MATTER-RADIATION INTERACTIONS IN EXTREMES*

R. W. Garnett, M. S. Gulley, LANL, Los Alamos, New Mexico 87545, U.S.A.

Abstract

LANSCE has been the centerpiece of large-scale science at Los Alamos National Laboratory for many decades. Recently, funding has been obtained to ensure continued reliable operation of the LANSCE linac and to allow planning to enable the first in a new generation of scientific facilities for the materials community. The emphasis of this new facility is "Matter-Radiation Interactions in Extremes" (MaRIE) which will be used to discover and design the advanced materials needed to meet 21st century national security and energy security challenges. MaRIE will provide the tools scientists need to develop next-generation materials that will perform predictably and on-demand for currently unattainable lifetimes in extreme environments. The MaRIE facility is based on a high-power upgrade to the existing LANSCE proton linac, a new electron linac and associated X-ray FEL to provide additional probe beams, and new experimental areas. A pre-conceptual description of this new facility and its requirements will be presented.

INTRODUCTION

The LANSCE accelerator complex currently supports a broad user base including the neutron scattering community, basic science, and national security programs by providing multiple beams to several diverse experimental areas. The concept of MaRIE builds upon this successful experience by providing new capabilities at LANSCE that will transform the science of microstructure, interfaces, and defects of materials in extremes. Materials challenges in extremes span discovery science, energy security, and national security. MaRIE will provide the tools for transformational materials performance in extremes by enabling the transition from "observation and validation" to "prediction and control" of materials. This will be accomplished by providing the necessary extreme environments (pressure, temperature, radiation, etc.) coupled with multiple beam (protons and electrons), optical laser, and X-ray probes, and state-of-the-art diagnostics. Comprehensive and integrated capabilities for high-performance materials modelling and materials synthesis and control are also expected.

The scope of MaRIE presently includes the development of three new experimental areas, a 20-GeV electron linac as a driver for a new XFEL, and a high-power upgrade to the existing proton linac. These will be discussed in more detail below.

As is well-known, LANSCE is an aging accelerator facility. A plan to upgrade major components of the LANSCE accelerator complex that will ensure long-term reliability has been funded recently and is key to the success of MaRIE [1]. These "risk mitigation" efforts include modern DTL 201.25-MHz final power amplifiers and intermediate amplifiers, 45 new 805-MHz klystrons, modern low-level RF controls for all RF systems, more broadly implementing EPICS-based data acquisition and controls, modernization of the linac master timing system, improved wire scanners and beam position and phase monitors, and improvements to many mechanical systems such as vacuum and water-cooling systems. Execution of the work must occur in parallel to operating the facility in order to maintain a viable user program. Installation of equipment would occur during scheduled annual maintenance periods over a six-year period starting in FY2011, with an estimated completion date in FY2016.

* Work supported by the U. S. Department of Energy Contract DE-AC52-06NA25396.

INTEGRATED FACILITY APPROACH

A systems-engineering approach is being used to develop integrated facility requirements for MaRIE. This methodology provides clear traceability from science requirements derived from "first experiments" to facility concept definition including particle beam and X-ray specifications required to create the necessary extreme environments and probe beams. It is expected that through the use of this approach a more optimized and integrated facility concept will result.

One of the tools we are using to provide traceability between science requirements and facility requirements is the *Dynamic Object-Oriented Requirements System* (DOORS) [2]. This is a commercially-available database system that has been used successfully by many projects. This database allows the user to set up a hierarchal structure that can be linked at all levels as necessary to generate the desired traceability.

NEW EXPERIMENTAL CAPABILITY

Three new experimental areas are proposed as part of the MaRIE concept. Each of these areas will have a different materials-in-extremes focus.

Multi-Probe Diagnostics Hall (MPDH)

The focus of the MPDH experimental area will be to study micro- and meso-scale systems in extreme dynamic environments. The types of experiments performed will include the response of multi-granular material to dynamic deformation, 3-D measurements of flow and turbulence, and extreme field interactions with matter. Spatial resolutions on the micron scale and time resolution in the 100-ps range are required.

Extreme environments in MPDH will be produced using high-explosives-driven gas guns and flyer plates, high magnetic fields and high-power laser systems. MPDH includes experimental hutches with multiple probe beams: a high-power laser system, a 20-GeV

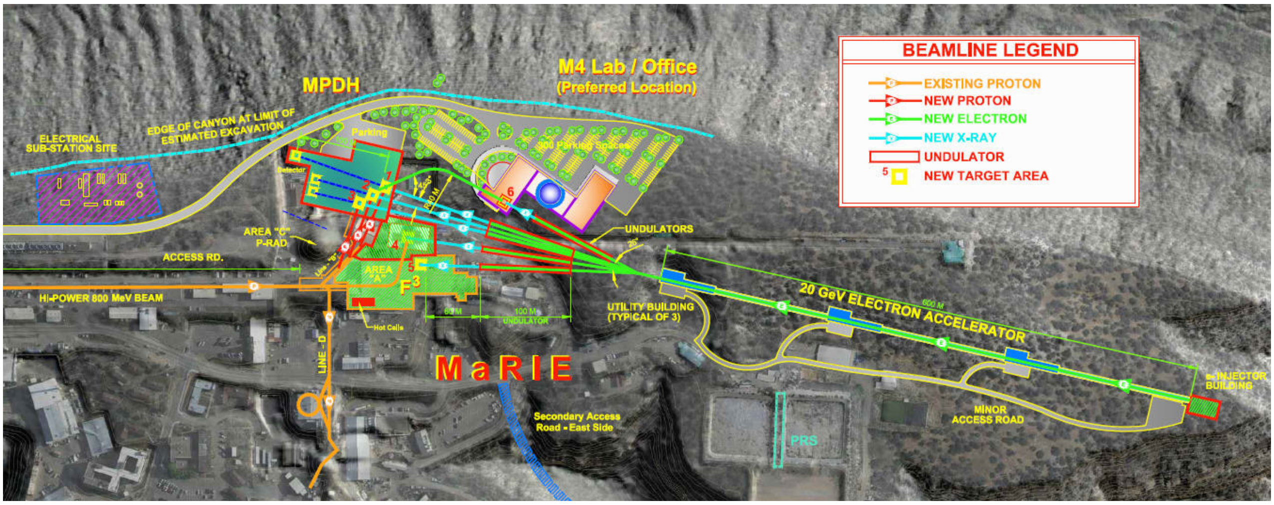

Figure 1: Aerial view of LANSCE showing the conceptual layout of the accelerator and experimental facility enhancements that comprise MaRIE. A proposed location of the 20-GeV electron linac and associated XFEL undulator lines are shown as are the three new experimental areas: the Multi-Probe Diagnostics Hall (MPDH), the Fission-Fusion Materials Facility (F^3) and the Making, Measuring, and Modelling Materials Facility (M4).

electron beam, a 50-100 keV X-ray beam, and a high-energy proton beam. The probe beams will be used for radiographic imaging or diffraction imaging. Fig. 1 shows the MaRIE conceptual layout including MPDH and its associated electron, proton, and X-ray undulator lines.

Fission-Fusion Materials Facility (F^3)

The F^3 facility will provide the ability to do in-situ measurements of samples in an intense fast-neutron environment (10^{15} n/cm^2/ sec) while probing the samples using proton radiography or X-ray imaging techniques. The concept for the F^3 irradiation area is based on the Materials Test Station (MTS) Project spallation target design [3] and a 2.0-MW upgrade to the LANSCE proton beam power. F^3 will also allow for removal of samples for near-in-situ examination using X-rays and protons and post-irradiation examination in a hot-cell environment.

Experiments performed at F^3 hope to address issues related to fast-reactor pellet-fuel combinations such as stress, microstructure stability and cracking, material fatigue, swelling, and corrosion. Fundamental radiation damage phenomena will also be studied with the goal of improving materials for future fission and fusion reactors.

Making, Measuring, and Modelling Materials Facility (M4)

The focus of the M4 facility will be to accelerate complex materials design through the integration of advanced synthesis, including single crystal growth, in situ characterization, and theory. The M4 facility will house advanced computing and visualization capabilities along with laboratories for materials characterization and processing. This facility will include an X-ray end station for in-situ measurements during materials synthesis.

20-GEV ELECTRON LINAC AND XFEL

A new 20-GeV electron linac is proposed for MaRIE that will provide a beam for electron radiography in the MPDH experimental area as well as a driver for an X-ray free-electron laser (XFEL) based light source that will drive multiple undulators providing X-rays to the three new experimental areas. This x-band, 11.4-GHz electron linac is based on expected NLC performance [4]. Preliminary parameters are shown below in Table 1. Detailed design and simulations to support this choice of parameters have not yet been done. The expected XFEL performance is based on LCLS XFEL baseline operational and performance parameters [5].

2-MW PROTON BEAM UPGRADE

Upgrade options for the high-power proton beam at LANSCE are being considered and are only preliminary at this time [6]. These options take into consideration limitations of the existing linac structures, trade-offs between increasing average beam current and beam energy, and technical readiness of implementation of each option. Cost will be considered in the future. Increasing the proton beam power directly impacts the performance of the MTS spallation target system and could impact the performance of proton radiography if an option is selected that increases the final beam energy to greater than 800 MeV. Two possible upgrade options are shown in Table 2.

Option 1 requires improvements in the 201.25-MHz drift-tube linac (DTL) tuning to reduce field errors that limit higher power operations. Replacement of the existing 750-kV Cockcroft-Walton injector with a 201.25-MHz RFQ is also required. Although new 805-MHz klystrons will be installed for most of the coupled-cavity linac (CCL), these klystrons may not be capable of operating at the required higher duty factor for 2 MW. They would need to be evaluated in a test stand to determine if long-term reliable operation could be achieved operating so close to their design point. The preferred approach would be to replace the klystrons with units capable of providing the RF power requirements with reasonable operating margin. The HVDC power systems that provide the cathode voltage to the klystrons would also need to be improved to support operation at higher duty factors. Both conventional systems and a converter-modulator system similar to that developed for the Spallation Neutron Source (SNS) will be considered.

Option 2 requires essentially the same upgrades as discussed for Option 1, however this option relaxes the required peak beam current and beam and RF duty factors since the final beam energy is increased to 1.5 GeV using SNS-like superconducting (SC) cryomodules to provide the higher 2-MW beam power. This option also requires increasing the number of klystrons to provide additional power for the SC linac. The approximate peak power that each klystron would need to deliver is less than 250 kW. Allowing for control margin, it should be possible to support the new, lower-power klystrons for the SC linac with the existing LANSCE high-voltage system as currently installed in these sectors. No changes would be required to the existing RF system for the DTL or the CCL to support this 2- MW option. Additional beam switchyard and other modifications would also be necessary to preserve all existing modes of operation.

REFERENCES

[1] John L. Erickson, et al "Status of the LANSCE Refurbishment Project," ICANS XIX, Grindelwald, Switzerland, March 8-12, 2010.
[2] http://www-01.ibm.com/software/awdtools/doors/.
[3] E. J. Pitcher, "The materials test station: A fast-spectrum irradiation facility," Journal of Nuclear Materials, Vol. 377, Issue 1, 30 June 2008, p. 17.
[4] T. Raubenheimer, et al., "Parameters of the SLAC Next Linear Collider," PAC'95 , Dallas, Texas, May 1-5, 1995, p. 698.
[5] LCLS Conceptual Design Report, SLAC-R-593, April 8, 2002.
[6] L. Rybarcyk, et al., "Technical Options for High-Power Beams," LANL AOT Division internal report.

Table 1: Preliminary 20-GeV Electron Linac and XFEL Specifications Based on NLC and LCLS Performance

Linac	
Energy	20 GeV
RF Frequency	11.4 GHz
Structure Type	Room Temp. Copper
Cavity Gradient	70 MV/m
Max. Beam Bend Angle	20 degrees
Bunch Compressor 1/2	6 meters/22 meters
RF Pulse Duration/Rep. Rate	3 microseconds/10Hz
Beam Power /Total Power	30 kW/2MW
Active Length/Total Length	284 meters/386 meters
Electron Beam	
Source Technology	Photoinjector
Pulse Length (XFEL/eRAD)	30 fs/10ps
Emittance (XFEL/eRAD)	0.4μm/1000 μm (norm.)
Pulse Charge (XFEL/eRAD)	0.1nC/3nC
No. Pulses (XFEL/eRAD)	1000/30
Energy Spread (XFEL/eRAD)	0.004%/0.25%
Undulator	
Length/Period	80 meters/2.4 cm
Peak Magnetic Field	0.93 Tesla

Table 2: 2-MW Upgrade Options

Option	Requirements	Rep Rate (Hz)	Beam Pulse Length (μs)	RF Duty Factor (%) DTL, CCL, SCL	E_{final} (GeV)	I_{peak} (mA)	I_{avg} (mA)	SC cryomodules/ klystrons
2-MW Option 1	Fix DTL field errors, Increase duty factor & peak beam current, 201.25-MHz RFQ, upgrade HPRF & HVDC	100	922	13.2, 12.3, N/A	0.8	27.5	2.5	N/A
2-MW Option 2	Increase duty factor & peak beam current, add 201.25-MHz RFQ, HPRF & HVDC, increase final beam energy	100	788	12.4, 10.9, 9.7	1.5	17.0	1.33	18/72