High-Power Options for LANSCE

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2011 Particle Accelerator Conference
New York, New York
March 31, 2011

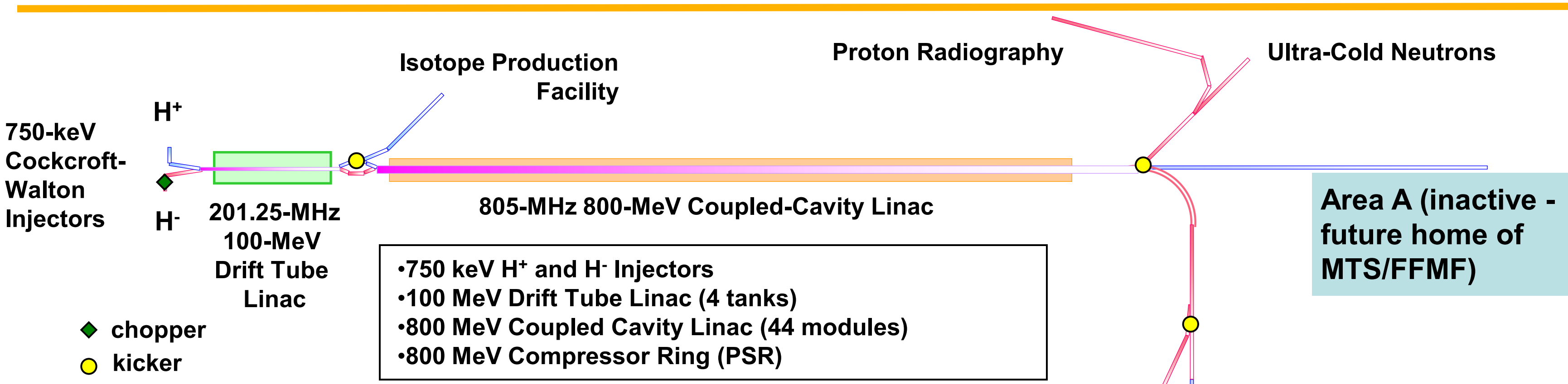
Abstract

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

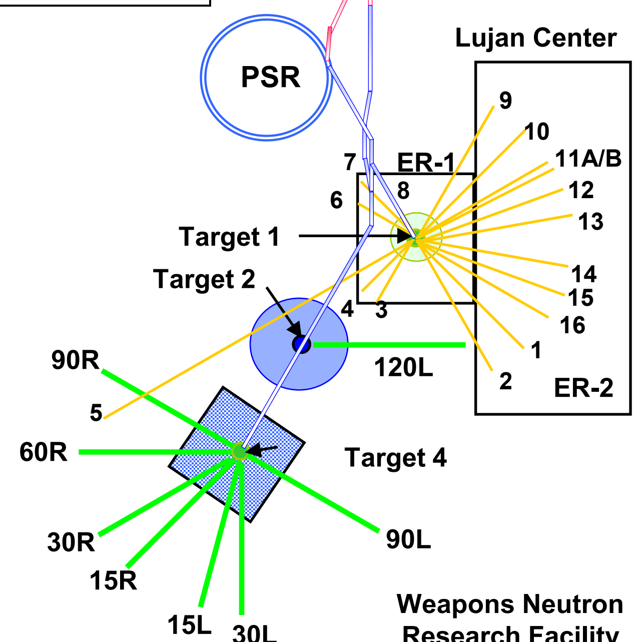
- LANSCE Facility Overview
- Motivation – MTS & MaRIE/FFMF
- Existing Limitations
- High-Power Options
- Our Preferred Option

LANSCE Facility Overview



- •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)

Area	Typical Repetition Rate [Hz]	Typical Pulse Length [µs]	Linac Beam Species	Typical Chopping Pattern	Average Beam Current [µA]	Nominal Energy [MeV]	Avg Beam Power [kW]
Lujan	20	625	H-	290 ns/358 ns	100 -125	800	80 - 100
WNR Tgt4	≤40	625	H-	1 µpulse every ~1.8 µs	≤ 2	800	< 1.6
UCN	20	625	H-	Lujan-beam like to unchopped	< 5	800	< 4
pRad	~1	625	H-	60 ns bursts every ~1 µs	< 1	≤800	< 1
IPF	≤30 in Pulsed mode	625	H+	NA	≤ 250	100	≤ 25
AreaA inactive	≤100	625	H+	NA	1000	800	~ 800



Linac Performance - Historical, Demonstrated & Present

- **Historical Performance**
  - 120 Hz x 625 μs beam gates; 7.5% duty factor (100-Hz H^+, 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 1MW → MaRIE/FFMF 2 MW

Linac Risk-Mitigation efforts will enable a return to high-power operations by 2016 – Restores 120-Hz capability.

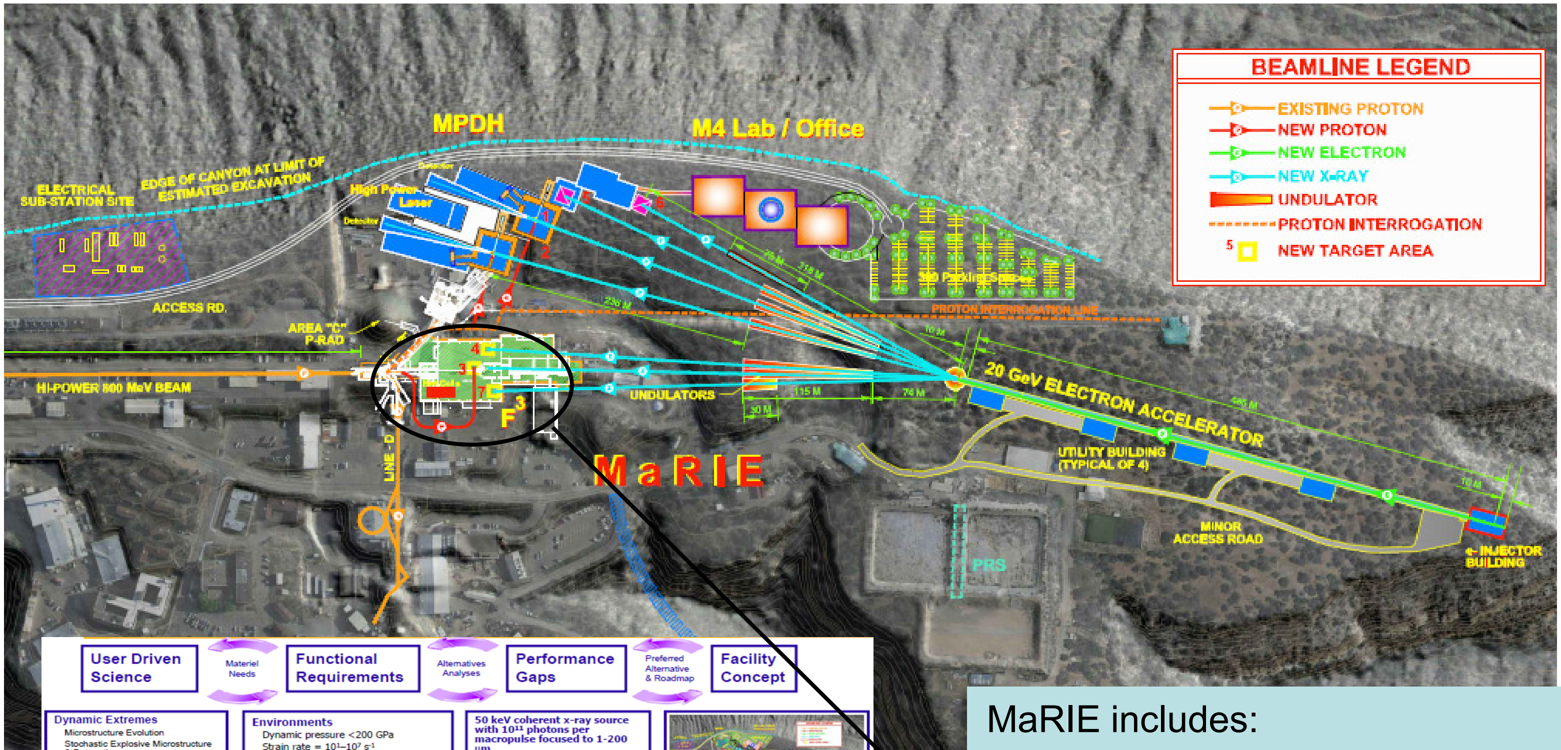
Linac Risk Mitigation plans will provide needed linac modernization by 2016.

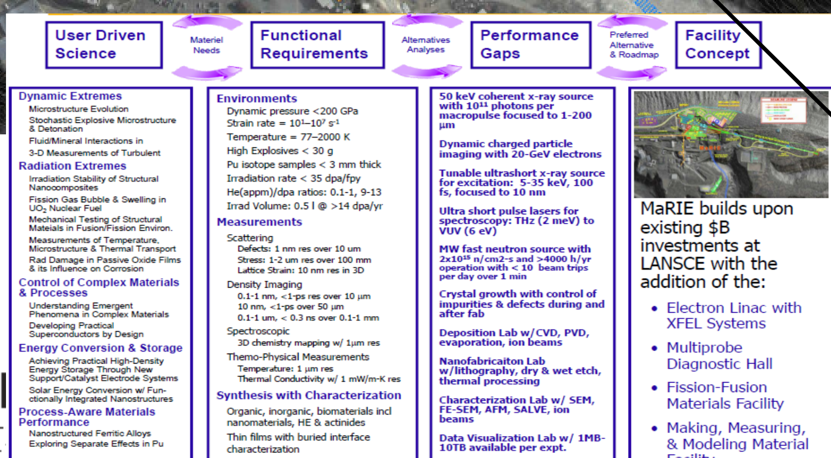
- **Install modern, maintainable Instrumentation & Control and Diagnostics systems**
- **Refurbish the 805-MHz RF amplifier systems for the Coupled Cavity Linac (100 - 800 MeV)**
- **Remediate accelerator structures, supporting equipment and power supplies**
- **Replace the 201-MHz RF system for the 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.





User Driven Science → Materiel Needs → Functional Requirements → Alternatives Analyses → Performance Gaps → Preferred Alternative & Roadmap → Facility Concept

Dynamic Extremes
- Microstructure Evolution
- Stochastic Explosive Microstructure & Detonation
- Fluid/Mineral Interactions in
- 3-D Measurements of Turbulent

Radiation Extremes
- Irradiation Stability of Structural Nanocomposites
- Fission Gas Bubble & Swelling in UO_2 Nuclear Fuel
- Mechanical Testing of Structural Mateials in Fusion/Fission Environ.
- Measurements of Temperature, Microstructure & Thermal Transport
- Rad Damage in Passive Oxide Films & its Influence on Corrosion

Control of Complex Materials & Processes
- Understanding Emergent Phenomena in Complex Materials
- Developing Practical Superconductors by Design

Energy Conversion & Storage
- Achieving Practical High-Density Energy Storage Through New Support/Catalyst Electrode Systems
- Solar Energy Conversion w/ Functionally Integrated Nanostructures

Process-Aware Materials Performance
- Nanostructured Ferritic Alloys
- Exploring Separate Effects in Pu

Environments
- Dynamic pressure <200 GPa
- Strain rate = 10^1–10^7 s^{-1}
- Temperature = 77–2000 K
- High Explosives < 30 g
- Pu isotope samples < 3 mm thick
- Irradiation rate < 35 dpa/fpy
- He(appm)/dpa ratios: 0.1-1, 9-13
- Irrad Volume: 0.5 l @ >14 dpa/yr

Measurements
- Scattering
  - Defects: 1 nm res over 10 um
  - Stress: 1-2 um res over 100 mm
  - Lattice Strain: 10 nm res in 3D
- Density Imaging
  - 0.1-1 nm, <1-ps res over 10 µm
  - 10 nm, <1-ps over 50 µm
  - 0.1-1 um, < 0.3 ns over 0.1-1 mm
- Spectroscopic
  - 3D chemistry mapping w/ 1µm res
- Themo-Physical Measurements
  - Temperature: 1 µm res
  - Thermal Conductivity w/ 1 mW/m-K res

Synthesis with Characterization
- Organic, inorganic, biomaterials incl nanomaterials, HE & actinides
- Thin films with buried interface characterization

50 keV coherent x-ray source with 10^{11} photons per macropulse focused to 1-200 µm

Dynamic charged particle imaging with 20-GeV electrons

Tunable ultrashort x-ray source for excitation: 5-35 keV, 100 fs, focused to 10 nm

Ultra short pulse lasers for spectroscopy: THz (2 meV) to VUV (6 eV)

MW fast neutron source with $2x10^{15}$ n/cm2-s and >4000 h/yr operation with < 10 beam trips per day over 1 min

Crystal growth with control of impurities & defects during and after fab

Deposition Lab w/CVD, PVD, evaporation, ion beams

Nanofabricaiton Lab w/lithography, dry & wet etch, thermal processing

Characterization Lab w/ SEM, FE-SEM, AFM, SALVE, ion beams

Data Visualization Lab w/ 1MB-10TB available per expt.

MaRIE builds upon existing $B investments at LANSCE with the addition of the:
- Electron Linac with XFEL Systems
- Multiprobe Diagnostic Hall
- Fission-Fusion Materials Facility
- Making, Measuring, & Modeling Material Facility

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 2.5×10^{15} n/cm^2/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 5×10^{15} n/cm^2/s
  - Would be highest neutron flux in the world; equivalent to JOYO reactor; exceeds BOR-60 (3.4×10^{15} n/cm^2/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.

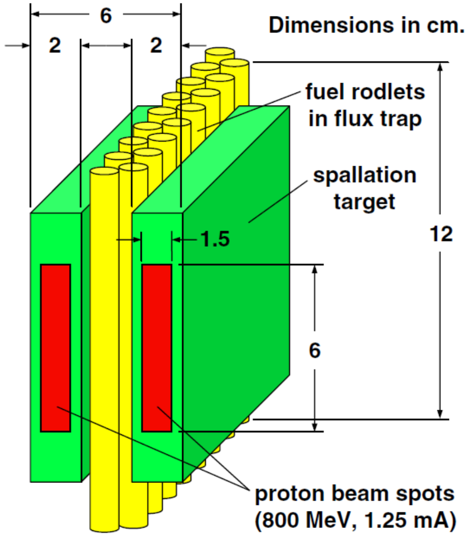


Fig. 1. Basic configuration of the MTS target assembly.

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

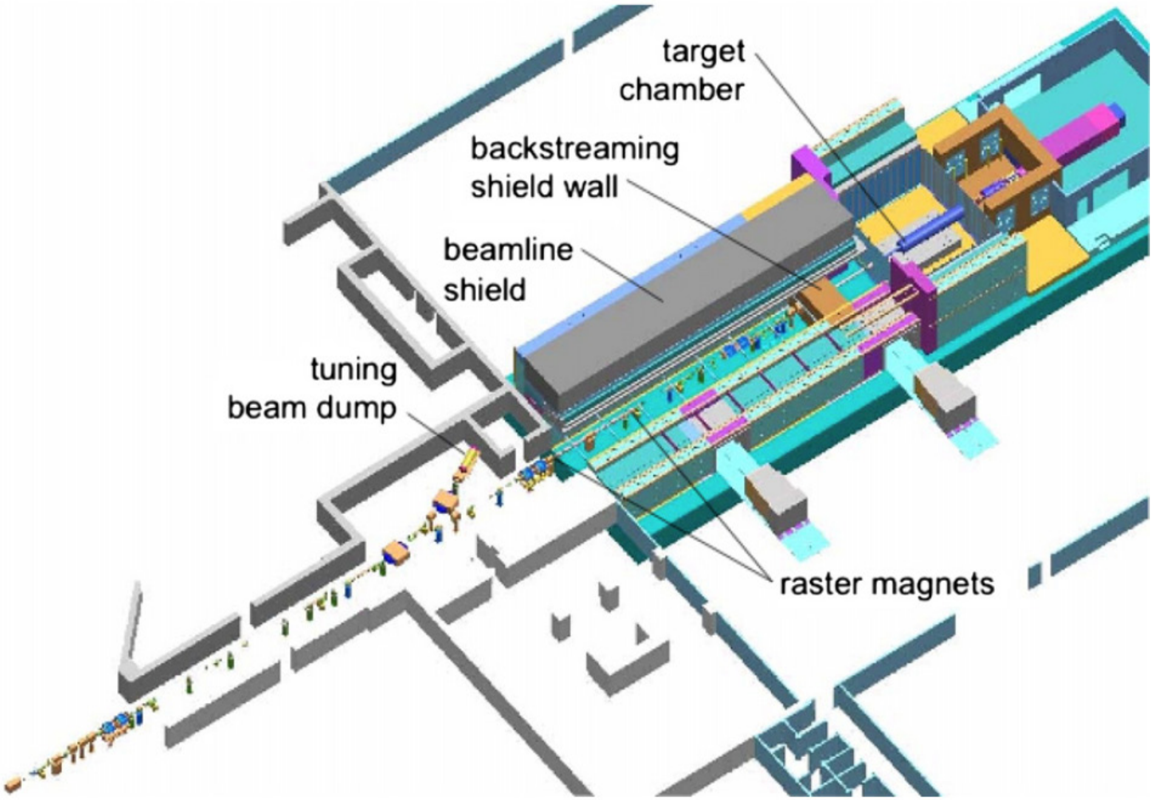
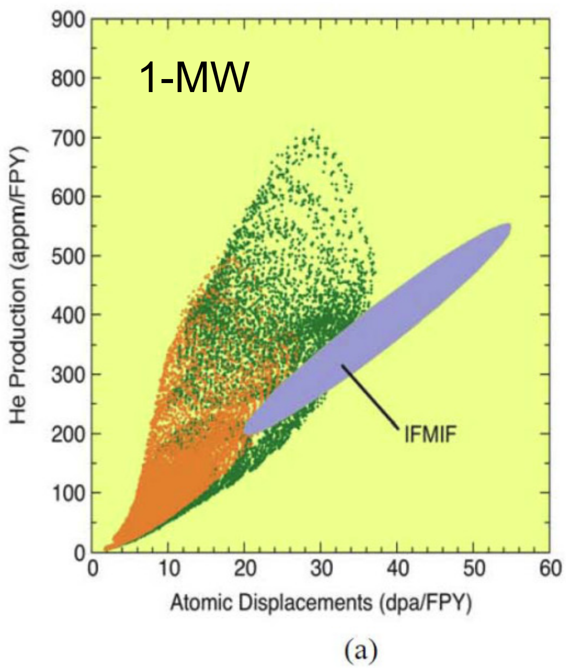
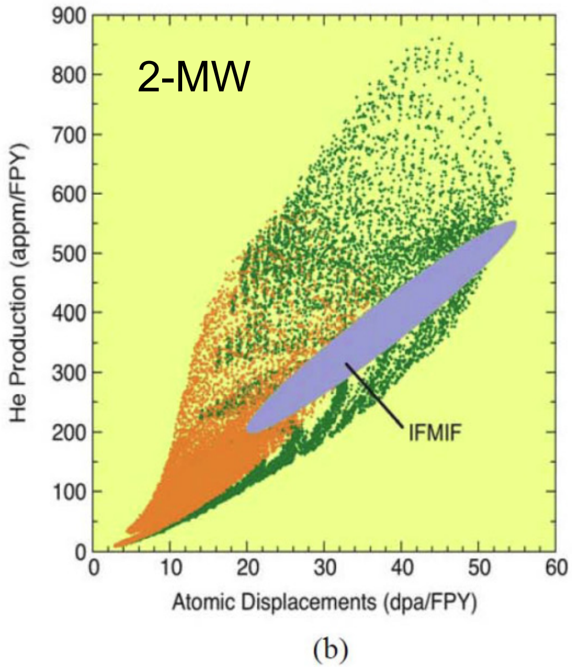


Fig. 4. Physical layout of the beam transport system.

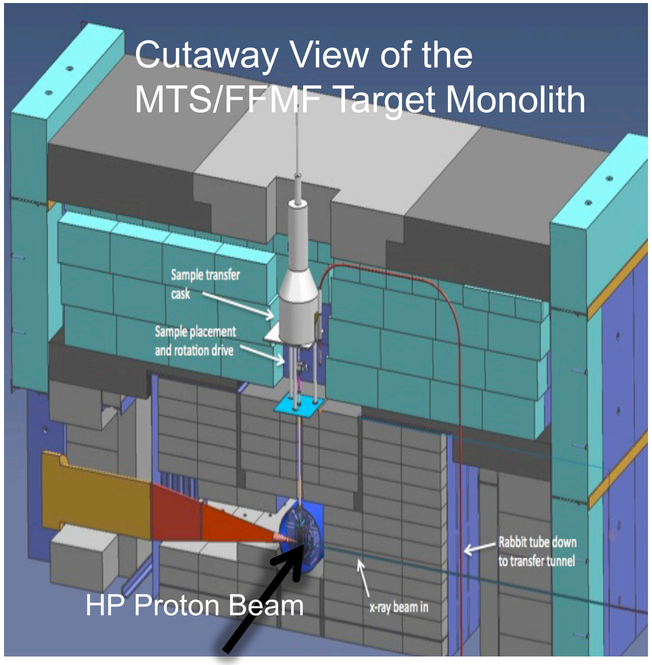
E. J. Pitcher, "The materials test station: A fast-spectrum irradiation facility," *Journal of Nuclear Materials, 377, Issue 1, 30 June 2008.*

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





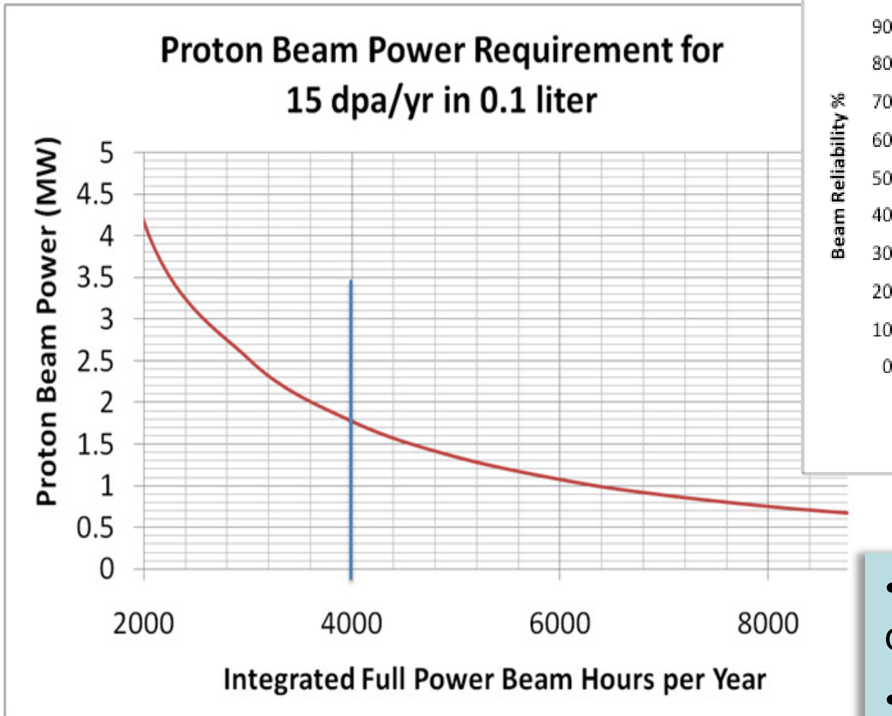
Calculated displacement and helium production rates in the MTS at (a) 1-MW and (b) 2-MW beam powers. Also shown is the parameter space covered by the IFMIF-HFTM (blue ellipse).

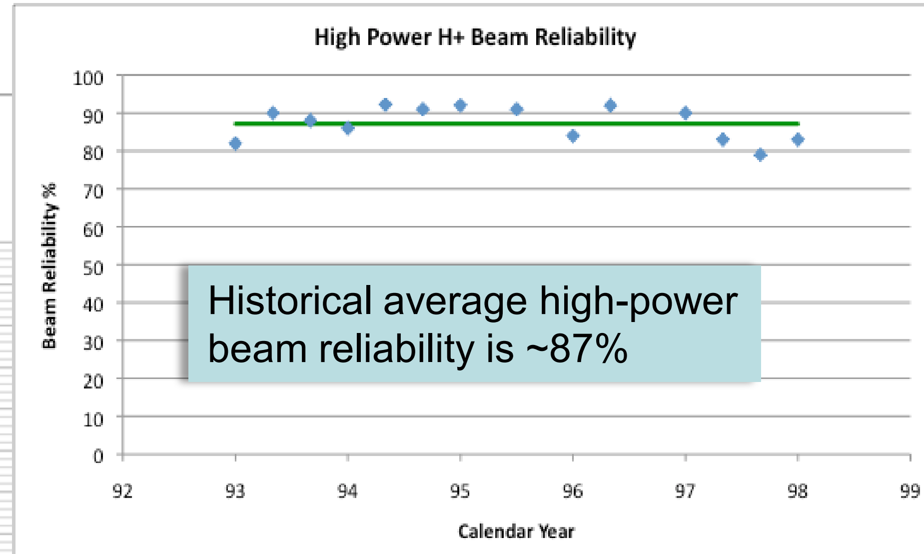


FFMF in-situ characterization and multi-probe capabilities integrated into the MTS target assembly.

E. J. Pitcher, "Fusion materials irradiations at MaRIE's fission fusion facility," *Fusion Engineering and Design (2011)*

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

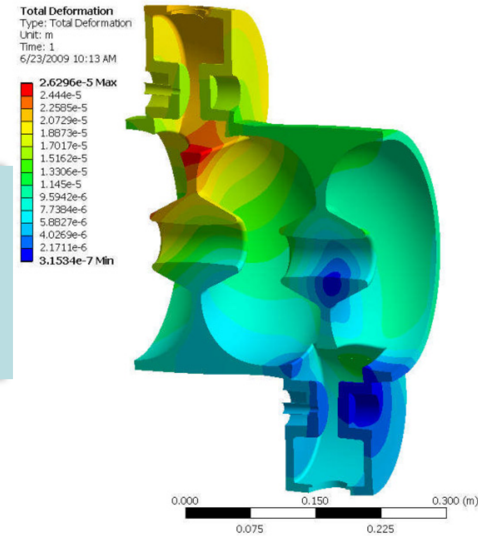




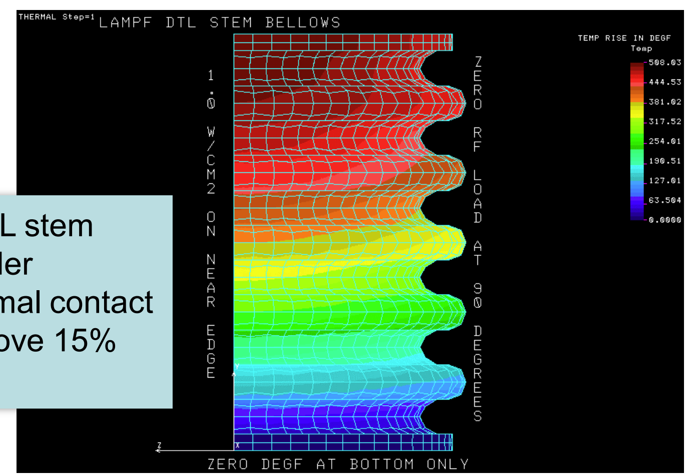
- CD-0 FFMF irradiation requirement is 15 dpa/year in 0.1 liter volume.
- 4500 hours/year scheduled beam
- ~3900 hours on target (87% reliability assumed): Requires ~2-MW beam power.

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

	DTL	CCL	201.25 MHz (HVDC PS)	805 MHz (Klystron)
RF Duty Factor	**12.4%** (structure limited)	**12.2%** (structure limited)	11.8% (10% beam) – Present **12.5%** (10.7% beam) – Post LRM	**12.0%** (120 Hz, 1 ms)

- 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+)

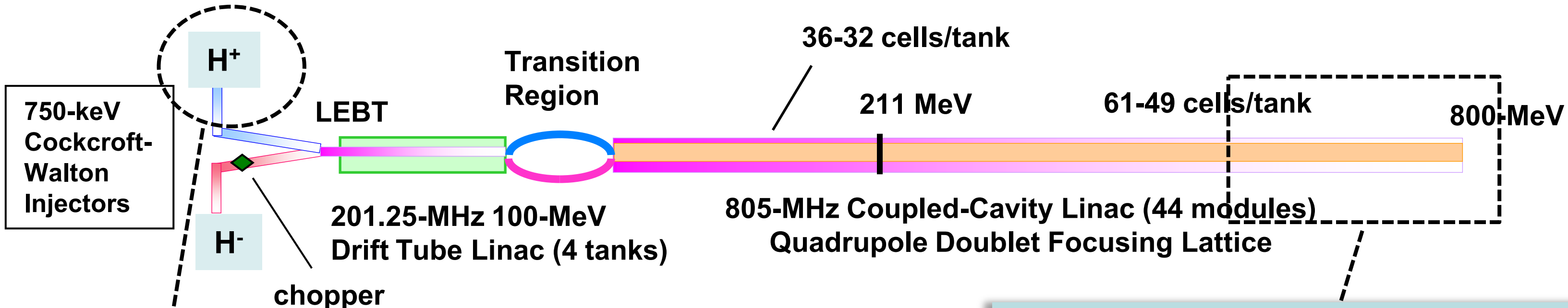
Option	Beam Power (MW)	Requirements	Beam Pulse Length (μs)	RF Duty Factor (%) DTL, CCL, SCL	E_{final} (GeV)	I_{peak} (mA)	I_{avg} (mA)	SC cryomodules/klystrons
1-MW Option 1	1	Increase duty factor	770	12.3, 10.8, N/A	0.8	16.5	1.25	N/A
1-MW Option 2	1	Increase duty factor & peak beam current	688	11.3, 9.8, N/A	0.8	18.5	1.25	N/A
Max. Beam Power	1.16	Increase duty factor & peak current	797	12.4, 11.0, N/A	0.8	18.5	1.45	N/A
2-MW Option 1	2	Fix DTL field errors, Increase duty factor & peak beam current, add 201.25-MHz RFQ, upgrade HPRF & HVDC	922	13.2, 12.3, N/A	0.8	27.5	2.5	N/A
2-MW Option 2	2	Increase duty factor & peak beam current, add 201.25-MHz RFQ, upgrade HPRF & HVDC, increase final beam energy	788	12.4, 10.9, 9.7	1.5	17.0	1.33	18/72
5-MW Option 1, Not Viable	5	Increase peak beam current, increased RF power to CCL	913					
5-MW Option 2	5	Increase final beam energy, increase peak beam current, add 402.5-MHz RFQ & 402.5-MHz DTL, Upgrade HPRF, HVDC	913	TBD	1.5	37.0	3.3	18/72
5-MW Option 3	5	Increase final beam energy, increase peak beam current, add 402.5-MHz RFQ & 402.5-MHz DTL, Upgrade HPRF, HVDC	913	TBD	2.0	28.0	2.5	25/100

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)



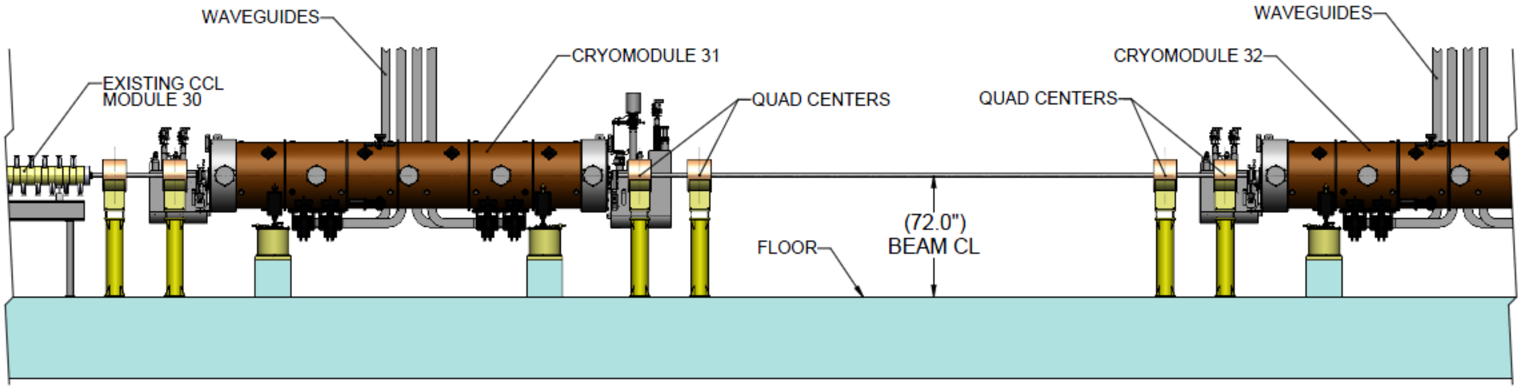
201.25-MHz RFQ + new LEBT

- Replacement of CCL structures with SC cryomodules (500 MeV-1.5 GeV)
- Modified beam switchyard at 800-MeV point to maintain H^- beam delivery.

- 201.25-MHz RFQ type TBD.
- 18 SNS-like, 805-MHz, β=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

Beam Pulse Length (μs)	RF Duty Factor (%) DTL, CCL, SCL	E_{final} (GeV)	I_{peak} (mA)	I_{avg} (mA)
788	12.4, 10.9, 9.7	1.5	17.0	1.33

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?