High-Power Options for LANSCE


Accelerator Operations and Technology Division

E. J. Pitcher

Materials Test Station Project Office, Los Alamos Neutron Science Center

Los Alamos National Laboratory

2011 Particle Accelerator Conference

New York, New York

March 31, 2011
Abstract

The LANSCE linear accelerator at Los Alamos National Laboratory has a long history of successful beam operations at 800 kW. We have recently studied options for restoration of high-power operations including approaches for increasing the performance to multi-MW levels. In this paper we will discuss the results of this study including the present limitations of the existing accelerating structures at LANSCE, and the high-voltage and RF systems that drive them. Several options will be discussed and a preferred option will be presented that will 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.
Outline

• LANSCE Facility Overview
• Motivation – MTS & MaRIE/FFMF
• Existing Limitations
• High-Power Options
• Our Preferred Option
LANSCE Facility Overview

- **Isotope Production Facility**
- **Proton Radiography**
- **Ultra-Cold Neutrons**

**750-keV Cockcroft-Walton Injectors**

- **H**
- **H**

- **201.25-MHz 100-MeV Drift Tube Linac**

- **805-MHz 800-MeV Coupled-Cavity Linac**
  - 750 keV \( H^+ \) and \( H^- \) Injectors
  - 100 MeV Drift Tube Linac (4 tanks)
  - 800 MeV Coupled Cavity Linac (44 modules)
  - 800 MeV Compressor Ring (PSR)

**Isotope Production Facility**

**Proton Radiography**

**Ultra-Cold Neutrons**

**Area A (inactive - future home of MTS/FFMF)**

---

**Table:**

<table>
<thead>
<tr>
<th>Area</th>
<th>Typical Repetition Rate [Hz]</th>
<th>Typical Pulse Length [( \mu \text{s} )]</th>
<th>Linac Beam Species</th>
<th>Typical Chopping Pattern</th>
<th>Average Beam Current [( \mu \text{A} )]</th>
<th>Nominal Energy [MeV]</th>
<th>Avg Beam Power [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lujan</td>
<td>20</td>
<td>625</td>
<td>H-</td>
<td>290 ns/358 ns</td>
<td>100 - 125</td>
<td>800</td>
<td>80 - 100</td>
</tr>
<tr>
<td>WNR Tg4</td>
<td>(&lt;40)</td>
<td>625</td>
<td>H-</td>
<td>1 ( \mu \text{pulse} ) every (&lt;1.8 \mu \text{s})</td>
<td>(&lt;2)</td>
<td>800</td>
<td>(&lt;1.6)</td>
</tr>
<tr>
<td>UCN</td>
<td>20</td>
<td>625</td>
<td>H-</td>
<td>Lujan-beam like to unchopped</td>
<td>(&lt;5)</td>
<td>800</td>
<td>(&lt;4)</td>
</tr>
<tr>
<td>pRad</td>
<td>(&lt;1)</td>
<td>625</td>
<td>H-</td>
<td>60 ns bursts every (&lt;1 \mu \text{s})</td>
<td>(&lt;1)</td>
<td>(&lt;800)</td>
<td>(&lt;1)</td>
</tr>
<tr>
<td>IPF</td>
<td>(&lt;30) in Pulsed mode</td>
<td>625</td>
<td>H+</td>
<td>( \text{NA} )</td>
<td>(&lt;250)</td>
<td>100</td>
<td>(&lt;25)</td>
</tr>
<tr>
<td>Area A inactive</td>
<td>(&lt;100)</td>
<td>625</td>
<td>H+</td>
<td>( \text{NA} )</td>
<td>1000</td>
<td>800</td>
<td>(&lt;800)</td>
</tr>
</tbody>
</table>

---

**Diagram:**

- **Lujan Center**
- **PSR**
- **Targets 1, 2, 4**
- **Weapons Neutron Research Facility**
Linac Performance - Historical, Demonstrated & Present

- **Historical Performance**
  - 120 Hz x 625 µs beam gates; 7.5% duty factor (100-Hz H\(^\pm\), 20-Hz H\(^-\))
  - Combined and simultaneous H\(^+\)/H\(^-\) operation (limited by peak RF power)
  - Typical maximum peak beam current (H\(^+\)): 16.5 mA
  - RF duty factor: ~10%
  - 800-kW average beam power (800 MeV, 1-mA average H\(^+\) current)
  - High-power operation halted in 1998

- **Demonstrated Performance (non-coincident, H\(^+\) only)**
  - RF duty factor: ~12% (1980’s?)
  - Beam gates: 1225 µs (800 MeV, 80 Hz, LPSS Demo 1996)
  - Peak H\(^+\) beam current: 21 mA (800 MeV, LPSS Demo 1996)
  - *Demonstrated 1-MW Average to Area A (800 MeV, 120-Hz H\(^+\), 1983)*

- **Present Performance**
  - 60 Hz Operation (limited by 7835 in DTL 201-MHz RF system)

---

Path to Future High-Power Operations

- LANSCE Risk Mitigation
- MTS 1 MW
- MaRIE/FFMF 2 MW
Linac Risk-Mitigation efforts will enable a return to high-power operations by 2016 – Restores 120-Hz capability.

Linac Risk Mitigation plans will provide needed linac modernization by 2016.

Install modern, maintainable Instrumentation & Control and Diagnostics systems

Refurbish the 805-MHz RF amplifier systems for the Coupled Cavity Linac (100 - 800 MeV)

Remediate accelerator structures, supporting equipment and power supplies

Replace the 201-MHz RF system for the Drift Tube Linac (0.75 - 100 MeV) to restore 120-Hz operation

201.25-MHz RFQ Test Stand / Front-End Replacement

Risk Mitigation Projects will ensure reliable operations and enable high-power applications.

Multi-Year Effort & Funding: FY09-FY11 $40.3M, FY12-FY17 $20M-$30M/yr
Matter-Radiation Interactions in Extremes (MaRIE) is the LANSCE future.

MaRIE includes:
- 20-GeV Electron Linac / XFEL
- Beam Power Upgrade to 2 MW
- Enhanced Experimental Capabilities
Our motivation to deliver higher-power beams is to produce intense neutrons for MTS and FFMF.

• 1 MW – Materials Test Station (MTS)
  - Baseline design for the MTS; achieves 4.5% per calendar year fuel burn-up in highly enriched fuel and 18 dpa/yr damage in steels.
  - 800 MeV, 4400 hrs of full beam power/year

• 2 MW – Fission-Fusion Materials Facility (FFMF) / IFMIF Equivalent
  - IFMIF equivalent neutron flux and irradiation volume; 50 dpa/FPY and 0.3 liter with >20 dpa
  - Achieves $2.5 \times 10^{15}$ n/cm²/s peak flux in fuel irradiation region, 6%/yr fuel burn-up, 28 dpa/yr in iron.
  - Rep Rate ≥ 100 Hz, Pulse Length ≥ 0.75 ms, 800 MeV ≥ Energy ≤ 3 GeV

• 5 MW – FFMF / JOYO Equivalent
  - Achieves peak neutron flux of $5 \times 10^{15}$ n/cm²/s
  - Would be highest neutron flux in the world; equivalent to JOYO reactor; exceeds BOR-60 ($3.4 \times 10^{15}$ n/cm²/s)
  - Same operational parameters as 2 MW (rep rate, etc.)
The Materials Test Station (MTS) will enable testing fission reactor fuels and structural materials in a fast-neutron environment.

- LBE Target
- 1-MW LANSCE beam will produce $10^{17}$ neutrons/sec.

The MTS/FFMF is the next high-power mission for LANSCE.

Calculated displacement and helium production rates in the MTS at (a) 1-MW and (b) 2-MW beam powers. Also shown is the parameter space covered by the IFMIF-HFTM (blue ellipse).

E. J. Pitcher, “Fusion materials irradiations at MaRIE’s fission fusion facility,” *Fusion Engineering and Design* (2011)
Operated by the Los Alamos National Security, LLC for the DOE/NNSA

Neutron environment requirements and accelerator system reliability/availability drive upgrade paths.

- CD-0 FFMF irradiation requirement is 15 dpa/year in 0.1 liter volume.
- 4500 hours/year scheduled beam
- ~3900 hours on target (87% reliability assumed): Requires ~2-MW beam power.

Historical average high-power beam reliability is ~87%
Some simple assumptions were made to develop the high-power options.

- Free parameters to increase beam power include:
  - RF duty factor
  - peak beam current
  - final beam energy

- To reduce cost impacts use existing structures, if possible.

- Operational systems and existing structures constraint the RF duty factor.

**ANSYS Calculations**
show plastic deformation of CCL cavities at 15% RF duty factor. (2009)

**COSMOS model of DTL stem bellows**
shows that under conditions of poor thermal contact melting could occur above 15% RF duty factor. (2005)
Operational and accelerator structure limits constrain the upgrade paths to higher average beam power.

Maximum Safe RF Duty-Factor Limits for the LANSCE Linac Structures and RF Systems

<table>
<thead>
<tr>
<th>RF Duty Factor</th>
<th>DTL 12.4% (structure limited)</th>
<th>CCL 12.2% (structure limited)</th>
<th>201.25 MHz (HVDC PS) 11.8% (10% beam) – Present</th>
<th>805 MHz (Klystron) 12.0% (120 Hz, 1 ms)</th>
</tr>
</thead>
</table>

- **DTL**
  - Poor thermal contact / poor cooling of bellows on drift-tube stems.
  - Post-coupler heating may also contribute.
  - Significant field errors (measured vs. design at location of tuning slugs)
  - Operating set-point errors (assumed ±5% assumed)

- **CCL**
  - Structures cooled via external cooling channels.
  - Need to avoid plastic deformation (15% limit)
  - Bead pull measurement reveals ±6% field amplitude variations
  - Operating set-point errors (assumed ±5% assumed)

- **Klystron** peak-power and power supply name-plate ratings limit RF duty factor.
# High-Power Upgrade Options (All assume 100-Hz rep rate, H+)

<table>
<thead>
<tr>
<th>Option</th>
<th>Beam Power (MW)</th>
<th>Requirements</th>
<th>Beam Pulse Length (µs)</th>
<th>RF Duty Factor (%) DTL, CCL, SCL</th>
<th>E&lt;sub&gt;final&lt;/sub&gt; (GeV)</th>
<th>I&lt;sub&gt;peak&lt;/sub&gt; (mA)</th>
<th>I&lt;sub&gt;avg&lt;/sub&gt; (mA)</th>
<th>SC cryomodules/klystrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-MW Options</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Increase duty factor</td>
<td>770</td>
<td>12.3, 10.8, N/A</td>
<td>0.8</td>
<td>16.5</td>
<td>1.25</td>
<td>N/A</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Increase duty factor &amp; peak beam current</td>
<td>688</td>
<td>11.3, 9.8, N/A</td>
<td>0.8</td>
<td>18.5</td>
<td>1.25</td>
<td>N/A</td>
</tr>
<tr>
<td>Max. Beam Power</td>
<td>1.16</td>
<td>Increase duty factor &amp; peak current</td>
<td>797</td>
<td>12.4, 11.0, N/A</td>
<td>0.8</td>
<td>18.5</td>
<td>1.45</td>
<td>N/A</td>
</tr>
<tr>
<td>2-MW Options</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Fix DTL field errors, increase duty factor &amp; peak beam current, add 201.25-MHz RFQ, upgrade HPRF &amp; HVDC</td>
<td>922</td>
<td>13.2, 12.3, N/A</td>
<td>0.8</td>
<td>27.5</td>
<td>2.5</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Increase duty factor &amp; peak beam current, add 201.25-MHz RFQ, upgrade HPRF &amp; HVDC, increase final beam energy</td>
<td>788</td>
<td>12.4, 10.9, 9.7</td>
<td>1.5</td>
<td>17.0</td>
<td>1.33</td>
<td>18/72</td>
</tr>
<tr>
<td>5-MW Options, Not Viable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Increase peak beam current, increased RF power to CCL</td>
<td>913</td>
<td>TBD</td>
<td>1.5</td>
<td>37.0</td>
<td>3.3</td>
<td>18/72</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Increase final beam energy, increase peak beam current, add 402.5-MHz RFQ &amp; 402.5-MHz DTL, Upgrade HPRF, HVDC</td>
<td>913</td>
<td>TBD</td>
<td>2.0</td>
<td>28.0</td>
<td>2.5</td>
<td>25/100</td>
</tr>
</tbody>
</table>

Risk mitigation efforts will restore 1-MW capability.

This is our preferred option that meets the 2-MW MTS/FFMF requirements.

Beyond 2 MW requires significant upgrades.
The Preferred 2-MW Option (baseline)

- 201.25-MHz RFQ type TBD.
- 18 SNS-like, 805-MHz, $\beta=0.81$ ($E_0T=15.8$ MV/m) SC cryomodules
- Requires replacement of CCL high-power RF systems with 72 (18 x 4; 4 cavities/cryomodule) lower-power klystrons – alternatives to be explored.
- Preliminary beam dynamics simulations completed – detailed end-to-end simulations planned.
- Final Beam Energy = 1.5 GeV

<table>
<thead>
<tr>
<th>Beam Pulse Length ($\mu$s)</th>
<th>RF Duty Factor (%)</th>
<th>$E_{\text{final}}$ (GeV)</th>
<th>$I_{\text{peak}}$ (mA)</th>
<th>$I_{\text{avg}}$ (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>788</td>
<td>12.4, 10.9, 9.7</td>
<td>1.5</td>
<td>17.0</td>
<td>1.33</td>
</tr>
</tbody>
</table>
Preferred 2-MW option has many advantages.

- One-for-one replacement of a CCL module with an SNS-like SC cryomodule.
- Uses existing tunnel wave-guide penetrations – minimizes waveguide runs.
- Uses existing klystron galleries.
- Takes advantage of SNS design, non-reoccurring engineering, and R&D.
- Upgradeable to higher beam powers.
Questions?