LANSCE Futures

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P-3: Nuclear and Particle Physics and Applications

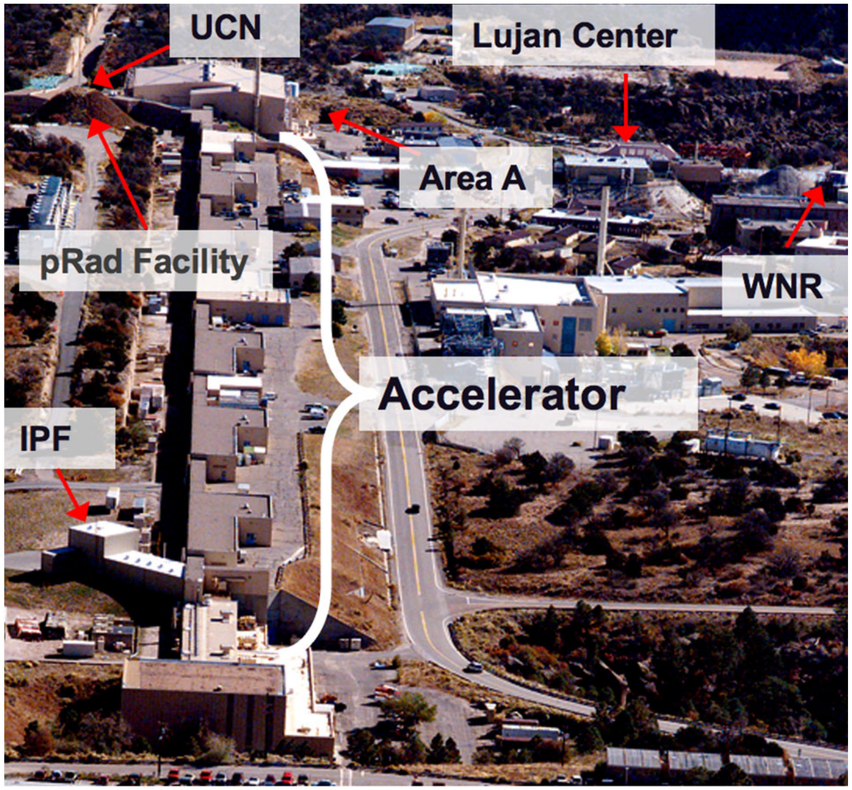
November 10, 2021

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.



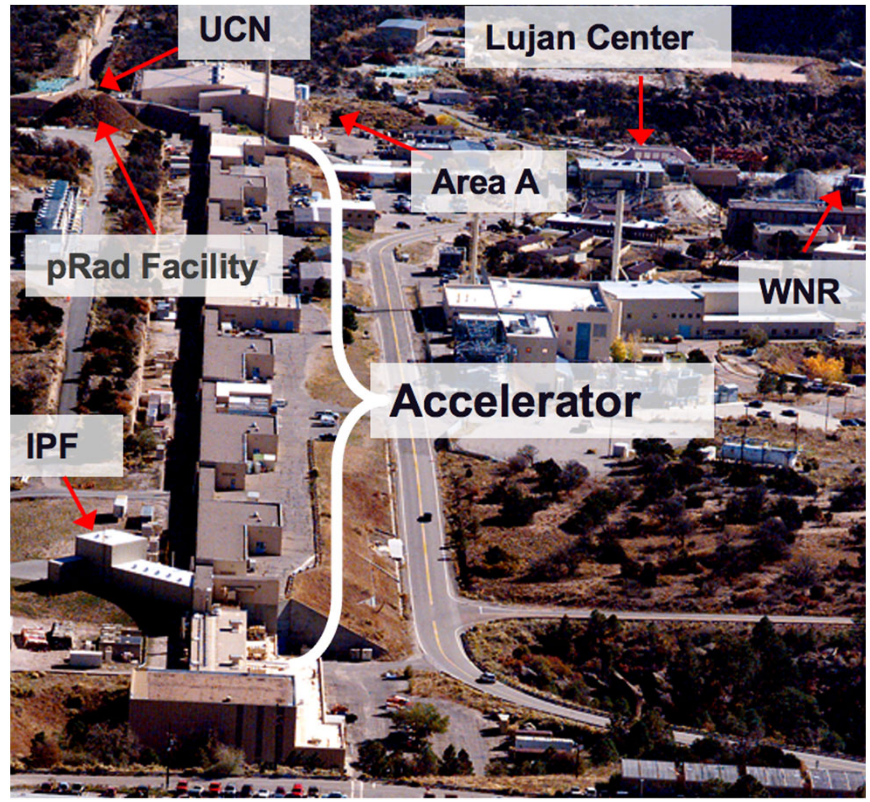
Snapshot of the LANSCE workshop series

- 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:

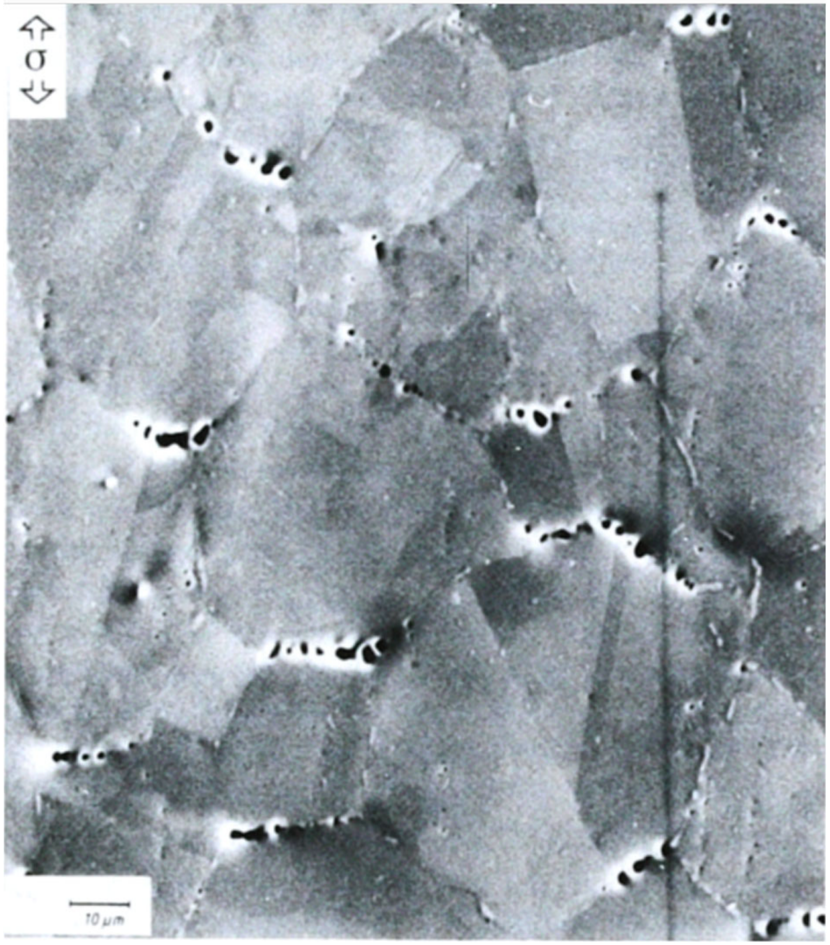
1. Dynamic Radiography (April 5 – 6)
2. Scattering Science (April 21)
3. Nuclear Science (May 10 – 11)
4. Area A Futures (June 1 – 2)

- 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

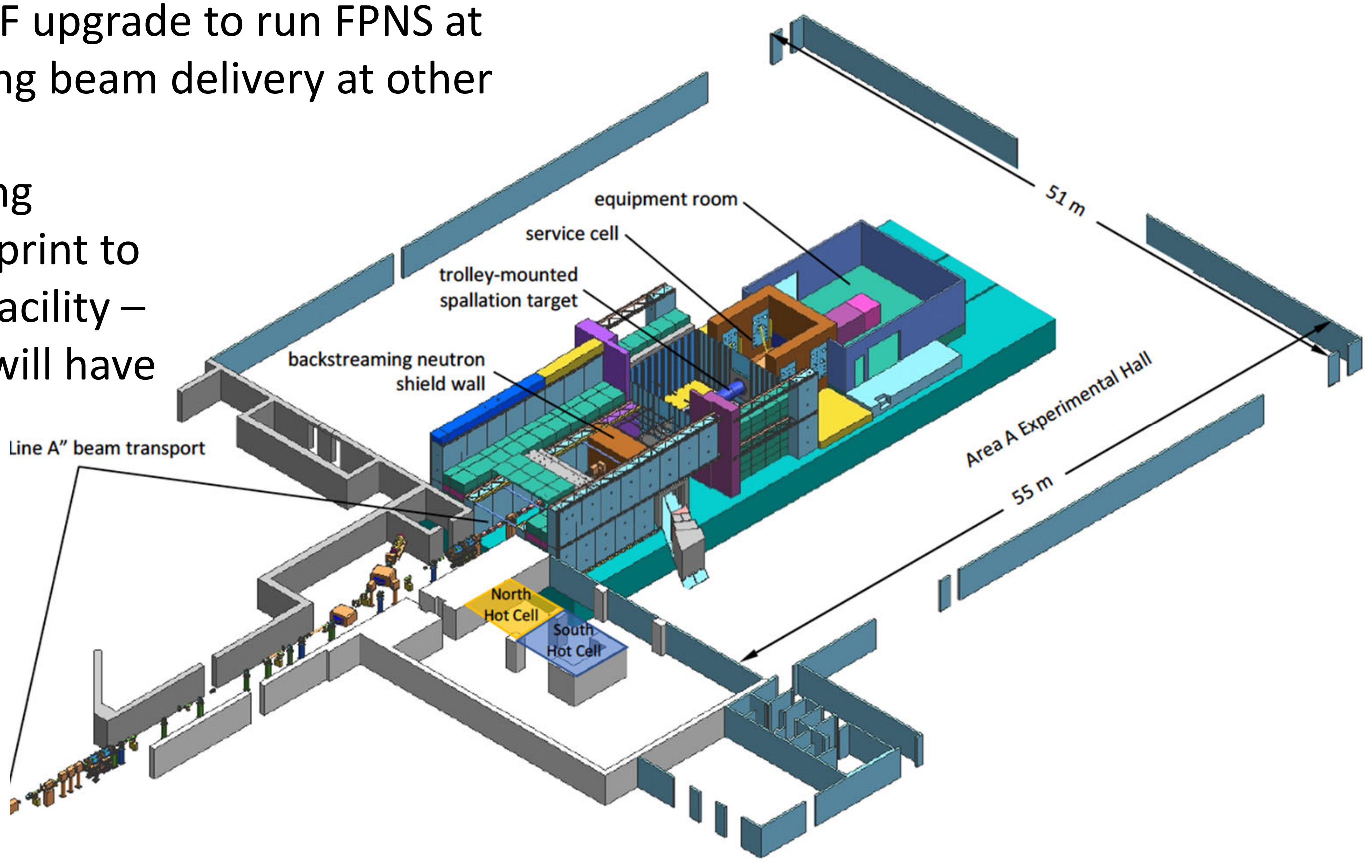
- In the structural materials that comprise the first wall, these neutrons will:
  - Displace atoms from their lattice sites.
    - Atomic displacements, measured in units of displacements per atom or dpa.
  - Induce nuclear reactions with He as a byproduct.
    - Helium can diffuse and coalesce at trapping 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]

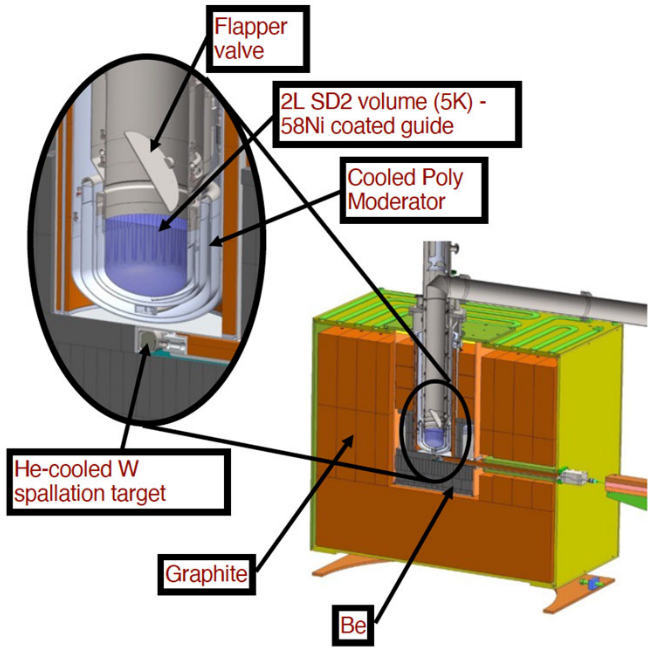
FPNS would utilize high-power LANSCE beams to drive the irradiation station

- 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.



Spallation neutrons from W target
K.E. ~ 2 MeV

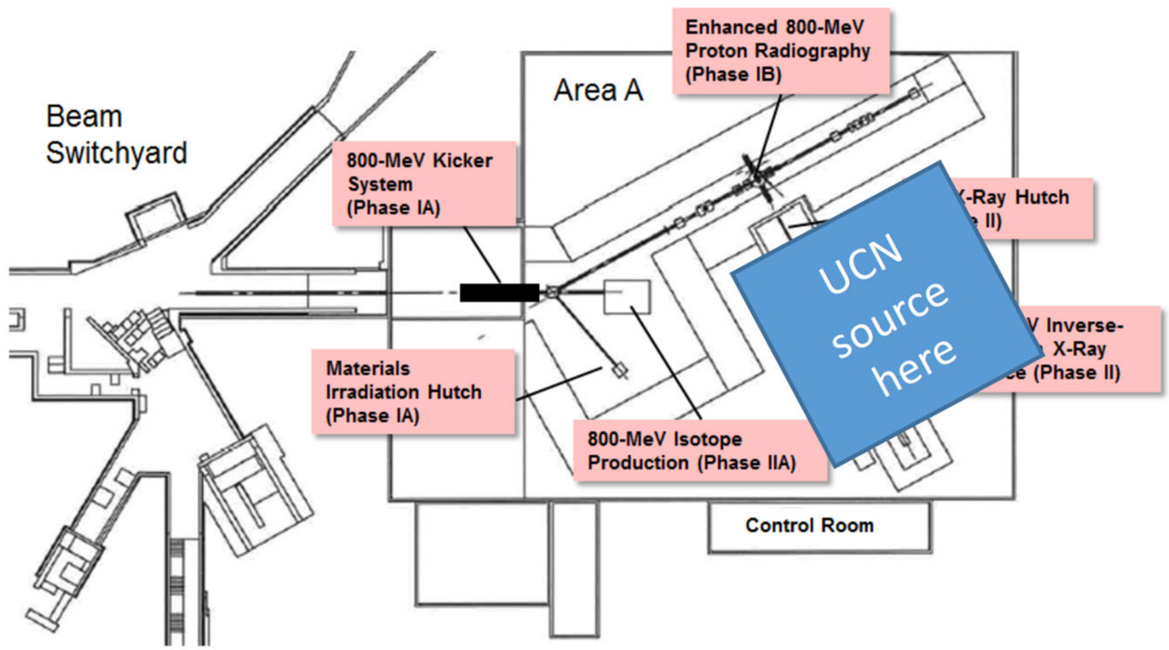
Thermal neutrons in Be and graphite moderator (300K)
K.E. ~ 25 meV

Cold neutrons in polyethylene cold moderator (40 K)
K.E. ~ 6 meV

Ultracold neutrons in SD2 converter
K.E. ~ 100 neV

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.



K. Leung et al., J. Appl. Phys. 126, 224901 (2019)

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

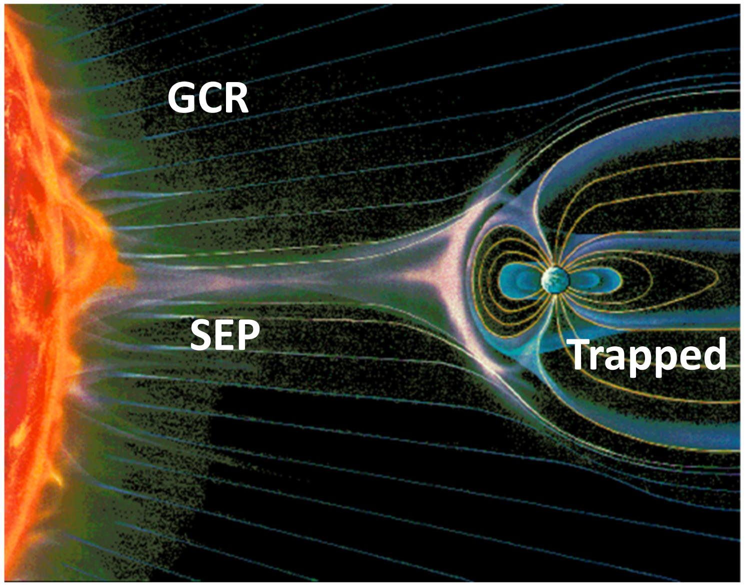
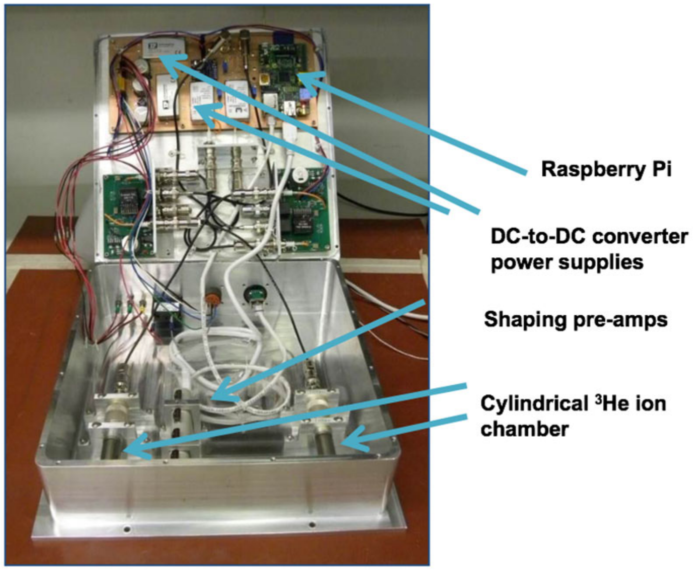


Illustration of space radiation environment



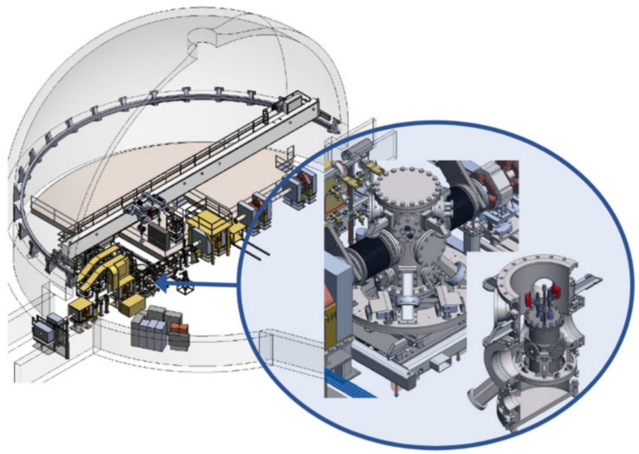
Tinman instrument to measure thermal neutrons in aircraft

- 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 $^{10}B(n,\alpha)$ 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.

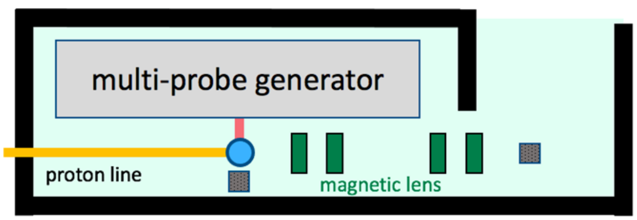
The remaining concepts are largely driven by NNSA interests, though there is significant scientific and technical overlap with other communities.

Dynamic radiography takeaway: new drivers, multiple probes, and energy upgrades best meet mission need

(right) Concept sketch for next-generation containment at pRad

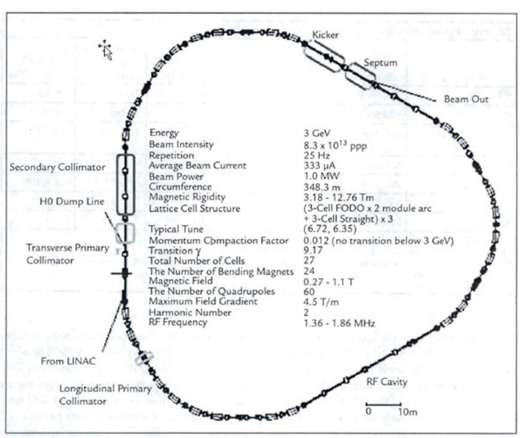


- **Near term: *completion*** of ongoing improvements to pRad's capabilities.
  - Multi-pulse x-ray source for pRad.
  - Pu@pRad project.
- **Intermediate term: *expansion*** of pRad beamlines and addition of new capabilities.
  - H^+ beam to pRad for better resolution – additional benefit if we add 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, θ (object scatter), and dp/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.



(left) Conceptual layout of pRad beamline in Area A (M. Freeman)

(right) JPARC's 3 GeV proton synchrotron provides some guidance on how to pursue 3-5 GeV protons at LANSCE



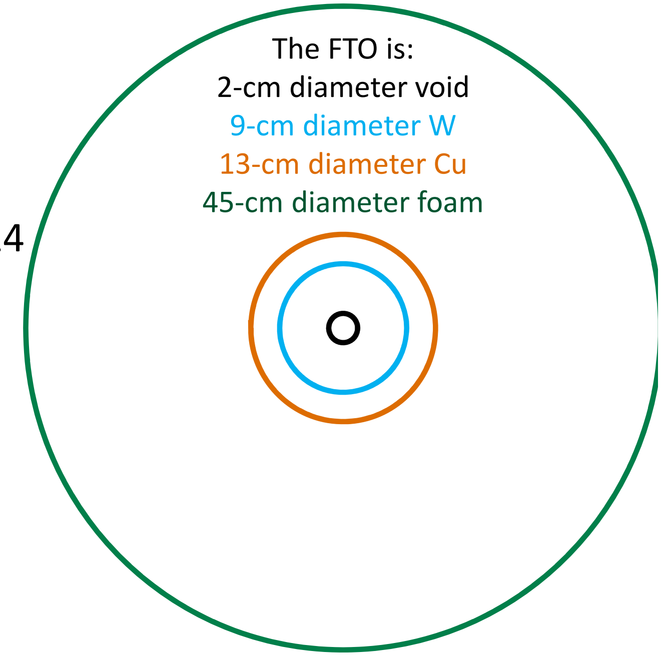
3-GeV pRad would increase image quality and depth penetration

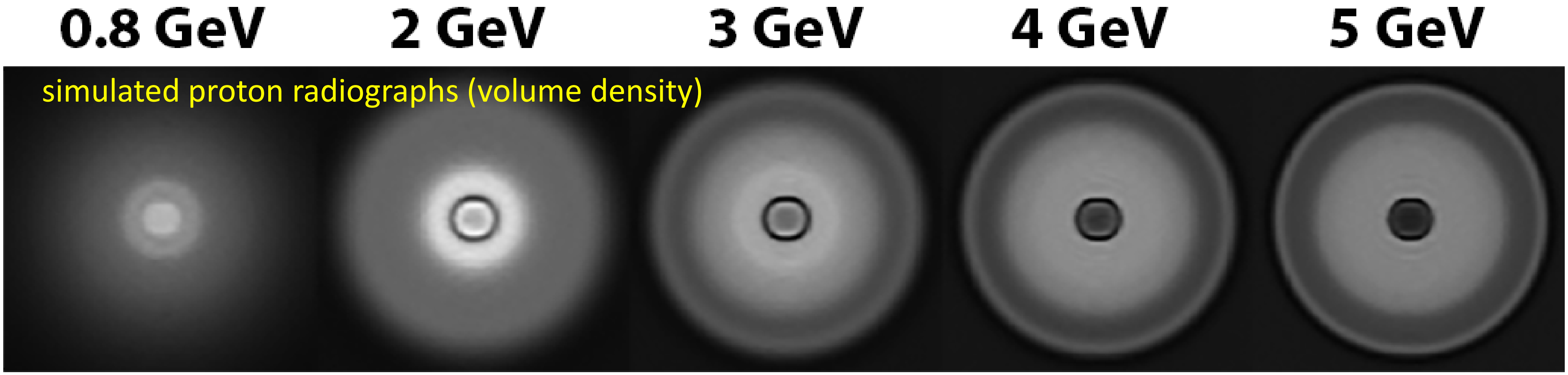
<u>*At 3 GeV, compared to 0.8 GeV*</u>:

- Loss in spatial resolution with increasing object thickness (chromatic effects) is decreased by βp^2, an improvement of ×7.9
- Depth penetration improves with βp, an improvement factor of ×3.0
- Approaching the ability to visualize something as thick as the FTO (214 g cm^{-2})

<u>*3-GeV pRad can be used for*</u>:

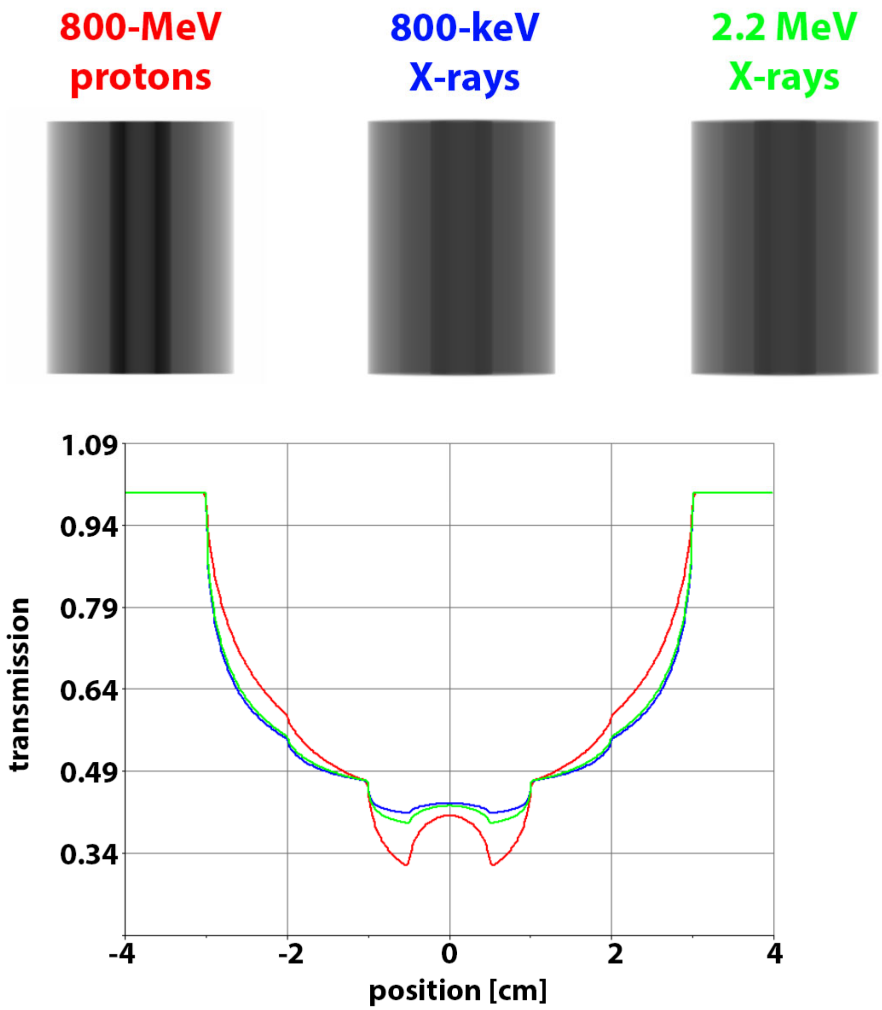
- small-scale plutonium experiments with thick aluminum windows
- ~cm-thick targets @ 10-µm spatial resolution
- validating continuum models
- studying ejecta formation, transport and breakup
- material damage: void formation, coalescence and failure





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

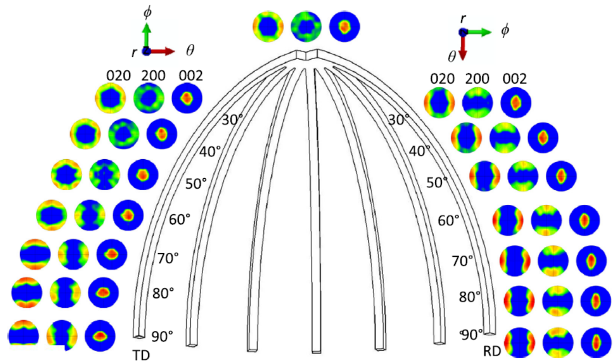


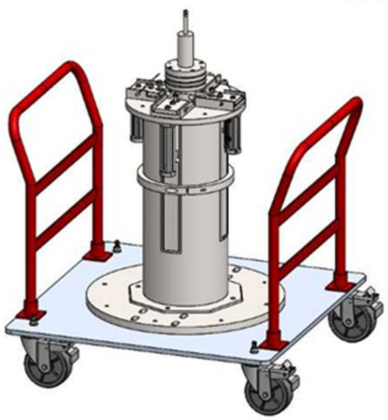
- Example: complementary x-rays provide unique attenuation profile to emphasize different parts of the experiment.
- Overlap in dynamic range for each probe permits cross-examination for improved systematics
- Placing the two probes on different axes allows overt tests of symmetry assumptions

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

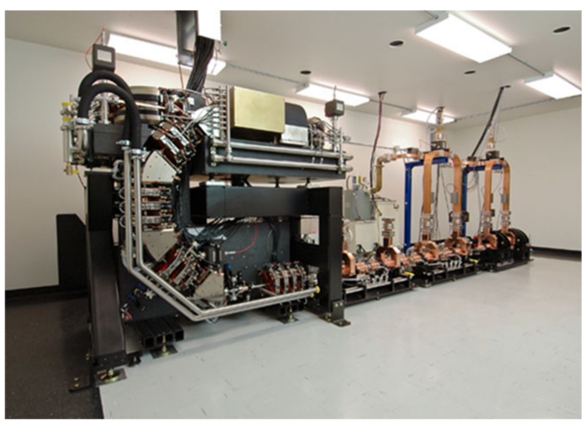
(right) Spatially resolved texture measurement uranium using HIPPO.





(left) Drawing of the Sample Handling Environment for Radioactive Material Analysis with Neutrons (SHERMAN) shielding cask for irradiated nuclear fuels.

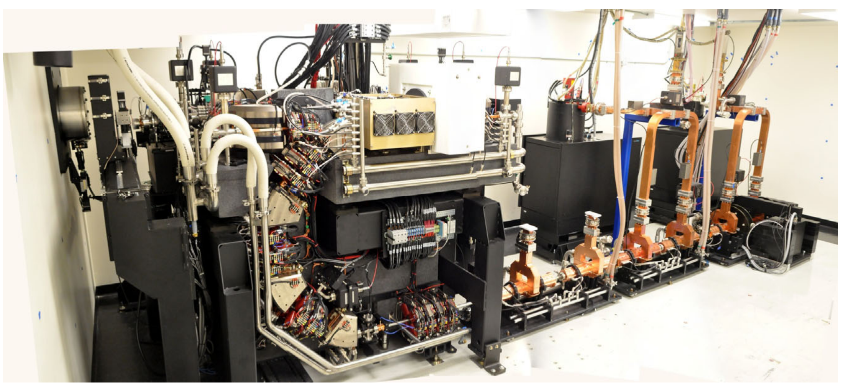
(right) Lyncean compact light source installed at TU Munich, Germany.



- **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.

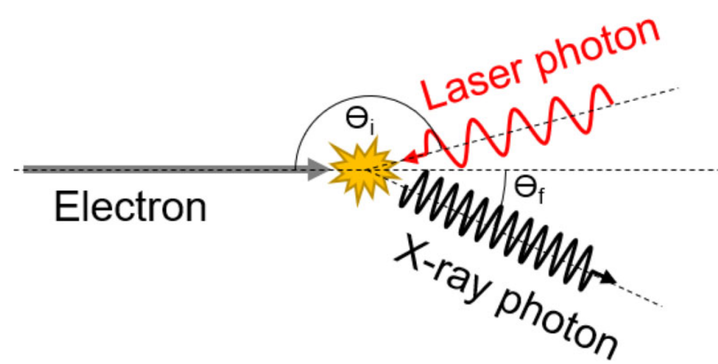
S. Vogel and D. Brown (MST-8: Materials Science and Radiation & Dynamics Extremes)

A compact light source with LANL's authorization basis enables a class of relevant measurements



Lyncean Compact Light Source

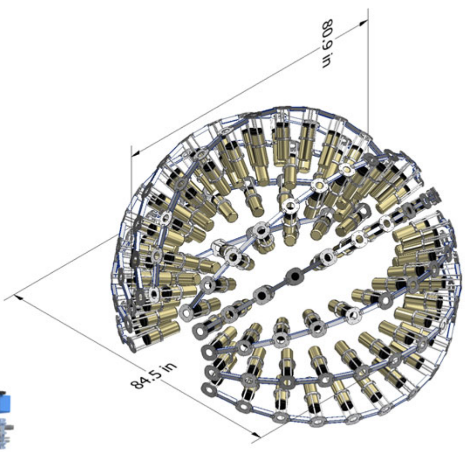
- X-rays are widely accepted as a very useful probe for material properties
- Some work at APS in support of LANL materials program has happened – authorization basis issues limit progress.
- Many experiments don't require APS luminosity… could we do something local?
- Commercially available compact 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.

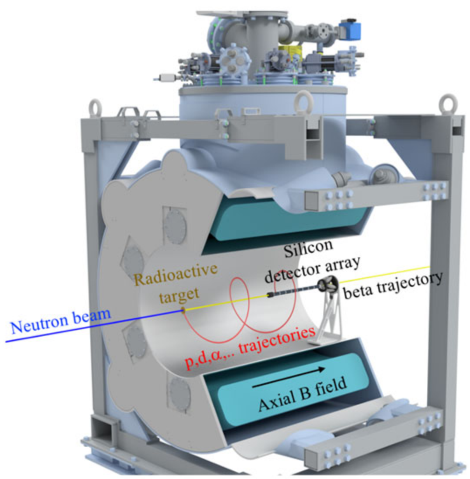


S. Vogel and D. Brown (MST-8: Materials Science and Radiation & Dynamics Extremes)

Nuclear physics takeaway: clear path from the evolutionary to the revolutionary

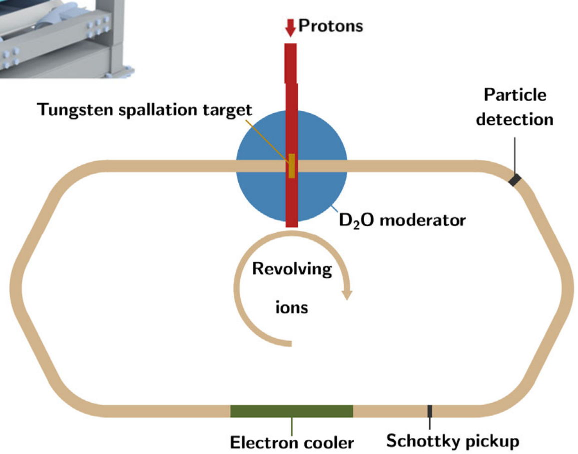
(right) Conceptual design for neutron scattering capability (K. Kelly)





(left) Schematic of solenoid spectrometer for radioactive isotope studies (H. Y. Lee)

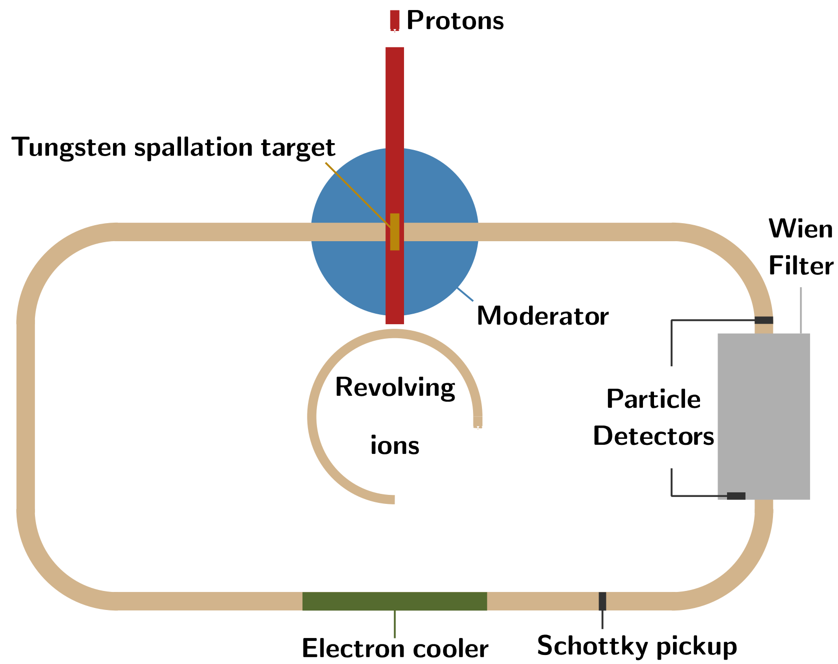
(right) Neutron target conceptual rendering for long-term radionuclide measurements (S. Mosby)



- **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.



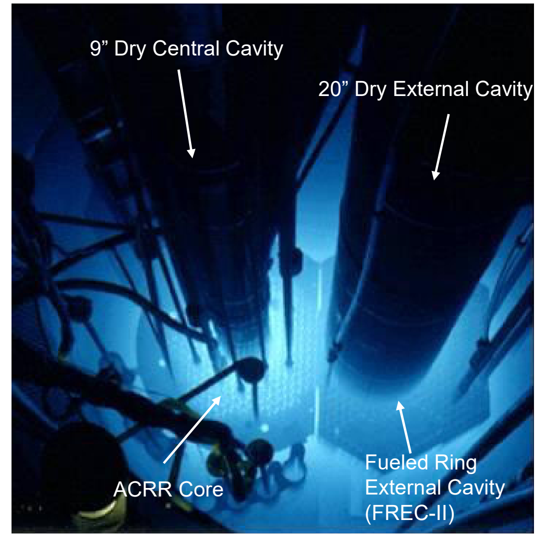
Schematic rendering of the neutron target concept from LA-UR-21-30261. 800 MeV protons (red) impinge on a tungsten spallation target (brown) to produce neutrons which are moderated in the sphere (blue). The ion storage ring penetrates the moderator such that neutrons flow through a section of the ring,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

S. Mosby et al., LA-UR-21-30261

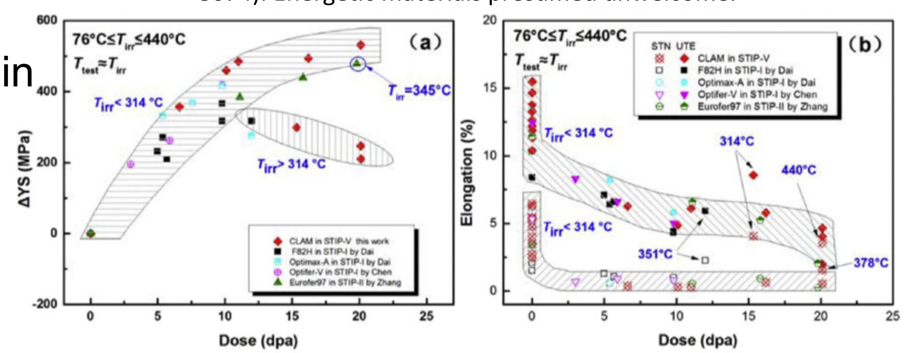
A burst facility offers a powerful complement to other facilities (if you can make it work)

- 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 a this problem using existing PSR – need 10x more dose

Facility	Volume [cm3]	Intensity [n/cm2]	Pulse width[μs]	Target Mat.
SPR	32000	$5*10^{14}$	55	HEU
WSMR	785	$2*10^{14}$	45-75	HEU
SPEF	7623	$5*10^{13}$	5	LEU



SNL ACRR & FREC operating at 2 MW steady-state. (SAND2017-8674). Energetic materials presumed unwelcome.

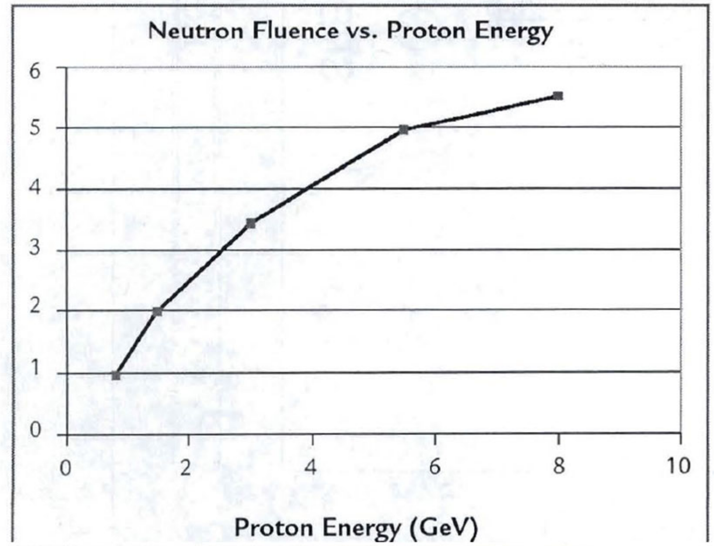


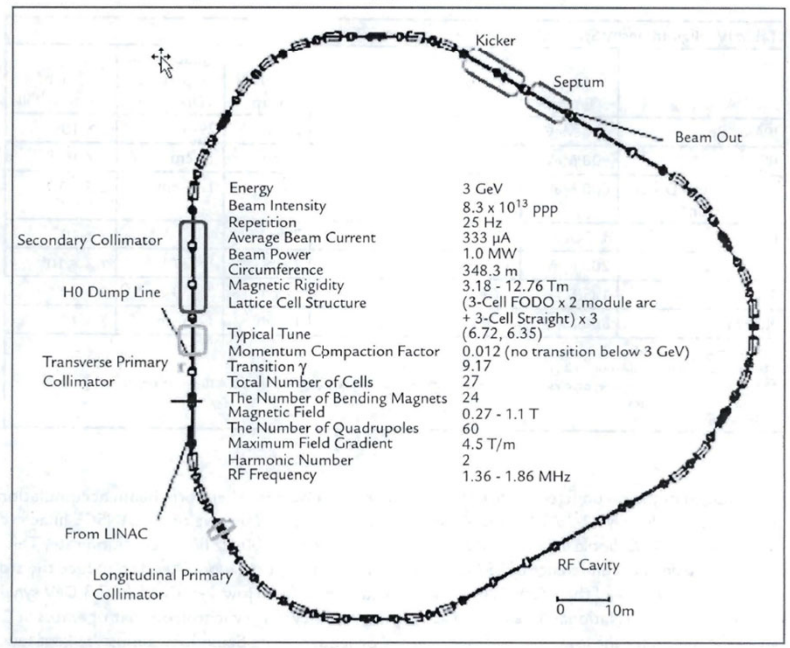
Survey of yield strength variance and elongation of RAFM steels exposed to neutron irradiation (Ge et. al. Journal of Nuclear Materials 468 (2016))

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

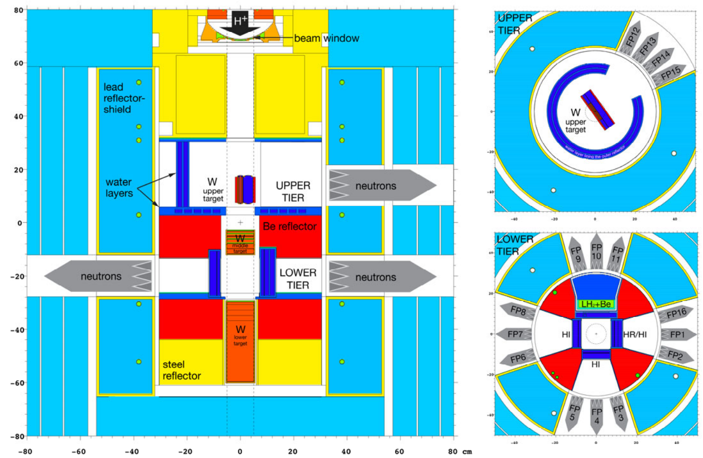
- Near-linear gain in neutron production until ~4 GeV – so inject 800 MeV protons into a synchrotron and go up from there.
- Still need more protons in a pulse than existing PSR, so would need to design accordingly.
- Existing rings (e.g. 3 GeV Rapid Cycling Synchrotron at J-PARC) could provide a place 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



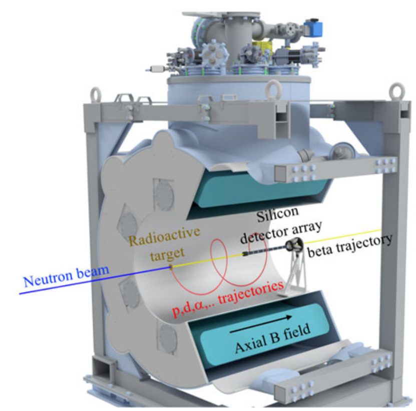


Where NNSA-relevant concepts landed (1): evolutionary improvements now, and natural alignment with LANE

- 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



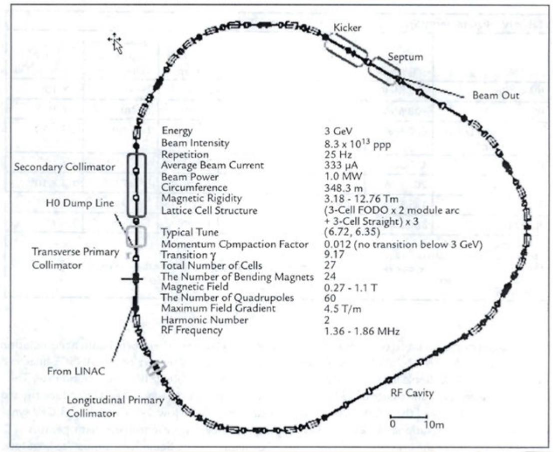
Mark IV 1L Lujan target



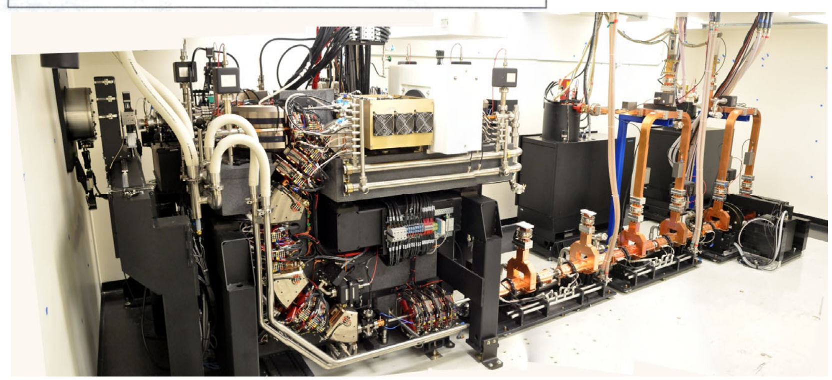
Proposed solenoid spectrometer for radioactive isotope studies

Where NNSA-relevant concepts landed (2): longer term (2030+), we are developing mission needs for more ambitious options

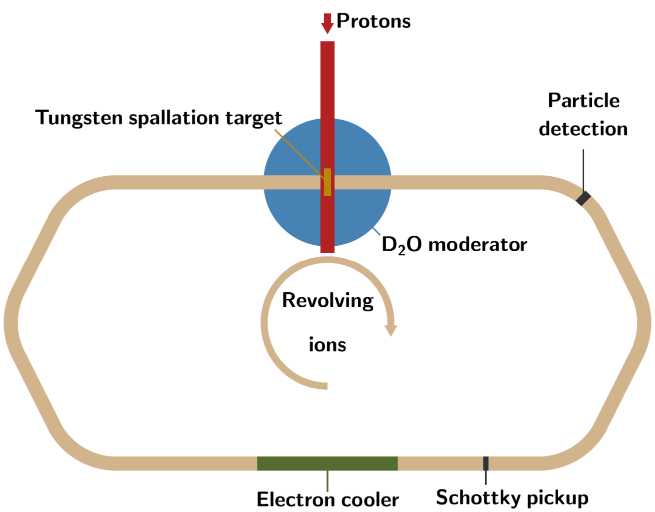
- Experimental area enhancements:
  - 3-5 GeV pRad
  - Neutron target
  - Burst facility
  - ICS x-ray source
- These upgrade paths enable – or at least do not interfere with – a future MaRIE facility as they would occupy different locations at TA-53.



JPARC 3 GeV proton synchrotron



Commercial ICS source



Neutron target for nuclear physics

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*