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PERFORMANCE REQUIREMENTS FOR THE LANSCE ACCELERATOR MODERNIZATION PROJECT*

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Abstract

The LANSCE accelerator concurrently accelerates two beam species, H^+ and H^-, and delivers beam to five distinct user stations, including slow and fast neutron scattering centers, ultra-cold neutron research, proton radiography, and isotope production. The LANSCE Accelerator Modernization Project (LAMP) will replace the initial sections of LANSCE, from the ion sources through the end of the 100-MeV drift-tube linac. The combination of multiple user stations, and the unique operation of LANSCE, present unique challenges and opportunities.

In this paper, we present the performance requirements for LAMP, an overview of the project status and timeline, an overview of the conceptual design, and outlook.

PERFORMANCE REQUIREMENTS

The LANSCE accelerator, shown in Fig. 1, presently uses Cockcroft-Walton DC injectors, supplying H^+ and H^- beams at 750 keV to a drift-tube linear accelerator (DTL). The H^+ beam is split off at 100 MeV to supply the Isotope Production Facility (IPF); the H^- beam is accelerated to 800 MeV by a cavity-coupled linac, and directed to one of the remaining four user facilities: Proton Radiography (pRad); Ultra-Cold Neutrons (UCN); Weapons Neutron Research (WNR); and the Lujan Neutron Scattering Center (Lujan). Figure 1 shows an overall depiction of the facility.

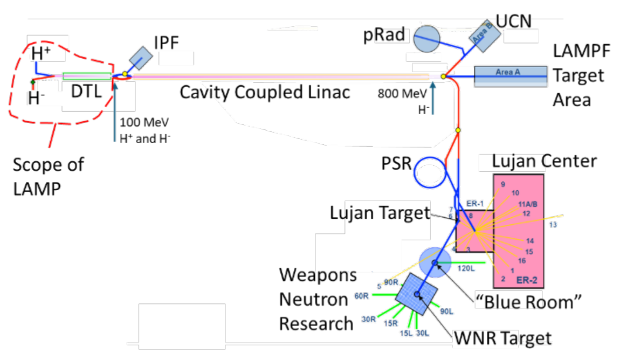

Figure 1: An overview of the LANSCE accelerator and user facilities. See text above for acronym definitions.

LANSCE generates 625-µs beam macropulses at a repetition rate of 120 Hz, with macropulses being interleaved between the various user facilities. During typical operations, Lujan receives beam at 20 Hz; the remaining 100 pulses per second are used to concurrently accelerate H^+ and H^- beams directed to IPF and WNR, respectively.

The LANSCE Accelerator Modernization project (LAMP) will replace the upstream portions of the 50-year-old LANSCE accelerator, from the ion sources through the end of the drift-tube linac. The project has multiple performance requirements in terms of beam delivery to the various user facilities, as well as general goals for availability, uptime, etc., and are specified in the LAMP Program Requirements Document [1].

General Requirements

LAMP must supply H^+ and H^- ion beams at 100 MeV, with the proper timing structure, peak and average beam current for each of the LANSCE user facilities. This requires high flexibility in macropulse bunch pattern generation.

LAMP must be designed to support 5300 beam hours of operation per annual run cycle with greater than 90% availability. (As LAMP scope extends only through the end of the DTL, the distinction between "support" versus "deliver" is important to make.) This requirement has implications for beam loss downstream of LAMP, and thus parameters such as beam emittance, to which the majority of LANSCE user stations are otherwise insensitive.

Finally, as a "soft" condition, LAMP will work towards developing a design that not require modification of the physical infrastructure of the LANSCE site. This includes, for instance, attempting to stay within the cooling and electrical power capacity of the existing facility; modifications to existing buildings – shielding enclosures and outer walls in particular – are also to be avoided. Figure 2 shows a CAD model of the LAMP conceptual design in the existing LANSCE accelerator vault.

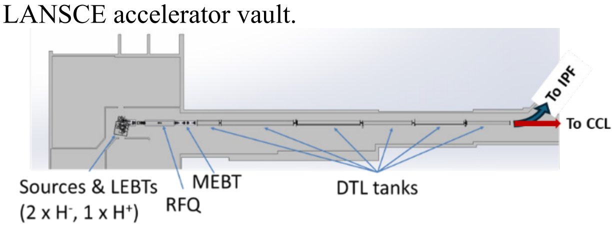

Figure 2: The LAMP conceptual physics design overlaid onto the existing LANSCE vault and building envelope.

Isotope Production Facility

The Isotope Production Facility (IPF) produces isotopes for the US medical isotope program, as well as for various research and characterization efforts.

IPF requires an average beam current of 250 µA, delivered at a rate of 100, 625-µs macropulses per second. H^+ beams for IPF are accelerated concurrently through the

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DTL with H^- beam for WNR. The transition region between the DTL and CCL magnetically separates the two species, directing the H^+ beam to IPF and the H^- beam to the CCL for acceleration to 800 MeV.

Weapons Neutron Research (WNR)

The WNR facility is used to perform fast neutron (energies above ~ 1 MeV) imaging, reaction studies, and radiation effects on electronics. A high-charge proton bunch of approximately 115 pC is delivered to the unmoderated WNR target every 1.8 µs during a macropulse; the bunch-to-bunch separation facilitates energy-resolved measurements via time-of-flight from target to experiment. Macropulses are repeated at 100 pulses per second, as a series of 5 pulses at 120 Hz followed by a "skipped" pulse. The average beam current to WNR is nominally 4 µA under typical operation.

Experimental resolution at WNR is limited by the presence of "satellite" pulses, or charge in the buckets immediately adjacent to the individual 115-pC pulses. LAMP must ensure that satellite bunches must contain no more than 0.1 pC, and that the overall "dark current" in the macropulse is less than 0.01% of total beam current [2]

Lujan Center

The Lujan Center performs materials characterization using neutron scattering, energy-resolved neutron imaging, nuclear reaction studies, and fundamental physics. Lujan has a moderated target, and is optimized for experiments making use of neutron energies below approximately 1 MeV.

At 20 Hz, beam is directed from the LANSCE linac into the proton storage ring (PSR) and accumulated over the course of a 625-µs macropulse. The accumulated charge is delivered to the Lujan target as a single, 5-µC bunch.

Linac macropulses delivered to the PSR are formatted to incorporate an extraction gap of approximately ¼ the PSR revolution period of 360 ns. During a macropulse, "minipulses" with 10-mA average current, lasting for 290 ns, are interlaced with 70-ns blank times with no beam current, as shown in Fig. 3.

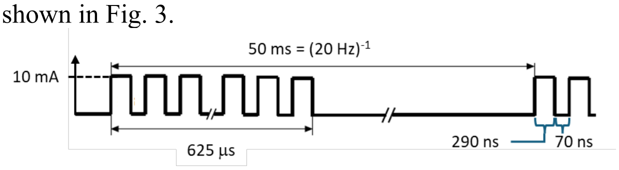

Figure 3: Time structure of the Lujan macropulse.

Proton Radiography (pRad)

The Proton Radiography facility provides the ability to take movies of dynamic events such as shock and detonation events, with unique features such as support of high-hazard activities such as explosives.

pRad receives beam in an "on-demand" fashion for either imaging shots or beamline tune-up. As the nature of the experiments change, both the number and timing of the "frames" used to generate images must be variable.

A typical pRad "frame" is defined as a series of microbunches spaced at 201.25 MHz (the frequency of the DTL), with ~50 pC per bunch. Each "frame" is approximately 96 ns, or 19 bunches, in duration. A macropulse consists of typically 20 – 40 frames with variable timing between frames. A "precursor" bunch is also delivered at the beginning of the macropulse. The precursor bunch provides a trigger to initiate the dynamic processes to be imaged, e.g. triggering a powder gun or pulsed-power implosion [3]. Figure 4 illustrates a notional pRad macropulse structure.

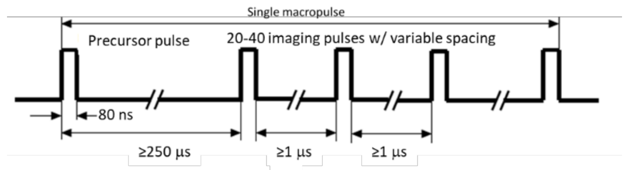

Figure 4: Proton radiography macropulse format.

Ultra-Cold Neutron

The Ultracold Neutron (UCN) facility provides the lowest-energy neutrons at LANSCE, less than 300 neV, for fundamental science studies including neutron beta-decay correlations, neutron lifetime, and the neutron electric dipole moment. Nominal UCN run conditions are up to 10 µA average beam current, delivered as a macropulse chain. Every 5 seconds, a series of 9 to 11 macropulses are delivered at 20 Hz, for a total "chain" duration of approximately ½ seconds. The UCN macropulse structure is similar to that delivered to the PSR for Lujan.

Blue Room

Nominally a part of the WNR facility, The "Blue Room," located upstream of the WNR spallation target, allows direct access to the proton beam for space radiation studies, diagnostic development, and other experiments. Beam power deposited in the Blue Room is limited by local radiation shielding; beam structure within the macropulse must be configurable to meet the needs of the experiment in question.

PROJECT STATUS

The LAMP project received Critical Decision (CD)-0, Acknowledgement of Mission Need, in late November 2024. As of this writing the Project has completed its conceptual physics design and is finalizing the Conceptual Design Report. We are anticipating CD-1 in mid-2026, at which point we will formally begin the preliminary-to-final design process.

LAMP Conceptual Design

The LAMP conceptual design incorporates a single H^+ ion source to provide beam for IPF, an SNS-type H^- ion source producing 35-mA beam currents to provide the required per-bunch charge for the WNR facility, and a 16-mA SNS-type H^- source to provide beams for the remaining LANSCE user facilities. The H^- beams are merged by a pulsed dipole; a DC dipole is used to merge the H^+ and H^- transport lines into a single radio-frequency quadrupole (RFQ), which accelerates the beams from 100 keV to 3 MeV. The transport line between the RFQ and DTL

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incorporates fast choppers to ensure the required WNR signal-to-noise levels are maintained. The LAMP conceptual design uses a 6-tank DTL to accelerate to beam to 100 MeV; focusing is provided by permanent magnet quadrupoles placed in every other drift tube. Please see, for instance, [4] and [5] for additional details of the front-end, multiple source concept, and the beam chopping scheme, respectively.

Technology Maturation

The US Department of Energy has specific criteria for the Technical Readiness Levels (TRLs) of Critical Technology Elements (CTEs) at the various CD stages of a project [6]. The project has performed an initial internal assessment of CTEs based on the conceptual design [7]. To ensure LAMP meets the criteria for technological maturity, the project is developing two test stands. The RFQ test stand (RFQTS) is intended to provide initial demonstrations of key features of the LAMP conceptual design, specifically, direct injection and capture of a prebunched beam into an RFQ, and concurrent capture and acceleration of both H^+ and H^- beams in a single RFQ. The RFQTS is making use of existing sources and a 750-keV RFQ, so will not provide a full-scale demonstration of LAMP performance, but is a vital tool for validating simulation results and demonstrating key proof-of-concept approaches. The RFQTS is under construction currently and is expected to be generating beam by the end of the 2025 calendar year.

The LAMP in ADEF Tunnel (LAT) test stand is intended to be a full-scale version of the LAMP conceptual design, from sources through the end of the first DTL tank. To be constructed in the ADEF (formerly LEDA) tunnel, LAT will enable both verification that CTEs have reached sufficient technical maturity, and demonstration of the required operating modes for LAMP to meet its program requirements. That is, LAT is intended to demonstrate the full range of macropulse timing, interleaving, and formatting as will be required for the LAMP upgrade.

Project Timeline

As mentioned, the project received CD-0 in November 2024, and is presently preparing for a review of the conceptual physics design. An internal review has identified several critical technology elements and is designing and constructing test stands to ensure the requisite maturity levels at the appropriate points along the project's life cycle.

The RFQTS is expected to demonstrate bunch-beam RFQ injection in 2026. The design process for LAT will also commence at the start of the 2026 fiscal year. In 2027, the RFQTS will demonstrate dual-species acceleration, and LAT will begin preparations for installation into the ADEF tunnel.

With first beam anticipated in 2028, the LAT experimental campaign should conclude by 2030.

Finally, a 2-year shutdown for LANSCE front-end removal, and LAMP installation, is expected to start in 2031. The commissioning process is expected to benefit significantly from experience with LAT, and should commence in 2033, followed by transition to operations and project closeout.

CONCLUSIONS

The LAMP project will replace the current "front end" of the LANSCE accelerator, sources through the end of the drift-tube linac, with a multi-source, RFQ-based injector and new DTL. LAMP will provide the LANSCE user facility complex with beam intensities commensurate with current operational modes, while concurrently improving uptime and maintainability. The LAMP conceptual physics design meets all beam delivery requirements.

To ensure all key areas of technology are demonstrated prior to the start of construction, LAMP is constructing two test stands, the RFQTS and LAT. The RFQTS will demonstrate key aspects of the LAMP conceptual design, albeit at a subscale; LAT will provide a full-energy and -current demonstration of the initial portions of LAMP, along with the requisite macropulse timing structures required to support the LANSCE user facility complex.

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