DOE Business Plan for the Office of Science's Thomas Jefferson National Accelerator Facility

Mission and Overview

The Thomas Jefferson National Accelerator Facility (TJNAF), located in Newport News, Virginia is a program-dedicated laboratory for Nuclear Physics under the Department of Energy's Office of Science. Built, managed and operated by the Southeastern University Research Association (SURA) for Office of Science, TJNAF began operations in 1995 with the completion of the Continuous Electron Beam Accelerator Facility (CEBAF), a unique international electron-beam user facility for the investigation of nuclear and nucleon structure based on the underlying quark structure. TJNAF research and engineering staff are world experts in superconducting radio-frequency technologies. CEBAF has an international user community of over 2,000 researchers and research has resulted in scientific data for 110 experiments, more than 147 *Physics Letters* and *Physical Review Letters* published, and 322 publications in other refereed journals. Collectively, there have been over 10,000 citations for work done at CEBAF. Research at TJNAF and CEBAF has also contributed to thesis research material for about one-fourth of all U.S. Ph.D.'s awarded annually in Nuclear Physics.

Laboratory Focus and Vision

TJNAF has a central role in the field of nuclear physics, both in the U.S. and worldwide. TJNAF's present and future program relies on maintaining core competencies in:

1. Hadronic Physics
2. Superconducting Accelerator Technologies

The Office of Science believes that these core competencies will enable TJNAF to deliver its mission and customer focus, to perform a complementary role in the DOE laboratory system, and to pursue its vision for scientific excellence and pre-eminence in the areas of nuclear physics:

- The structure of the nuclear building blocks including: the nucleon's charge and magnetization distribution; the degrees-of-freedom governing the nucleon's excitation; the internal structure of the nucleon in the valence region; and the experimental and theoretical tools necessary to carry out a program of nucleon tomography.
- The structure of nuclei including: the nuclear interior

Lab-at-a-Glance

Location: Newport News, VA

Type: Program Dedicated Lab

Contract Operator: Southeastern University Research Association (SURA)

Responsible Site Office: Thomas Jefferson Site Office

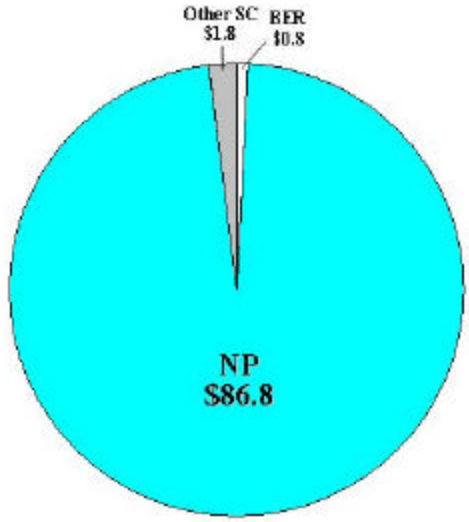
Website: http://www.jlab.org

Physical Assets:
- 97 Buildings
- 206 Acres

Human Capital:
- 617 Employees;
- 315 Students (Undergraduate and Graduate);
- 2,200 Facility Users and Visiting Scientists

FY 2005 Total DOE Funding: $89.4M

DOE Funding by Source (in Millions):



FY 2005 Work for Others: $11.2M

with controlled impurities; short-range component of the nucleon-nucleon interaction in nuclei; the neutron radius of ^{208}Pb; and the underlying quark-gluon structure of the nucleus.

- Symmetry tests in nuclear physics including the weak charge of the proton to test predictions of the Standard Model.
- Enabling technologies and emerging fields - photon science and electron-light ion colliders – including advance radiofrequency superconductivity, 2K cryogenic engineering technology (ERL), advanced high power free electron lasers, energy recovering linacs, and electron-light ion collisions at ultra-high luminosity.

Business Lines

The following capabilities, aligned by business lines, 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 business lines and the distinguishing capabilities outlined in the table below provide an additional window into the mission focus and unique contributions and strengths of TJNAF and its role within the Office of Science laboratory complex. Items in italics within the column, Distinguishing Capabilities, identify research facilities that convey particular, strategic strengths and capabilities to the Lab. Descriptions of these facilities can be found at the website noted in the Lab-at-a-Glance section of this Plan.

Business Lines	Distinguishing Capabilities	Distinguishing Performance	Mission Relevance
Nuclear Physics – 6 GeV Research	· **Continuous beams of polarized high-energy electrons for studies of the quark structure of matter;** · **State-of-the-art Equipment & Detectors;** · ***Continuous Electron Beam Accelerator Facility, Hall A, Hall B (CLAS), Hall C***	World-wide unique user facility for studies of nuclei and nucleons using the electromagnetic probe, with spatial resolutions from large nucleus to a fraction of a nucleon's diameter; Highest intensity in the world for highly polarized continuous electron beams with the energy and helicity correlated properties necessary to explore the details of nucleon structure; Detector and data acquisition capabilities coupled with these beams provide the highest luminosity capability in the world for these experiments.	Explore Nuclear Matter-from Quarks to Stars – Understand the structure of the nucleon and nucleonic matter
Nuclear Physics – Theory Center	· **High Performance Computing Effort in Lattice Quantum Chromodynamics (LQCD).**	World-recognized theory group; Software development used worldwide (Chroma); First calculations of moments of GPD's.	Understand the structure of the nucleon and nucleonic matter; Deliver Computing for the Frontiers of Science.
Superconducting Radio Frequency (SRF) and Related Accelerator Physics	· **Experience building SRF for CEBAF & SNS;** · **Energy Recovery Techniques;** · **World-wide unique capability in 2K Cryogenic technology;** · ***The Testlab and Applied Research Center.***	Large-grain Niobium operating at an accelerating field of 45 MV/m -world record achieved with minimal processing; Benchmarking exercise, concluded that JLab is a world leader par with DESY; World record in Energy Recovery Linac Technology demonstrated via operating a 1MW class electron beam with 10 mA current and 100 MeV energy with only tens of kilowatts of klystron power.	Understand the structure of the nucleon and nucleonic matter; Provide the Resource Foundations that Enable Great Science.

Business Lines	Distinguishing Capabilities	Distinguishing Performance	Mission Relevance
Photon Science and Technology	· **ERL-based Free Electron Laser;** · **Potential kW to MW class lasers;** · **Micromachining;** · ***Infrared Free Electron Laser.***	Unique assets of ultra-fast pulses with broad tunability at unprecedented power levels with continuous/high repetition rate operation; World record of 10 kW average power laser at infrared wavelengths with a few hundred femtosecond pulse length.	Provide the Resource Foundations that Enable Great Science.

Major Activities

Following is a set of major activities that TJNAF would like to pursue to support aspects of the DOE mission and build on core strengths and capabilities of the laboratory. The Office of Science is examining all of these potential activities and they are at different stages of development. Some are currently underway and some are mere concepts at this time. For those that are still in the conceptual phase, TJNAF has indicated significant interest and is viewed to have current supporting research and mission focus to pursue such activities. Budgets, the Office of Science's strong commitment to a fair and competitive funding process and technical advice from its major scientific advisory committees will ultimately contribute to decisions about which activities can be pursued and at which sites. The companion documents, the DOE's Five Year Plans, provide greater insights into these activities in terms of various five-year budget scenarios.

The major activities are:

1. 12 GeV Upgrade of Continuous Electron Beam Accelerator Facility (CEBAF)
2. Excited Baryon Analysis Center
3. Lattice Quantum Chromodynamics (LQCD)
4. International Linear Collider

1. 12 GeV Upgrade

- **Summary:** Upgrade CEBAF, a unique research facility and world leader in hadronic physics. The scope of the proposed project includes doubling the accelerator beam energy, adding a new experimental Hall and associated beamline, and upgrading the equipment in existing experimental Halls.
- **Expectations:** The Upgrade will allow experimental study of the confinement of quarks and address the question, "why are quarks never found alone?" Confinement is a remarkable and not understood feature of quantum chromodynamics (QCD) and is one of the major gaps in our understanding of nature. Gluonic excitation, in the form of exotic mesons, is a prediction of QCD that is expected to provide key insights into the nature of confinement. The only planned or existing facility that can test this prediction is the 12 GeV CEBAF.
- **Benefit Perspective:** Potentially *Transformational* Benefits
- **Risk Perspectives:**
  - Technical: *Low risk* – superconducting radio frequency (SRF) work on other projects has significantly reduced the technical risks of this project.
  - Market/Competition: *Low risk* – CEBAF is a unique facility.
  - Management/Financial: *Moderate risk* - due to federal budget uncertainties.

CEBAF occupies a racetrack-shaped footprint. Each straight section contains a linac made up of 20 cryomodules. To recirculate the beam, magnetic transport channels making up the curved sections, the so-

called arcs, connect these linacs. Several factors contribute to make the 12 GeV Upgrade cost effective. First, on average, the existing critical components of the accelerator exceed their design specifications by 50% resulting in the capability to run at 6 GeV electron beam energy rather than the originally specified 4 GeV. Second, continued efforts have led to the development of a new cryomodule type capable of exceeding the original CEBAF specifications by a factor of five. Third, for reasons of project construction history, each linac contains five empty slots with most of the ancillary provisions ready to accept the new high performance cryomodules. Fourth, the radius of the arcs was generously designed to avoid serious emittance degradation that might have precluded ever achieving higher energies.

In the new experimental Hall D, a tagged coherent bremsstrahlung beam – created using the full 12 GeV beam energy - and solenoid detector will be constructed for a program of gluonic spectroscopy to experimentally test our understanding of quark confinement. Additional experimental equipment proposed for the Upgrade project will optimize the scientific capabilities and takes full advantage of apparatus developed for the present program. All three existing Halls will be able to receive the full 5-pass beam energy. Critical Decision Zero (CD-0) was approved in March 2004. Approval of Critical Decision One (CD-1) for the 12 GeV Upgrade is anticipated in FY 2006. As part of the preparation for the CD-1 decision, the DOE conducted a Review of the Science of the 12 GeV Upgrade in April 2005. The committee concluded that the science capabilities are very compelling and noted two specific areas as having "discovery potential". The next step toward CD-1 was the successful completion of an Independent Project Review of the cost and schedule convened by DOE in July 2005. The review committee concluded that all requirements for CD-1 approval were complete.

2. Excited Baryon Analysis Center

- **Summary:** World-recognized theory group provides critical foundation for experimental program; activity in Excited Baryon Analysis Center allows enhanced analysis and understanding of experimental results.
- **Expectations:** Success in this activity will lead to a profound understanding of the spectrum of excited baryons and hence the nature of confinement, including the way excited hadronic matter modifies the nonperturbative QCD vacuum.
- **Benefit Perspective:** Potentially *Transformational* Benefits
- **Risk Perspectives:**
  - Technical: *High risk* - It is an extremely challenging problem for theoretical physics.
  - Market/Competition: *Moderate risk* – Other groups are also working in this area.
  - Management/Financial: *Moderate risk* - This effort requires a sustained commitment. Human Capital is critical to this effort.

Office of Science's Strategic Plan for Nuclear Science states that connecting the observed properties of baryons with the underlying framework provided by QCD is one of the central challenges of modern science. In order to address these questions it is essential to have a clear understanding of the spectrum of excited states of the nucleon. However, it has become clear over the past few years that the analysis of data for the production of such states at TJNAF and elsewhere requires a far more coherent and advanced theoretical understanding than had been anticipated. With this in mind, a proposal to establish an Excited Baryon Analysis Center was submitted to DOE. The key idea is to build a network of all relevant theoretical and experimental groups world-wide to agree on a coherent program of data analysis. In parallel with the development of new theoretical tools to deal with the complex, multi-particle final states encountered in this field one would need a team of phenomenologists working with the relevant experimental groups to apply the state of the art theoretical models to their data.

It is an extremely challenging problem for theoretical physics to deal with multi-particle final states in a manner consistent with the constraints of unitarity, crossing and analyticity. One cannot guarantee success but it is clear that success is not possible without serious, sustained theoretical effort at the highest level, in cooperation with

those involved in data analysis. This can only be carried out at a national laboratory, such as TJNAF, with significant investment.

3. Lattice Quantum Chromodynamics (LQCD)

- **Summary:** Expand existing High Performance Computing Effort in Lattice Quantum Chromodynamics (LQCD) essential to understand QCD in the confinement regime and contribute to national scientific computing enterprise.
- **Expectations:** Success will mean that TJNAF has calculated the consequences of nonperturbative QCD with unprecedented accuracy in order to test its predictions against the precise new data provided by the 12 GeV Upgrade.
- **Benefit Perspective:** Potentially *Transformational* Benefits
- **Risk Perspectives:**
  - Technical: *Low risk*- Progress in this area has been promising
  - Market/Competition: *Moderate risk* - Risk reduced through collaboration and the unique capabilities of CEBAF, though Brookhaven Lab is also involved in QCD studies
  - Management/Financial: *Low risk* – Small additional investments could have a substantial impact in this effort.

Lattice QCD currently provides our only means of solving QCD in the low-energy regime. Dr. Nathan Isgur recognized, in 1998, the crucial role that lattice QCD must play in hadronic and nuclear physics by founding, together with Prof. John Negele of MIT, the Lattice Hadron Physics Collaboration (LHPC). Subsequently, under the auspices of the Department of Energy's SciDAC activity, the US theory community has developed the computational infrastructure to employ lattice QCD to solve a spectrum of problems in nuclear and particle physics. TJNAF (particularly Drs. R. Edwards and D. Richards of the Theory Center) plays a pivotal role in this SciDAC activity and is now exploiting this role to address key questions across the TJNAF program.

The Jefferson Lab Theory Center will continue to play central roles in the SciDAC activity over the next four years with a focus on exploiting the technology to the world's most precise computations of hadron properties. A White Paper outlining the highest priority calculations which need to be made and the synergy between those calculations and the TJNAF program at 6 GeV and 12 GeV was submitted to DOE earlier this year. To optimize the physics output in relation to the 12 GeV Upgrade, this activity requires an additional $0.5M per year over current levels from FY07 through FY12 for lattice QCD hardware. An additional national advantage is that TJNAF will explore the limits of clusters of commercial computers for high performance computing. Already, there are hints that these clusters may be more cost effective than specialized machines.

4. International Linear Collider (ILC) R&D

- **Summary:** Develop enabling technologies in support of International Linear Collider (ILC). Since the announcement in 2004 of the technology choice for the ILC, TJNAF has been actively engaged in preliminary discussions on the ILC project and as a member of numerous ILC Working Groups including a recent formal role in the ILC Global Design Group and in MOUs with the principal ILC coordinating lab in the US, FNAL.
- **Expectations:** The TJNAF's experience and expertise in Superconducting Radiofrequency (SRF) technology will enable future scientific accelerators (ILC, etc.), as well as accelerators for basic science, defense, bioscience and nano-technology, and potential commercial materials processing (Free Electron Laser).
- **Benefit Perspective:** *Significant/Sustaining* Benefits
- **Risk Perspectives:**
  - Technical: *Moderate risk* – Work for CEBAF Upgrade, SNS, and DOD has given TJNAF a great deal of experience and world-leadership in this technology. The 12 GeV Upgrade will further enhance this

position.

- Market/Competition: *High risk* – Many U.S. and international labs are interested in this part of the ILC effort. TJNAF is currently in a leadership position but this could change and international negotiations will be a factor.
- Management/Financial: *High risk* - Due to tight federal budgets and the high project costs and long construction period for the ILC should it be built.

TJNAF has submitted multiple proposals to the Office of Science's High Energy Physics (HEP) division in support of ILC dealing with new materials R&D involving single crystal/large grain niobium, studies of cavity processing and their control to make robust production of cavities with predictable performance, development of specific value-engineered high gradient superconducting cavities and cryomodules, and preparations for industrialization of SRF technology in support of the ILC. This scope of work will substantively reduce the project's technical risks and costs and will be the hallmark of TJNAF's contributions to this challenging international project. Simultaneously, intense effort on high gradient and low-loss cavity R&D has already led to the ground-breaking large- and single-grain cavity fabrication and testing leading to the achievement of the highest gradient possible in niobium.

TJNAF has established a productive partnership with Fermilab (FNAL) relative to their Superconducting Module Test Facility (SMTF) activity, supporting development and growth of an SRF infrastructure that will benefit FNAL as the primary HEP lab taking ILC responsibility at large. It is TJNAF's vision to remain an essential partner and collaborator and be the consolidator of SRF developments in support of the ILC, including the eventual industrialization of the technology. TJNAF plans to design and prototype a model-integrated cryomodule production plant suitable for technology transfer to US industry.

Also, TJNAF is leveraging its SRF core competency in a major activity, a 100 kW IR upgrade to its ERL-based 10 kW Free Electron Laser funded by DoD. Additionally, SRF ERL-based technology R&D for an electron light ion collider and light source is ongoing. An electron light ion collider at a center-of-mass energy of 30 GeV could achieve an ultra-high luminosity of 10^{35} $cm^{-2}s^{-1}$ reaching the limit where possible color glass condensates of quarks and gluons could be observed and study quark-gluon plasma not only at high temperatures but at high densities. An ERL-based light source would provide the highest achievable spectral brilliance of photons and shortest pulses achievable not only at x-ray wavelengths but also at longer wavelengths of infrared and THz.

Financial Outlook

Detailed information regarding the financial outlook for the Thomas Jefferson National Facility is subject to 1) competition and merit review, 2) the availability of appropriated funds and 3) programmatic decisions. The first two factors can not be predicted or estimated in advance. The third, programmatic decisions, are developed in accordance with the planning targets reflected in the Department of Energy programmatic Five Year Plans, a companion document to these strategic laboratory business plans. In addition, because of the Office of Science commitment to competition and merit review, there is often a time lag between programmatic decisions and the determination of which research provider can best deliver the greatest value in conducting the research. Thus, it is not always apparent how programmatic decisions unfold for particular laboratories. Nevertheless, some decisions, such as the plans for large scientific user facilities, show clear paths to individual labs and therefore inform their business plans.

Support for Non-DOE funded work is a vital role our national laboratories, contributing to national security, energy security, environment stewardship, scientific discovery, and more fundamentally, the competitiveness of the U.S. economy. For the Thomas Jefferson National Facility, this is no exception. The Office of Science is supportive of this work and although it is not addressed in any detail within the accompanying Five Year Plans,

the Office of Science believes it is sufficiently important and appropriate to address within this strategic laboratory business plan. A brief perspective and financial outlook is therefore provided.

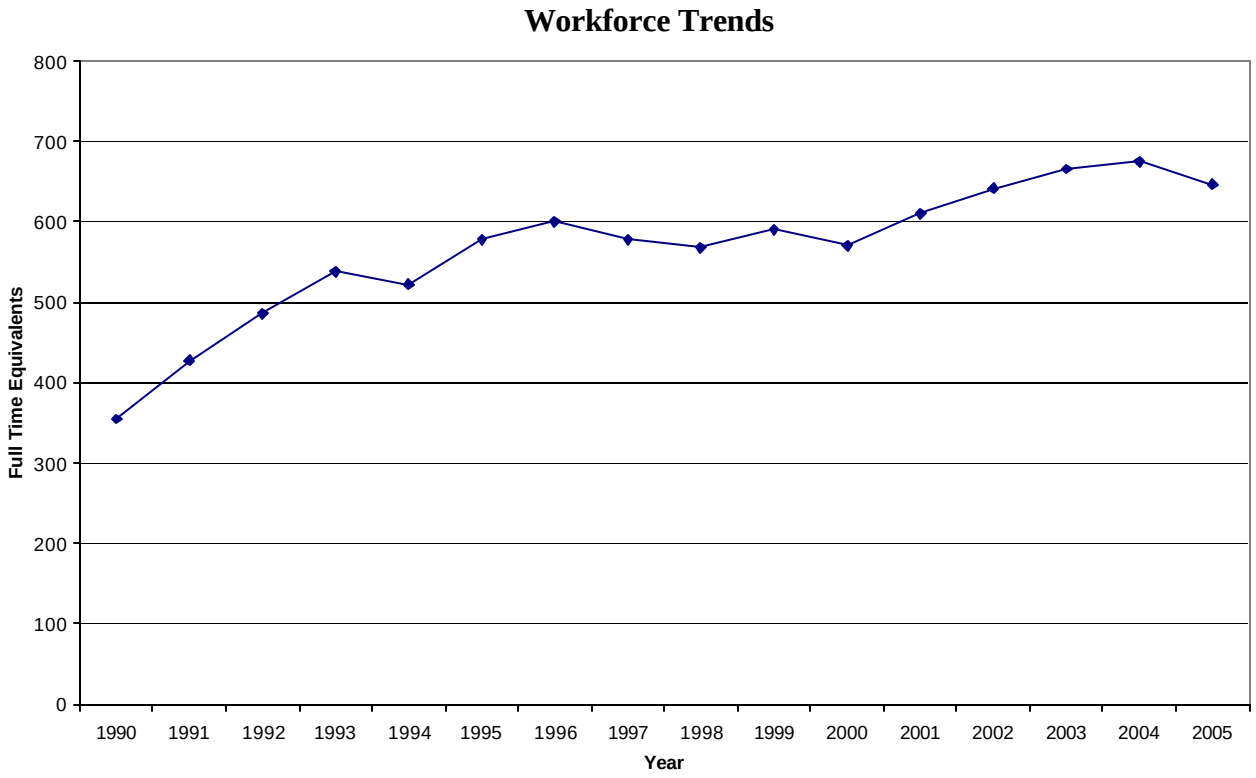
The current TJNAF non-DOE funded activities are primarily funded by the Department of Defense (Navy, Air Force and Army) and focus on technology development to scale Free-Electron Lasers (FELs) to 100kW-MW power class, to study laser materials damage and atmospheric propagation, to construct and commission a 1kW UV FEL for materials science and processing, and to commission a far-infrared (THz) beam-line and User Lab for THz spectroscopy and imaging.

TJNAF's world-class FEL provides an accelerator physics/technology test bed which allows them to enhance CEBAF's performance and capabilities. This is a tremendous benefit to their in-house Nuclear Physics program and to DOE as a unique repository of technology expertise available to other science and technology facilities throughout the nation. Over the next five years and beyond, TJNAF anticipates continued and possibly increased funding from the DoD, allowing the laboratory to continue to build on their investment and ensuring continued world leadership on the frontiers of FEL, Energy Recovered Linac (ERL) and superconducting radiofrequency (SRF) technology.

Uncertainties and Risk Management

External Factors: TJNAF, as an integral part of the national lab system, provides unique and complementary capabilities to the other labs in the system contributing to the DOE missions and to the overall national S&T agenda. The Lab is poised to lead the world in experiment and theory of nuclear confinement physics and related accelerator and SRF technologies. The internationally based nuclear physics program complements the work being done at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, while enabling a program of hadronic physics research that is unique in the world to answer key questions about the structure of matter at its most fundamental (quark and gluon) level. There are, however, major risks to this future- scientific, technical, management and financial. If the funding for the 12 GeV Upgrade project is not available, there is a pipeline of first class 6 GeV experiments in place for the next decade. TJNAF will continue to pursue alternative approaches to make the 12 GeV Upgrade a reality. TJNAF has a history of effectively leveraging Work for Others (WFO) to benefit Nuclear Physics and the Office of Science. DOD investments toward a world-class Free Electron Laser (FEL) provide an accelerator physics/technology testbed with potential for basic energy sciences. In addition, joint activities, are poised to capitalize on FEL capabilities for laser bioscience. TJNAF will continue to build on the investment by DOD and others to remain on the frontier of FEL and ERL technology.

S&T Workforce: The success of TJNAF's scientific program is anchored by the leadership of its key managers and depends on its ability to attract and retain a diverse world-class workforce. TJNAF utilizes a comprehensive staffing plan that identifies, prioritizes and projects programmatic labor needs. Through careful monitoring of hiring and attrition TJNAF's workforce trending in the out years demonstrates constant effort in the indirect functions. Programmatic needs point to a small increase in labor force.



Employee Diversity: TJNAF, as with all national DOE laboratories, must make significant progress in the recruitment and retention of underrepresented populations, particularly African American and Hispanic scientific staff. In particular, TJNAF is committed to pacing the rapidly increasing representation of women and underrepresented minority science and engineering Ph.D.'s graduating from tier 1 universities. TJNAF's existing education activities range from K-12 (most notably the BEAMS program, which serves as a national model) to graduate education and laboratory affiliations (joint faculty positions, post docs and graduate students) that emphasize Minority Serving Institutions (MSI's).

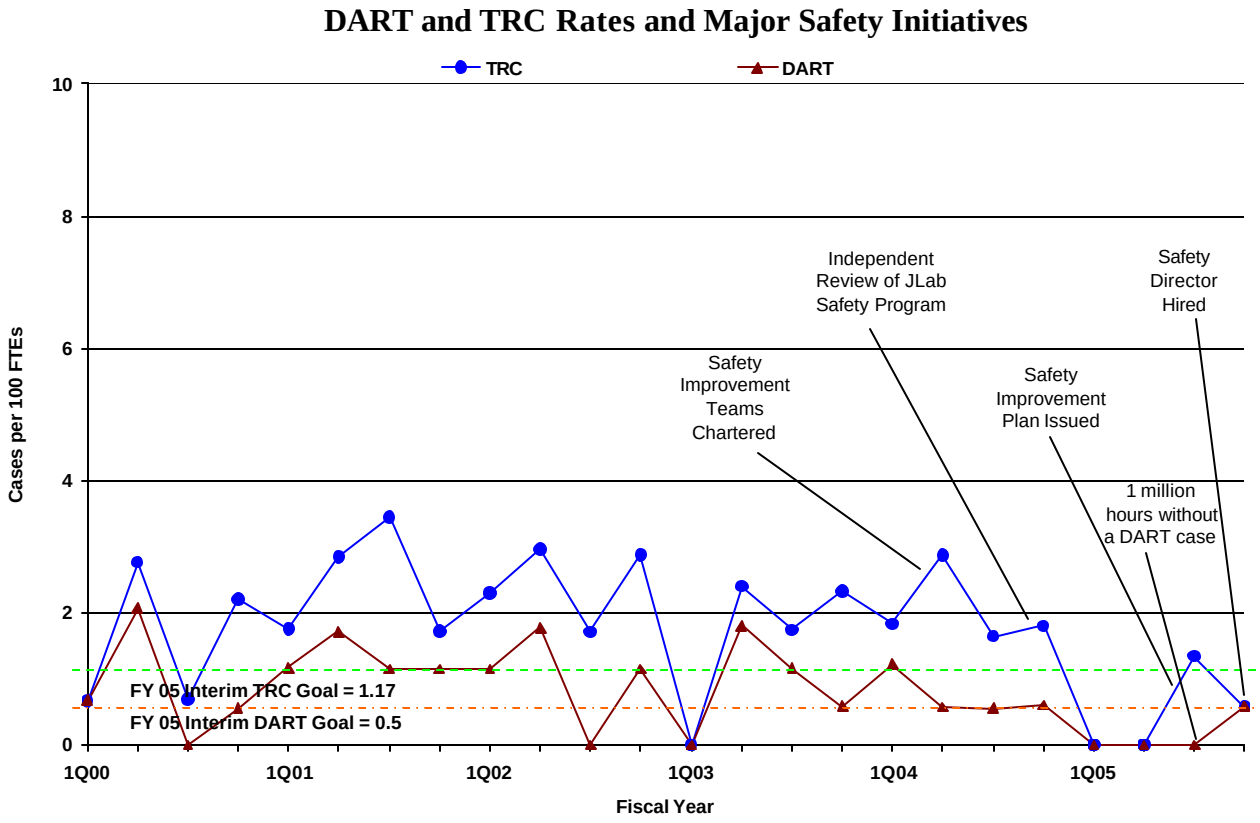
TJNAF, in alliance with its M&O contractor, Southeastern Universities Research Association's network of more than 60 member universities, (5 of which are MSI's), will collaborate on recruiting, improving and retaining workforce diversity and strength. Efforts will include utilizing an inventory of potential diverse candidates in all scientific areas and in particular for senior role model scientific and management fields; identifying and cultivating potential employees early via summer schools and focused workshops; insisting on qualified diverse candidates for postings; encouraging employee affinity groups; and addressing exit issues critical to retaining a diverse workforce.

Safety: TJNAF has moved aggressively to improve its safety performance through a multi-activity initiative. The Lab's new safety challenge "Accidents are preventable, zero injuries are the TJNAF's goal." began in 2004 analyzing its safety performance with the help of an expert outside contractor and initiated the following action items:

- Instituted organization changes including the addition of the Associate Director of Safety reporting to the Lab Director and a member of the senior management team
- Articulated the safety challenge at all levels of the organization
- Chartered integrated teams to improve electrical safety and material handling

- Conducted a safety culture survey to baseline and guide safety initiatives
- Emphasized timely reporting of minor injuries/incidents
- Developed and rolled out a comprehensive safety strategy
- Established a Worker Safety Committee for routine floor level feedback

A review of current lagging indicators (Total Recordable Case, TRC, Rate and Days Away/Restricted/Transferred, DART, Rate) show significant improvement and compares well with results at other Office of Science labs. TJNAF has logged over 1 million hours without a lost workday away injury in FY 2004 and 2005. For this improved performance, the Lab credits its multi-pronged approach and its capability to convince an increasing number of Lab employees that management has a genuine concern for their safety and well-being.



Physical Infrastructure: TJNAF is located on a 163 acre Federal reservation in Newport News, Va. The reservation, including three facilities (97,000 sf), was transferred from NASA to DOE in 1987. Subsequently, DOE constructed 311,000 sf of new facilities, including the Continuous Electron Beam Accelerator and support facilities. In total, TJNAF has 408,000 sf with 76% less than 20 years old. TJNAF's AUI is 1 (excellent).

TJNAF will attain a maintenance investment level of 2% of replacement plant value in FY 2006 which will be which will be continued in FY 2007 and the outyears. TJNAF's deferred maintenance backlog is $9.6M, resulting in an ACI of 0.92 (adequate). A deferred maintenance reduction initiative was implemented in FY 2006 and will be continued in FY 2007 with funding of $396,000. The FY 2007 GPP funding request is $0.8M.

A 61,000 square foot addition to CEBAF Center was completed in January 2006. It provides an expanded computer center, cafeteria, and offices and made it possible to demolish 32,000 square feet of existing trailer space.

TJNAF's future recapitalization and modernization challenges include: a shortage of technical, experimental, and storage space; a renovation of the Test Laboratory to improve process flow; updating of building equipment and code updates; and, new office space to consolidate staff and allow termination of leasing office space offsite.