LANSCE Futures

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P-3: Nuclear and Particle Physics and Applications

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LANSCE User Group Meeting

LA-UR-21-31223
Beyond LAMP, we are initiating a conversation about the long-term future for LANSCE

• Securing investments to ensure the long-term viability of the accelerator demands a long-term narrative of what science LANSCE will deliver to the nation.

• The next generation of LANSCE science will require investment in experimental stations beyond LAMP.

• The LANSCE Futures Spring 2021 Workshop Series served to initiate this conversation.

• We are interested in sharing the initial results with the broader community to spawn further discussion.

• Ultimately, this conversation will motivate LANSCE Enhancements (LANE), the concept for a portfolio of mid-scale experimental station investments in the intermediate future.
Snapshot of the LANSCE workshop series

• The purpose of this series was to develop the case for cutting-edge science at the (primarily NNSA-supported) LANSCE experimental stations to 2050 and beyond. This feeds into the objectives of the LAMP and LANE concepts to secure long-term investment in LANSCE as a facility.

• The workshops themselves were a conversational opener, not an end-game.

Workshop breakdown:

1. Dynamic Radiography (April 5 – 6)
2. Scattering Science (April 21)
3. Nuclear Science (May 10 – 11)
4. Area A Futures (June 1 – 2)

• Workshops 1 – 3 focused on the connection between concepts and mission need.
• Area A was considered as a fielding location based on input from workshops 1 – 3.
• We will review concepts and highlights from these workshops.
Concept from fusion energy science: the first wall of a D-T fusion reactor sees an intense flux of 14-MeV neutrons

- In the structural materials that comprise the first wall, these neutrons will:
  - Displace atoms from their lattice sites.
    - Atomic displacements, measured in units of displacements per atom or dpa.
  - Induce nuclear reactions with He as a byproduct.
    - Helium can diffuse and coalesce at trapping sites like grain boundaries.
- An iron-based alloy in a fusion reactor first wall is predicted to experience ~20 dpa and ~250 appm He per year.
- Fusion Prototypic Neutron Source (FPNS) proposed as a method to subject components to such a harsh radiation environment for testing.

Bubble growth at grain boundaries in 316SS implanted with 100 ppm He at 1023 K
[H. Schroeder et al., Nuclear Engineering and Design/Fusion 2 (1985) 65-95]

E. Pitcher (P-DO: Physics Division Office)
FPNS would utilize high-power LANSCE beams to drive the irradiation station

- Concept would deliver 1 MW (1.25 mA) of 800 MeV protons to irradiation station.
- Would utilize central floor of Area A with 8-ft-thick base mat with magnetite concrete for shielding.
- Concept includes RF upgrade to run FPNS at 78 Hz while retaining beam delivery at other end-stations.
- Concept would bring significant FES footprint to dominantly NNSA facility – interaction model will have to be defined.
Concept for Office of Science: a high-power ultracold neutron (UCN) source would be a game changer.

- LANSCE currently operates a UCN source using ~9 uA of 800 MeV protons to study fundamental physics.
- Currently, < 100 UCN/cc available which limits sensitivity of all UCN based experiments.
- A 100x increase in UCN density would drastically improve the physics reach of the facility.
A high-power, optimized UCN source would be a flagship facility for UCN based research

- Concept utilizes 600 kW of proton beam
- Optimized spallation target design with cold LD2 moderator and thermal D2O pre-moderator.
- Rastered proton beam to distribute heat-load
- Predicted 80x gain in neutron density over existing UCN source.
- Concept would bring significant Office of Science footprint to dominantly NNSA facility – interaction model will need to be defined.

Community demand is building the case for radiation effects testing with protons and thermal neutrons

- Galactic cosmic rays (GCR), solar energetic particles (SEP), and trapped particles contribute to space radiation environment, and can damage electronics. Much of the concern is with energetic protons.
- Cosmic rays hitting atmosphere create neutrons. Thermal neutrons can induce $^{10}\text{B}(n,\alpha)$ and cause electronics failures.
- Demand for component testing for both cases outstrips supply in the U.S.
- Concepts being generated to use LANSCE protons, thermal neutrons to address.

S. Wender (P-2: Applied and Fundamental Physics)
The remaining concepts are largely driven by NNSA interests, though there is significant scientific and technical overlap with other communities.
Dynamic radiography takeaway: new drivers, multiple probes, and energy upgrades best meet mission need

- **Near term:** completion of ongoing improvements to pRad’s capabilities.
  - Multi-pulse x-ray source for pRad.
  - Pu@pRad project.
- **Intermediate term:** expansion of pRad beamlines and addition of new capabilities.
  - H\(^+\) beam to pRad for better resolution – additional benefit if we add beam lines in the process.
  - Two-stage gun in Area C for enhanced experimental capability.
- **Long term:** an energy upgrade will enable new classes of experiments.
  - Resolution scales according to \(\delta x = L_C \theta \delta p/p\)
    - At higher magnification, \(L_C\) (chromatic length) is reduced
    - At higher energy, \(\theta\) (object scatter), and \(\delta p/p\) (proton momentum spread) are dramatically reduced.
  - This means: thicker objects and higher spatial resolution.
  - Small-scale Pu experiments with (1\" - 2\") thick, aluminum windows.
  - Combine with next-generation x-ray source to maximize data quality.
- There is potentially significant **technical overlap** between energy-upgraded pRad and an acute radiation effects capability.
  - One potential technical solution for both is a 3-5 GeV proton synchrotron with both fast and slow injection/extraction schemes.
  - Pursuing resources to enable more detailed concept development now.
3-GeV pRad would increase image quality and depth penetration

At 3 GeV, compared to 0.8 GeV:
• Loss in spatial resolution with increasing object thickness (chromatic effects) is decreased by $\beta p^2$, an improvement of $\times7.9$
• Depth penetration improves with $\beta p$, an improvement factor of $\times3.0$
• Approaching the ability to visualize something as thick as the FTO (214 g cm$^{-2}$)

3-GeV pRad can be used for:
• small-scale plutonium experiments with thick aluminum windows
• ~cm-thick targets @ 10-µm spatial resolution
• validating continuum models
• studying ejecta formation, transport and breakup
• material damage: void formation, coalescence and failure

The FTO is:
2-cm diameter void
9-cm diameter W
13-cm diameter Cu
45-cm diameter foam

K. Prestridge (XTD-DO: X Theoretical Design) and M. Freeman (P-1: Dynamic Imaging and Radiography)
A complementary light source would increase dynamic range, improve systematics and data quality

- Example: complementary x-rays provide unique attenuation profile to emphasize different parts of the experiment.
- Overlap in dynamic range for each probe permits cross-examination for improved systematics
- Placing the two probes on different axes allows overt tests of symmetry assumptions

M. Freeman (P-1: Dynamic Imaging and Radiography) and K. Prestridge (XTD-DO: X Theoretical Design)
Scattering science takeaway: neutrons and x-rays, with the right authorization basis, enable unique measurements

- **Near term:** *deploy* vault-type room for classified experiments.
  - LANSCE can run hazardous and/or classified experiments, but overhead for classified operations is high.
  - A dedicated classified beam line would allow more efficient operations.

- **Intermediate term:** *develop* existing and unused Lujan flight paths for scattering and/or radiography
  - Modest upgrades to SMARTS and HIPPO for sample environments and backgrounds keep them competitive.
  - An optimized, multi-probe version of FP5 in conjunction with proper sample environment can provide energy resolved imaging and bulk characterization for several programs.

- **Long term:** a *compact x-ray source* will enable new classes of experiments.
  - X-rays are a powerful complement to neutrons, with a complementary attenuation profile and specialization in high-resolution, small-scale experiments.
  - The LANSCE authorization basis allows neutron measurements with hazardous and/or classified components, gaining x-ray capability would expand capability for those types of measurements.

S. Vogel and D. Brown (MST-8: Materials Science and Radiation & Dynamics Extremes)
A compact light source with LANL’s authorization basis enables a class of relevant measurements

- X-rays are widely accepted as a very useful probe for material properties.
- Some work at APS in support of LANL materials program has happened – authorization basis issues limit progress.
- Many experiments don’t require APS luminosity… could we do something local?
- Commercially available compact synchrotron source could enable this.
- Inverse Compton Scattering (ICS) allows shrinking a synchrotron to laboratory size while maintaining many of the beam properties.
- Looking at costs, potential siting locations now.

S. Vogel and D. Brown (MST-8: Materials Science and Radiation & Dynamics Extremes)
Nuclear physics takeaway: clear path from the evolutionary to the revolutionary

• **Near term:** *optimizations* to Lujan and WNR facilities and endstations will enable next generation measurements for NNSA
  - Neutron scattering work is a known priority, development already begun
  - Initial measurements on radioactive isotopes exploit new Lujan target, will need enhanced WNR capabilities

• **Intermediate term:** *partnering* with LANSCE Isotope Production Facility (IPF) will be key
  - Increasing demand for radioactive isotope measurements require new capabilities in target production.
  - Purified research isotopes will become important – drives demand for a radionuclide separator at LANSCE.

• **Long term:** community discussion has begun regarding a *completely new approach* to radionuclide science
  - Concept would use LANSCE to drive a radioactive ion beam facility and “neutron target” to perform measurements that are currently impossible
  - Feedback between experimenters, program has begun to balance program impact and technical feasibility

• There is a clear *feedback loop* between “basic” science (reaction rates) and “applied science” (diagnostic development)
  - Multiple concepts for advanced diagnostics leverage expertise in experimental nuclear physics
A “neutron target” would permit direct neutron-induced reaction studies on short-lived isotopes

- Many nuclear reaction rates of interest to both applications and nuclear astrophysics are on short-lived radioactive isotopes.
- Traditional neutron-beam on radioactive target measurements are limited by the radiation field or half-life of the target.
- The neutron target concept would interact a radioactive ion beam with a standing field of neutrons to get around traditional limitations.
- Existing calculations suggest that the half-life limit for a credible measurement could move from the existing days-to-years limit to ~seconds.
- A proof-of-principle measurement is under development.

Schematic rendering of the neutron target concept from LA-UR-21-30261. 800 MeV protons (red) impinge on a tungsten spallation target (brown) to produce neutrons which are moderated in the sphere (blue). The ion storage ring penetrates the moderator such that neutrons flow through a section of the ring, thus creating the neutron target.

S. Mosby et al., LA-UR-21-30261
A burst facility offers a powerful complement to other facilities (if you can make it work)

- Driver: acute and chronic radiation dose can have profound effects on materials properties and electronics reliability
  - Point-defects
  - Embrittlement and hardening
  - Nucleation of voids and bubbles
  - Transmutation and activation

- Existing facilities are either oversubscribed or just barely capable of the fluences required to do interesting physics
  - Reactors have the fluence but are confined in many other ways
    - Dynamic experiment inside reactor core…
    - Time scales and spectra not as flexible as accelerator driven systems
    - Limited space for materials inside the core

- LA-UR-08-7486 looked at this problem using existing PSR – need 10x more dose

<table>
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<th>Facility</th>
<th>Volume [cm³]</th>
<th>Intensity [n/cm²]</th>
<th>Pulse width [μs]</th>
<th>Target Mat.</th>
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<td>32000</td>
<td>5*10¹⁴</td>
<td>55</td>
<td>HEU</td>
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<td>5*10¹³</td>
<td>5</td>
<td>LEU</td>
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</tbody>
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Survey of yield strength variance and elongation of RAFM steels exposed to neutron irradiation (Ge et. al. Journal of Nuclear Materials 468 (2016))

C. Prokop (P-3: Nuclear and Particle Physics and Applications) and J. Goett (P-2: Applied and Fundamental Physics)
A 3 - 5 GeV ring could provide needed performance, has potential synergy with pRad futures

- Near-linear gain in neutron production until ~4 GeV – so inject 800 MeV protons into a synchrotron and go up from there.
- Still need more protons in a pulse than existing PSR, so would need to design accordingly.
- Existing rings (e.g. 3 GeV Rapid Cycling Synchrotron at J-PARC) could provide a place to start thinking.
- …and pRad wants 3 GeV protons for its own future. Could one ring serve both purposes?
  - A ring could provide more protons/bunch than the booster
  - Dual purpose ring has technical challenges for injection/extraction
  - Working group to discuss trade space between booster linac, ring for pRad

C. Prokop (P-3: Nuclear and Particle Physics and Applications) and J. Goett (P-2: Applied and Fundamental Physics)
Where NNSA-relevant concepts landed (1): evolutionary improvements now, and natural alignment with LANE

- Improvements already underway:
  - Multi-pulse x-ray source for pRad
  - Pu@pRad project
  - Vault-type room for unattended classified experiments at Lujan
  - Mark IV 1L Lujan target for enhanced nuclear physics
  - Short-lived isotope production, isolation, and study at both Lujan and WNR

- Possible options for LANE (or in addition to it)
  - H\(^+\) beam to pRad for better resolution
  - Two-stage gun in Area C for enhanced experimental capability
  - Enhanced isotope production and separation for nuclear physics
  - Use of currently unused Lujan flight paths for scattering and/or radiography
  - Initial use of Area A with low-power proton beams for pRad and effects
Where NNSA-relevant concepts landed (2): longer term (2030+), we are developing mission needs for more ambitious options

- Experimental area enhancements:
  - 3-5 GeV pRad
  - Neutron target
  - Burst facility
  - ICS x-ray source

- These upgrade paths enable – or at least do not interfere with – a future MaRIE facility as they would occupy different locations at TA-53.
State of play and the path forward

• All workshops are complete and the reports communicated to LANSCE Facility Director.
  − These will feed the LAMP documentation which is in preparation, as well as conceptual development for LANE

• The quality and breadth of ideas presented at the workshops clearly demonstrates the need for LANSCE-based experimental science for the next several decades.

• Working groups have addressed certain key technical questions to feed next steps.
  − pRad energy upgrade and overlap with burst facility
  − Multi-probe pRad
  − Low current protons in Area A

• Certain broader collaborations formed during workshop preparation, are working toward follow-on investment to move the conversation forward.
  − Nuclear physics is pursuing follow-on reaction studies relevant for intermediate and long-term plans.

• Next: secure resources to follow the workshop recommendations for further concept development and broader discussion (like here) – *sustain the conversation*