). Participation in the load demand management program has been limited due to onsite construction and accelerator shutdown. Full participation is expected to resume for the campus in FY 2014 and for the accelerator site in FY 2016.

Sustainability elements have been incorporated into all facility designs. The CEBAF Center Addition was constructed in 2006 utilizing geothermal heat pumps for office heating and air conditioning as well as a heat wheel to pre-treat makeup air. The experimental staging and general purpose storage buildings constructed in 2010 also utilize geothermal heat pumps. The Technology and Engineering Development (SLI) project, including geothermal heat pumps, constructed a new building and expanded the Test Lab totaling 120,000 square feet resulting in two LEED Gold buildings achieving certification in December 2012 and January 2014. The Utilities Infrastructure Modernization (UIM) project currently under construction will reduce energy consumption through HVAC improvements in the Lab's Data Center.

The Lab is working in coordination with the TJSO and others to establish a Utility Energy Service Contract (UESC) to provide financing through identified energy savings measures. The Annual Plan "Sustainability Summary" discusses the UESC in more detail. This mechanism will allow the Lab to recapitalize aging building systems potentially with no initial capital investment as well as assisting the Lab in meeting some DOE sustainability goals. TJNAF utility providers were contacted and responses expressing interest and qualifications were received. A variety of prospective heating, ventilation, and air conditioning, lighting, and water conservation projects have been identified with estimated total cost of $1.5-$2.5M and potential simple payback of less than ten years. The UESC qualifies as a performance based contract and contributes to the achievement of the Federal government's $2B target.

Infrastructure Modernization and Maintenance

Since 2000, the Office of Nuclear Physics has funded more than $24M in GPP projects plus $10M in ARRA GPP funds to enhance the infrastructure and meet Lab needs. SLI funding of $72.2M in FY 2009 – FY 2012 for the Technology and Development Facility and $29.2M in FY 2014 for the Utilities Infrastructure Modernization project is supporting major facility and utility modernization. Continued support from both SLI and GPP to complete the modernization process will provide the facilities necessary to support TJNAF's mission. Overall, the modernization will reduce increases in operating costs by:

- Eliminating 61% of the current deferred maintenance.
- Reducing energy consumption and cost by designing new facilities to High Performance Sustainable Building (HPSB) Guiding Principles. Energy reduction will be at least 30% of American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Std. 90.1. The TEDF project renovation of the Test Lab reduced electric and natural gas consumption 70% less than the previous building systems.
- Constructing long-term need facilities on site and reducing off site leases.
- Replacing temporary facilities with permanent ones with longer service life.

TJNAF consistently and aggressively reduces operating costs and reinvests those savings back into its scientific mission. Cost efficiency strategies have been developed to address the major cost drivers discussed above, as well as other areas throughout its business functions. The most significant impacts have been realized in the areas of infrastructure management and acquisitions. Significant savings and avoidances have also been realized by integrating various business management systems, the unique application of state-of-the-art computational technologies, application of value engineering strategies and utilization of corporate parent resources.

Some examples include:

- Minimized Cooling Tower downtime to one week per Tower by installing of header connecting existing systems and taps allowing installation of temporary towers during replacement of permanent tower.
- Revised conceptual CTF Building design reducing new building construction costs by 40% while reducing impact to operations.
- Reduced facilities maintenance costs by changing from contract to in-house electrical preventative maintenance.
- Reduced size of the Chiller—from VE study for the 12 GeV tunnel air conditioner.

Further, TJNAF's COO has been a member of the Lab Operations Board and was on the Core Team of the Infrastructure Subgroup whose charter is to provide DOE leadership insight into the actual condition, utilization, and capabilities of infrastructure across the DOE laboratory complex.

Enclosure 1: List of DOE/NNSA/DHS Missions

Scientific Discovery and Innovation (SC)

ASCR

1. To develop mathematical descriptions, models, methods, and algorithms to accurately describe and understand the behavior of complex systems involving processes that span vastly different time and/or length scales.

2. To develop the underlying understanding and software to make effective use of computers at extreme scales.

3. To transform extreme scale data from experiments and simulations into scientific insight.

4. To advance key areas of computational science and discovery that further advance the missions of the Office of Science through mutually beneficial partnerships.

5. To deliver the forefront computational and networking capabilities to extend the frontiers of science.

6. To develop networking and collaboration tools and facilities that enable scientists worldwide to work together.

BES

7. Discover and design new materials and molecular assemblies with novel structures, functions, and properties, and to create a new paradigm for the deterministic design of materials through achievement of atom-by-atom and molecule-by-molecule control

8. Conceptualize, calculate, and predict processes underlying physical and chemical transformations, tackling challenging real-world systems – for example, materials with many atomic constituents, with complex architectures, or that contain defects; systems that exhibit correlated emergent behavior; systems that are far from equilibrium; and chemistry in complex heterogeneous environments such as those occurring in combustion or the subsurface

9. Probe, understand, and control the interactions of phonons, photons, electrons, and ions with matter to direct and control energy flow in materials and chemical systems

10. Conceive, plan, design, construct, and operate scientific user facilities to probe the most fundamental electronic and atomic properties of materials at extreme limits of time, space, and energy resolution through x-ray, neutron, and electron beam scattering and through coherent x-ray scattering. Properties of anticipated new x-ray sources include the ability to reach to the frontier of ultrafast timescales of electron motion around an atom, the spatial scale of the atomic bond, and the energy scale of the bond that holds electrons in correlated motion with near neighbors

11. Foster integration of the basic research conducted in the program with research in NNSA and the DOE technology programs, the latter particularly in areas addressed by Basic Research Needs workshops supported by BES in the areas of the hydrogen economy, solar energy utilization, superconductivity, solid-state lighting, advanced nuclear energy systems, combustion of 21st century transportation fuels, electrical-energy storage, geosciences as it relates to the storage of energy wastes (the long-term storage of both nuclear waste and carbon dioxide), materials under extreme environments, and catalysis for energy applications.

BER

12. Obtain new molecular-level insight into the functioning and regulation of plants, microbes, and biological communities to provide the science base for cost-effective production of next generation biofuels as a major secure national energy resource

13. Understand the relationships between climate change and Earth's ecosystems, develop and assess options for carbon sequestration, and provide science to underpin a fully predictive understanding of the complex Earth system and the potential impacts of climate change on ecosystems

14. Understand the molecular behavior of contaminants in subsurface environments, enabling prediction of their fate and transport in support of long term environmental stewardship and development of new, science-based remediation strategies Understanding the role that biogeochemical processes play in controlling the cycling and mobility of materials in the subsurface and across key surface-subsurface interfaces in the environment enabling the prediction of their fate and transport.

15. Make fundamental discoveries at the interface of biology and physics by developing and using new, enabling technologies and resources for DOE's needs in climate, bioenergy, and subsurface science

16. Operate scientific user facilities that provide high-throughput genomic sequencing and analysis; provide experimental and computational resources for the environmental molecular sciences; and resolve critical uncertainties about the role of clouds and aerosols in the prediction of climatic process

FES

17. Advance the fundamental science of magnetically confined plasmas to develop the predictive capability needed for a sustainable fusion energy source

18. Support the development of the scientific understanding required to design and deploy the materials needed to support a burning plasma environment

19. Pursue scientific opportunities and grand challenges in high energy density plasma science to explore the feasibility of the inertial confinement approach as a fusion energy source, to better understand our universe, and to enhance national security and economic competitiveness

20. Increase the fundamental understanding of basic plasma science, including both burning plasma and low temperature plasma science and engineering, to enhance economic competitiveness, and to create opportunities for a broader range of science-based applications

HEP

21. Understand the properties and interactions of the elementary particles and fundamental forces of nature from studies at the highest energies available with particle accelerators

22. Understand the fundamental symmetries that govern the interactions of elementary particles from studies of rare or very subtle processes, requiring high intensity particle beams, and/or high precision, ultra-sensitive detectors.

23. Obtain new insight and new information about elementary particles and fundamental forces from observations of naturally occurring processes -- those which do not require particle accelerators

24. Conceive, plan, design, construct, and operate forefront scientific user facilities to advance the mission of the program and deliver significant results.

25. Steward a national accelerator science program with a strategy that is drawn from an inclusive perspective of the field; involves stakeholders in industry, medicine and other branches of science; aims to maintain core competencies and a trained workforce in this field; and meets the science needs of the SC community

26. Foster integration of the research with the work of other organizations in DOE, in other agencies and in other nations to optimize the use of the resources available in achieving scientific goals

NP

27. To search for yet undiscovered forms of nuclear matter and to understand the existence and properties of nuclear matter under extreme conditions, including that which existed at the beginning of the universe

28. Understand how protons and neutrons combine to form atomic nuclei and how these nuclei have emerged during the 13.7 billion years since the origin of the cosmos.

29. Understand the fundamental properties of the neutron and the neutrino, and how these illuminate the matter-antimatter asymmetry of the universe and physics beyond the Standard Model.

30. Conceive, plan, design, construct, and operate forefront national scientific user facilities for scientific and technical advances which advance the understanding of nuclear matter and result in new competencies and innovation. To develop new detector and accelerator technologies that will advance NP mission priorities

31. Provide stewardship of isotope production and technologies to advance important applications, research and tools for the nation.

32. Foster integration of the research with the work of other organizations in DOE, such as in next generation nuclear reactors and nuclear forensics, and in other agencies and nations to optimize the use of the resources available in achieving scientific goals.

WDTS

33. Increase the pipeline of talent pursuing research important to the Office of Science

34. Leveraging the unique opportunities at DOE national laboratories to provide mentored research experiences to undergraduate students and faculty)

35. Increase participation of under-represented students and faculty in STEM programs

36. Improve methods of evaluation of effectiveness of programs and impact on STEM workforce

Energy Security (ES)

1. Supply - Solar
2. Supply - Nuclear
3. Supply - Hydro
4. Supply - Wind
5. Supply - Geothermal
6. Supply - Natural gas
7. Supply - Coal
8. Supply - Bioenergy/Biofuels
9. Supply - Carbon capture and storage

10. Distribution - Electric Grid
11. Distribution - Hydrogen and Gas Infrastructure
12. Distribution - Liquid Fuels
13. Use - Industrial Technologies (including efficiency and conservation)
14. Use - Advanced Building Systems (including efficiency and conservation)
15. Use - Vehicle Technologies (including efficiency and conservation)
16. Energy Systems Assessment/Optimization

Environmental Management (EM)

1. Facility D&D
2. Groundwater and Soil Remediation
3. Waste Processing

National Security (NNSA)

1. Stockpile Stewardship and Nuclear Weapons Infrastructure
2. Nonproliferation
3. Nuclear Propulsion

Homeland Security (HS)

1. Border Security
2. Cargo Security
3. Chemical/Biological Defense
4. Cyber Security
5. Transportation Security
6. Counter-IED
7. Incident Management
8. Information Sharing
9. Infrastructure Protection
10. Interoperability
11. Maritime Security
12. Human Factors

Appendix 1. Annual Strategic Partnership Projects Report

TJNAF provides a summary description of the laboratory's Strategic Partnership Projects activities as listed in Table 1 (Strategic Partnership Projects Funding).

With respect to TJNAF 's activities categorized in Table 1 as "DOD" and "All Other Federal Work," the description below 1) identifies the Federal entities that comprise this group, and 2) provides a brief explanation of the work effort for each Federal entity in Sections A and B below. Similarly, with respect to the laboratory's activities categorized in Table 1 as "Non-Federal Work," TJNAF uses descriptions in this Appendix in Section C below to identify 1) the types of non-Federal organizations that comprise this group, and 2) individual significant efforts.

A. DOD

Agency: Department of Defense
Office of Naval Research:

Total Funds Expected	**FY15:**	**$150,000**	**FY16: $0**
Total Funds Received through	**Q2 FY15:**	**$150,000**	

Scope: Have utilized both the UV and IR Free Electron Lasers at TJNAF for studies related to electron beam production, transportation, and light generation that underpin performance requirements for high performance FELs in areas related to high power scaling. Efforts will also include tasks related to optical and electron beam diagnostics and critical material testing. Utilize the FEL electron beam to study the effects of RF impulses on electronics. In FY15, workings to develop automatic timing and synchronization for the application of FELs as a practical system on board a ship.

B. ALL OTHER FEDERAL WORK

None.

C. NON-FEDERAL WORK ($7.6M FY15) ($3.3M FY16)

1. UNIVERSITIES

Michigan State University:

Total Funds Expected	**FY15:**	**$3,187,132**	**FY16: $3,145,515**
Total Funds Received through	**Q2 FY15:**	**$1,028,273**	

Scope: Support FRIB's current planned specification, procurement, installation & commissioning of the 2K Central Helium Refrigerator & its supportive subsystems, and FRIB cavity hydrogen de-gassing & pansophy support. Also finalize FRIB cryomodule engineering and design.

Old Dominion University:

Total Funds Expected	**FY15:**	**$150,000**	**FY16: $150,000**
Total Funds Received through	**Q2 FY15:**	**$0**	

Scope: Provide support to Old Dominion University (ODU) Center for Accelerator Science.

2. COMMERCIAL BUSINESSES

Organization: Southeastern Universities Research Association, Inc.

Total Funds Expected	**FY15:**	**$3,950,000**	**FY16: $0**
Total Funds Received through	**Q2 FY15:**	**$0**	

Scope: MEIC preparation includes but is not limited to geotechnical investigation, land survey, environmental studies and assessments, storm water management plan, site plan development, construction phase plan, and design requirements documents for the electron ion collider project, and recruitment of personnel with expertise to address the minimum requirements for the United States Department of Energy for its electron ion collider project in conjunction with support from the Commonwealth of Virginia.

Total Funds Expected	**FY15:**	**$830,000**	**FY16: $0**
Total Funds Received through	**Q2 FY15:**	**$830,000**	

Scope: Awake SPECT Upgrades and Improvements (Imaging Project) ($60k). Also includes Low Energy Recirculator Facility (LERF) resuscitation support ($250k), funds to leverage MEIC and other inititatives ($400k), and Theory department support through a Six Month Term Staff Scientist II from University of Ljubljana, Slovenia. Support scientific and engineering research that could have an economic impact in Virginia consistent with the objectives in the current Commonwealth of Virginia Biennial Budget.

Organization: Bailey Tool & Manufacturing Co.

Total Funds Expected	**FY15:**	**$50,187**	**FY16: $0**
Total Funds Received through	**Q2 FY15:**	**$0**	

Scope: Seamless SRF cavity fabrication by spin-necking and hydroforming.

Appendix 2 - Laboratory Investments Template

Objectives	
Construct and upgrade facilities and utilities to fully support mission	
Replace substandard temporary and leased space with permanent facilities	
Increase energy efficiency and support DOE sustainability goals and	

Project	Total	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	Funds
33 MVA Substation	1,000	1,000													GPP
EHS&Q Building	3,000	1,000	2,000												GPP
Computer Center Consolidation	2,000			2,000											GPP
CEBAF Center Renovation	6,300				1,500	1,500	1,500	1,800							GPP
Facilities Operations Building	2,500				1,000	1,500									GPP
Cryogenics He Purifier	1,000						1,000								GPP
Shipping & Receiving Center	2,000						500	1,500							GPP
Machine Shop Expansion	2,000								2,000						GPP
Fire Protection System Upgrade	1,500								1,000	500					GPP
Cryo Building Renovation	1,000									1,000					GPP
Equipment Warehouse	2,000									1,500	500				GPP
Water Reuse Capture & Tank	1,500										1,500				GPP
CEBAF Center Wing D	4,500										500	2,000	2,000		GPP
Site Stormwater Management	2,000													2,000	GPP
Cryogenics Infrastructure Modernization – Exp. Halls	8,000				3,000	3,000	2,000								GPP Cross-Cut
Experimental Equipment Lab Renovation	10,000							5,000	5,000						GPP Cross-Cut
CEBAF Center Office Addition	35,000				2,000	20,000	13,000								SLI
Sustainability Projects				500	2,000										UESC
	85,300	2,000	2,000	2,000	7,500	26,000	18,000	8,300	8,000	3,000	2,500	2,000	2,000	2,000	
Maintenance and Repair		4,562	5,800	5,900	6,500	6,600	6,700	6,800	6,400	6,500	6,600	6,700	6,800	6,900	
Deferred Maintenance Trend		8,565	5,501	5,701	5,718	5,787	5,987	3,990	4,190	3,783	3,627	3,827	4,027	4,041	

Appendix 2 (cont'd) - **Proposed Line Item Investment**

Proposed Line Item Investment

Site Office	Thomas Jefferson Site Office (TJSO)
Name (Acronym)	CEBAF Center Office Addition (CCOA)
Total Estimated Cost Low End	$30M
Total Estimated Cost High End	$35M
Projected Scope Elements	Construct a 60,000 – 70,000 SF additional wing with attaching atrium and associated site work to CEBAF Center. The addition will include office and meeting space to accommodate functions currently in leased space rated as substandard.
Support of DOE Strategic Goals	Strategic Objective 3 Strategic Objective 9
Capability Gap	The Service Support Center is a 1965 State owned building leased to the Lab since 1987. Many of the building systems are original and have exceeded their service life. Replacement parts are no longer available for the electrical switchgear. There have been multiple plumbing failures due to deteriorating under slab piping. It has been determined that over $5M is needed for recapitalization of the building. The State is considering repurposing the land for development of a tech park. Additional offices and support functions are located (occupied 26,869 SF) in Applied Research Center leased from the City of Newport News Virginia. The current lease expires September 30, 2017. This building is also rated as substandard and high energy consumption impacting the Lab to meet a portion of the DOE sustainability goals. The new facility will be designed to meet or exceed High Performance Sustainable Building (HPSB) Guiding Principles and is instrumental for the Lab meeting its sustainability goals
Alignment with Lab Core Capabilities	Large Scale User Facility
Mission Readiness	The project accommodates relocation of staff and users currently in leased space. Admin functions in a 1965 constructed state owned building in need of major recapitalization would relocate to CEBAF Center. Given the age and functionality of the state owned building expenditures at the needed level is not warranted. The Lab leased portions of the 1997 constructed City owned building is in need of a major renovation and energy efficiency upgrade. The facility will enhance the growing user community by collocating users for each experimental hall with staff scientists.
Impact if Not Funded	TJNAF will not be able to sustain a productive and safe working environment for current and future employees and users. The only alternative will require additional leased space away from the Laboratory campus at greater cost and lower productivity.