

Nevada Terawatt Facility Strategic Plan



College of Science

University of Nevada, Reno

Department of Physics

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FY 2008 – FY 2010 STRATEGIC PLAN

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I Overview

The Nevada Terawatt Facility (NTF) at the University of Nevada Reno (UNR) has been part of the UNR Department of Physics since its inception in 1999. It is one of the National Nuclear Security Administration's (NNSA's) Science Centers supported by the Stockpile Stewardship Academic Alliances (SSAA) program.

A strategic plan for the NTF has been developed with the intent of achieving the highest quality and highest success rate in the training of Ph.D., M.S. and undergraduate students. The quality of the science and technology undertaken at the NTF should reach above the norm for NNSA facilities. The programmatic performance, management, and planning should be at a level to exceed the expectations of NTF's NNSA sponsors. The work performed must be relevant to national needs and to agency missions. The NTF's mission, vision, and strategy directed towards achieving these goals.

The NTF Director, Dr. Joseph M. Kindel, convened a strategic planning workshop on December 4 and 5, 2007, with Dr. Dale B. Henderson, with long time and broad experience in defense science, as consulting facilitator. Dr. Bryan V. Oliver of Sandia National Laboratories Albuquerque represented scientific collaborators outside of the UNR community. Dr. Roberto C. Mancini, Chair of the Department of Physics, attended and participated in the workshop. In addition, faculty and staff of the NTF and members of the Physics Department attended and contributed to the discussions. This document is the result of that workshop and discussions outside the workshop with members of the Physics Department and College of Science.

II Introduction

The Nevada Terawatt Facility was created in 1999 when a powerful pulsed power generator (Zebra) was made available by the Los Alamos National Laboratory (LANL). Professor Bruno S. Bauer of the UNR faculty seized the opportunity, took possession of the equipment and actively sought funding to establish the NTF and develop its primary asset: the mega-ampere Z pinch facility, Zebra. The facility was dedicated by Senator Harry Reid in 2000.

NTF has attracted outstanding research staff and enhanced its scientific capabilities with funding mainly from the DOE/NNSA, as well as other funding sources. Facing significant financial pressures – but recognizing unique opportunities for itself, the NTF with the support of the Physics Department undertook this planning workshop. The purpose of the workshop was to identify: (1) the core mission of the NTF, (2) NTF's role in the scientific community, (3) alternative funding sources and (4) the optimum research strategy relative to its given strengths. The underlying goal is to maximize the value of our scientific university laboratory to the DOE/NNSA.

III Mission Statement

Recognizing its place within a major university, the NTF accepts the primacy of its mission to train and graduate students at all levels: Ph. D. and M. S. graduate students and B.S. undergraduates. NTF maintains excellence in high energy density physics research, the study of matter in all phases under extreme conditions of temperature and density. The Nevada Terawatt Facility focuses on z-pinch physics and high intensity laser plasma interaction.

IV Vision Statement

NTF seeks to become a preeminent user facility and science center in high energy density physics. Establish strategic collaborations to enhance and guide the scientific program. The NTF is the facility of choice for students studying z-pinch plasma physics and laser-matter interaction in magnetized plasmas. The NTF prepares the new generation of physicists to become scientific leaders in high energy density physics.

V Scope of Activities

The strengths of the Nevada Terawatt Facility consist of its unique experimental capabilities matched by outstanding theoretical and modeling support.

The Zebra pulsed power generator, the Leopard laser, and the extensive diagnostics set represents NTF's experimental capabilities. Crucial to the facility is the massive SAGE (previously military: Semi Automatic Ground Environment) building furnished by UNR which is well suited to house sensitive diagnostics alongside heavy, vibrating equipment. Also located within the building are the Phoenix interaction chamber, target fabrication facilities, a machine shop, the NTF 84-node and 48-node computer clusters, and a number of other capabilities

High-energy-density physics, the study of matter under extreme conditions of temperature and density is the focus of research at the Nevada Terawatt Facility. Presently, the NTF includes scientific tools and machines for investigation of high temperature dense plasmas. The NTF staff provides reliable operation of 1-MA Zebra generator with ~400 shots per year which are used for z-pinch studies, generation of Terawatt x-ray bursts, Megagauss magnetic fields, and investigation of magnetized laser plasmas. Plasma diagnostics include a unique set of multiframe laser probing, optical and x-ray imaging, particle diagnostics, and x-ray spectroscopy supported by a world recognized atomic physics group in the UNR Department of Physics. Promising new wire array loads for ICF applications were developed at the NTF. The NTF experimental and theoretical efforts support the understanding of implosion dynamics, instabilities, plasma turbulence, x-ray production in z-pinch, and laser plasma interaction in both unmagnetized and magnetized plasmas. This work also includes space and astrophysical plasmas. All experiments are carried out with active and wide participation of UNR students.

An important opportunity for the NTF is the close interaction and involvement with Physics Department faculty with background in atomic and radiation physics with emphasis on plasma spectroscopy applications. The combination of expertise in atomic processes in plasmas, plasma atomic kinetics, plasma spectral line broadening, and spectroscopic quality radiation transport represents a unique resource that can significantly contribute to the research at the NTF.

The 50-TW Leopard and 10-TW Tomcat lasers are available for experiments with the Zebra generator and in a separate vacuum chamber. Joint Leopard-Zebra experiments started in 2007 and promise outstanding results for isochoric plasma heating, laboratory astrophysics, and x-ray radiography (e.g. of z-pinch). Theoretical studies and simulations support z-pinch and laser-plasma experiments at the NTF and contribute to the basic plasma physics. Simulations of plasma are performed with a 3-D hybrid MHD-kinetic code and with a 3-D collisional PIC code running on the 84-node and 48-node computers. Results of experimental and theoretical researches at the NTF are published in highly-rated scientific journals.

Challenges Faced by the NTF

The UNR NTF has developed into an important research facility with unique capabilities, but it is now facing a number of significant challenges. One challenge is how to emerge from uncertain earmarked funding to a flow of steady financial support. This means seeking a diversified funding portfolio including other parts of the DOE, NSF, NASA and the DoD. Another issue has been the management of the facility. Recently that issue has been addressed by the University hiring a new Director, Dr. Joseph M. Kindel. Lastly, the principal sponsor, DOE/NNSA, has emphasized its concern for a more consistent production of graduated students to sustain its National Laboratories.

Underlying Assumptions

The program presented to achieve NTF's strategic objectives has two assumptions. First is that the funding level to the NTF will remain close to its present level. Secondly, that collaboration with other Physics Department researchers will continue.

VI Strategic Objectives

Enhance our student mission by increasing the number of degreed graduate students from the NTF

Specific hands-on training and conduct student-led experiments

- NTF continues to train students on all aspects of conducting an experiment and undertaking theory. The educational benefits to the student by having both the experimental and theoretical hands-on experience and academic expertise are highly regarded by future employers. By so doing, NTF will enhance its reputation and consequently attract more students and funding opportunities.
- NTF encourages students to submit experimental proposals in order to gain valuable working knowledge.

Improve its strategy for recruiting students

- Market High Energy Density Physics to future students by lecturing, giving tours, having exhibits in appropriate settings
- Attention is given to the experiments executed by students
- The website will include NTF-based thesis research topics to attract new students.

Future funding must be stabilized

- To enable graduate students to complete their thesis program without disruption
- Provide financial support for undergraduate students within their field of interest
- Provide the appropriate infrastructure for students to lead and conduct experiments

As a unique facility within the U. S., the NTF should expand its role in education

- Provide means for collaboration with students from other institutions
- Hosting graduate research thesis through collaborations with faculty from other higher education institutions

Develop a Business-like Culture and Use Formal Project Management in Executing NTF Programs

- Provide project management training for all research and support staff
- Focus on one activity to demonstrate the highest standards of project management

Become a NNSA User Facility

- Secure an agreement with NNSA to become a user facility based on continuation of greater than 300 shot annual rate of experiments for Zebra
- Seek high quality collaborations for NTF to maintain and raise its scientific quality and to increase user facility interest

Perform Fundamental Z-pinch Physics and Develop Pulsed Power Technology

While the 26-MA Z machine at Sandia is at the forefront of many applications, important aspects of z-pinch physics have been elucidated on generators at the 1 MA level of current. The advanced plasma diagnostics on Zebra allow detailed investigation of z-pinch plasma dynamics and measurement of plasma parameters. NTF will develop z-pinch physics in several scientific directions as follows.

- Investigation of implosion dynamics and plasma instabilities in wire arrays; includes seeding in solid targets by material manipulation
- Study of physical mechanisms of plasma heating in z-pinches including anomalous resistivity, plasma turbulence including magnetic effects and other mechanisms
- Study of generation of soft and keV x-ray radiation, optimization of loads and materials for maximum x-ray yield and power
- X-ray pulse shaping for ICF applications
- Theoretical study of plasma wave turbulence, nonlinear wave energy cascades and large scale transport in a high beta z-pinch plasma
- Investigate ion heating mechanisms and ion acceleration in imploding wire arrays associated with the magnetosonic shock formation

Other applications for Zebra

- Generation of supersonic plasma flows using wire arrays
- Magnetic acceleration of flyers for shock experiments

Development of pulsed power technology at the NTF includes:

- Study of new types of wire-array loads for ICF (linear, star-like, compact cylindrical and nested)
- Development of the method for current multiplication on the load

New types of loads with enhanced radiated x-ray power and energy could be implemented in multi-mega-ampere generators. The current multiplier can significantly increase the z-pinch current for future experiments.

Develop new plasma diagnostics at the NTF

Progress in z-pinch physics will be based on new plasma diagnostics developing at the Zebra facility:

- High spatial resolution multi-frame optical probing to study small-scale perturbations and turbulence in plasma
- UV laser probing to study z-pinch density structure
- High spatial resolution time-resolved x-ray imaging, including narrow band, to study z-pinch radiative structure and evolution
- Time-resolved x-ray spectroscopy to derive electron temperature and density of plasma
- Plasma polarization spectroscopy to extract information concerning plasma anisotropy
- X-ray Doppler spectroscopy to measure ion temperature
- Particle diagnostics to study generation of electron and ion beams in z-pinch and high energy γ and neutron flux

Utilize Leopard as diagnostic for z-pinch

NTF multi-terawatt lasers have a potential for development of dense z-pinch diagnostics, including the application of backlit techniques. New diagnostics could be deployed at the Zebra facility.

- X-ray radiography for probing of z-pinch plasma with electron density $>10^{20} \text{ cm}^{-3}$
- X-ray probing of the density structure and mass distribution in the stagnated pinch and dynamic effects in solid materials
- Monochromatic x-ray absorption for study of the plasma charge state

Implement other plasma diagnostics for z-pinch, for example:

- Proton radiography
- Thomson scattering

Proton radiography and deflectometry could deliver new data about the mass density, electrical and magnetic fields in z-pinch. The proton probing must be supported by other plasma diagnostics because of the complex contribution of many factors in z-pinch plasmas. Thomson scattering could be a powerful tool to study plasma turbulence and measure local plasma parameters in z-pinch. It is useful to characterize plasma temperature and density in experiments aimed at benchmarking spectroscopic diagnostics.

Coupled Leopard-Zebra experiments for High Intensity Laser Interaction

Zebra generates x-ray radiation with energies of 10-20 kJ and power $>0.5 \text{ TW}$, strong magnetic fields of $\sim 1 \text{ MG}$ (in a magnetic loop) and $\sim 3 \text{ MG}$ (in a z-pinch). It also produces dense plasmas with electron densities of 10^{18} - 10^{20} cm^{-3} and temperatures in the range of 10-400 eV. Planned experiments for magnetized plasmas, laboratory astrophysics, and material science have started for Zebra coupled with Leopard:

Experimental Support

- Isochoric heating of magnetized plasmas
- Expansion and instabilities of laser plasmas in strong magnetic fields
- Studies of propagation of high intensity laser radiation through plasmas in strong magnetic fields with applications to space and astrophysical plasmas
- Dynamic studies of solids in extreme conditions producing shocks
- Laser plasma studies with x-pinch

Theoretical Support

- Simulation of energy absorption and transport physics in ultra-short laser matter interaction
- Simulation of energy transfer and heating physics in extremely dense laser produced plasmas in high Z-charged state plasmas
- Theory and simulation of nonlinear effects during laser pulse transformation on the plasma boundary into electromagnetic mode, propagating in magnetized plasmas
- Kinetic and velocity shear effects on plasma flow in external magnetic fields
- Theory and simulation of laser energy conversion to particle acceleration in magnetized plasmas
- Simulation of isochoric heating
- Atomic processes in plasmas and plasma atomic kinetics
- Spectral line intensity modeling and radiation transport
- Magnetic sublevel kinetics and line polarization
- Stark-broadening of spectral line shapes, including magnetic field effects

The unique coupling of Zebra and Leopard for experiments gives the NTF the potential to become a world leader in high intensity laser interaction with magnetized plasmas. The magnetized plasma includes many complex loads on Zebra, which have been studied for optimized generation of x-rays.

Future upgrade of Zebra and Leopard

Leopard and Zebra could be further improved by more invasive and expensive upgrades.

Leopard Improvements

The Leopard laser operates on the wavelength of $\sim 1\mu\text{m}$ with the pulse duration $\sim 0.35\text{ ps}$ and energy 20 J. Future upgrades will improve the laser capability for intensity, contrast ratio, pulse duration range, and shot rate:

- Convert the radiation to the second harmonics for increasing the contrast ratio for experiments with solid targets
- Implement adaptive optics to improve the focal spot, increase the light intensity on the target to $>10^{19}\text{W/cm}^2$, and increase the shot rate
- Upgrade the Leopard (or Tomcat) laser to the long pulse regime (2-10ns)
- Implement compressed probe beam for plasma diagnostics

The upgrade to the long pulse regime will be used to study the propagation of laser radiation through a magnetized plasma, for the Thomson scattering diagnostic, the production of collisionless plasma flows, and the study of parametric instabilities in a magnetized plasma.

Zebra Upgrades

The Zebra generator operates with the 1-MA current pulse with 2 TW of power. Future upgrades can improve the current and power range for stability.

- Implement the current multiplier to increase the peak current at the load
- Increase the size of the vacuum chamber and modify the anode-cathode area to improve Zebra acceptance for different targets and diagnostics
- Implement a laser initiated gas switch for more accurate Zebra triggering, resulting in better synchronization between Zebra and Leopard pulses
- Upgrade the set of plasma diagnostics
- Improve the control of the current pulse and implement voltage measurement

These upgrades will significantly increase the Zebra capabilities for z-pinch experiments and joint experiments with Leopard.

Develop Collaboration

Previous collaborations will lead to new strategic alliances which will enhance the research agenda at the Nevada Terawatt Facility.

Experimental groups from the NTF, Department of Physics (UNR), Sandia National Laboratory, and University of Texas at Austin have carried out experiments at the NTF. Joint experiments were undertaken at outside facilities such as Cornell University, Los Alamos National Laboratory, Lawrence Livermore National Laboratory, LULI, University of California, Berkeley and Los Angeles, University of Michigan, and at other facilities. The NTF has supported strong theoretical collaborations with UCLA, SNL, LLNL, Air Force Research Laboratory and other institutions and universities. This resulted in a number of research publications between NTF scientists and outside collaborators.

Collaborating early on with researchers from other HEDP universities will promote the NTF capability and will result in attracting the best students to UNR / NTF. Well-chosen collaborators will be invaluable in strengthening and guiding the NTF scientific program. Researchers from HEDP national laboratories can advise the NTF about programmatic needs, in a timely and direct fashion.

VII Summary

This strategic plan defines and reveals the mission and vision for the Nevada Terawatt Facility. Its mission is to deliver well-trained graduates to sustain the National Laboratories and scientific research in the physics of high energy density plasmas. Its vision is to become a stably funded, preeminent user facility and science center in high energy density physics. The NTF should become the facility of choice for students studying z-pinch plasma physics and laser-plasma interaction in magnetized plasmas. Collaboration is a key element in achieving the above goals. Development of metrics consistent with the DOE/NNSA expectations to measure NTF scientific progress is an important tool for marking the progress to the NTF goals.

To reach the NTF vision, several strategic objectives were developed as a consequence of the workshop. In order to achieve these objectives, work at the NTF requires further focusing and follows the priorities as set forth. Two primary objectives involve increasing the number of degreed students and taking action to transform the NTF into a user facility. Additional objectives include a growing number of experiments addressing fundamental z-pinch physics, focusing on coupled Zebra-Leopard experiments and new theoretical and simulation approaches to explain future experimental results in z-pinches and magnetized laser-plasma interactions.

Below is a projected schedule of strategic milestones that the NTF is committed to achieving:

Milestones

2008

- Perform initial coupled experimental shots with Zebra and Leopard
- Continue experimental and theoretical program for Zebra
- Study Zebra and Leopard upgrades
- Select first model for a NTF user facility, to be confirmed by the NNSA DOE
- Install Cheetah (800 nm, 20 fs, 350 mJ laser)
- Begin scientific plan for Cheetah

2009

- Make necessary changes to Zebra, Leopard, and augment plasma diagnostics for user facility operation
- Improve coupled experimental shots with Zebra and Leopard
- Improve experimental and theoretical program for Zebra
- Initiate scientific experiments with Cheetah
- Complete the transformation from the current NTF to the selected user facility model and begin outside user experiments

2010

- To support regular outside user experiments
- Extend experimental shots with coupled Zebra and Leopard
- Improve scientific reach of experimental and theoretical program for Zebra
- Perform Cheetah scientific experiments
- Upgrade diagnostics to maintain state of the art