New capabilities for radiation effects

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Background

- Semiconductor devices are used in all aspects of modern life and the reliability of these devices is a major concern and may limit their applicability and performance
- LANSCE is a flexible source of radiation that can be used effectively to address many aspects of this problem
- This presentation will describe several areas where LANSCE capabilities are presently being used and areas where LANSCE can expand its role by expanding and upgrading its facilities

1 quintillion = 10^{18}
100 billion transistors for every man, woman and child on planet

There are two regimes of radiation effects

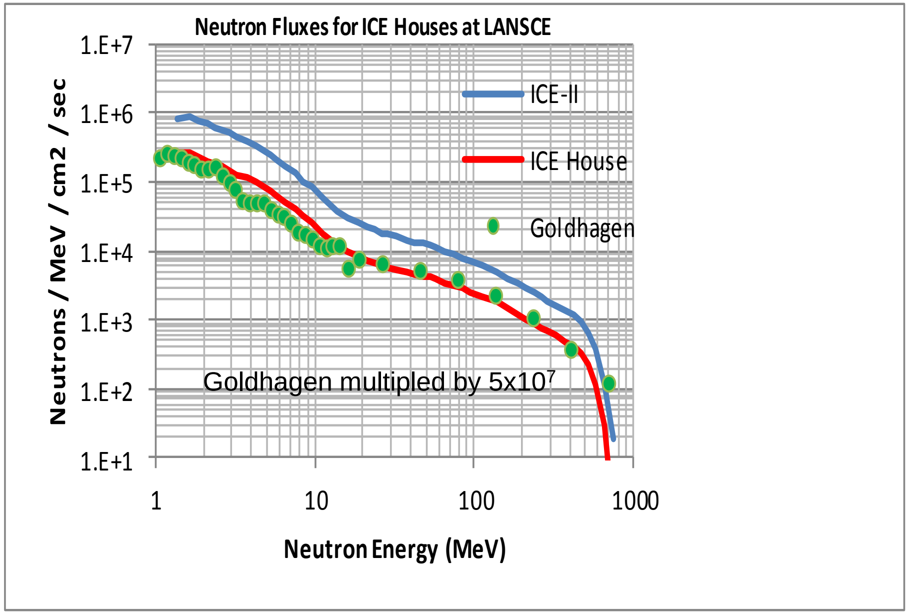
- **Massive doses of radiation** (similar to changes in mechanical properties- swelling, cracks, embrittlement- depends on DPA)
  - Significant displacements change electronic characteristics of silicon
  - Weapons environments – gain changes in transistors
  - Reactor (fission) / fusion environments
- **Single event effects:** a single particle (neutron reaction) deposits charge in a sensitive volume and causes a failure-- No mechanical analog
  - Hard failures – a failure results in a damaged device
    - Latchup
    - Gate rupture
    - Power devices (IGBT)
  - Soft errors- only data is corrupted deposited charge causes bits to flip and data to change but the device continues to operate normally
    - Single bit flips
    - Multiple bit flips- few % for single flip rate
    - The failure rate from neutron induced single event upsets is equal to all other failure rates combined
  - Accelerated testing is crucial

Radiation effect users at LANSCE

1. Avionics industry- Single event effects (SEE), requires both high-energy and thermal neutrons. Neutron flux at aircraft altitudes ~300 times sea level. First recognized by the Boeing Corp in certification of 777.
2. Semiconductor industry- Wide range of SEE studies, computer chips, automotive, graphics, servers, FPGAs, etc.
3. Medical equipment- pacemakers, etc.
4. High performance computers- silent data corruption
5. NASA- Radiation effects in space- Johnson Space Center –require 200 MeV (and above) protons- IUCF has shut down. Also needs neutrons
6. ISR Division- Radiation effects in space, requires protons and neutrons
7. Sandia- SEE and weapons effects
8. Universities- Radiation effects programs, radiation effects in detector materials and electronics

Particle beam capabilities at LANSCE – present and future

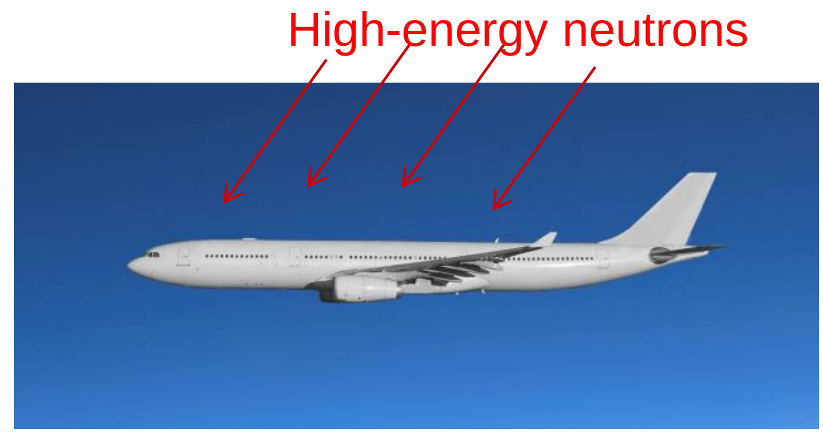
- ICE Houses: 2 flight paths to provide cosmic-ray neutron spectrum
- Lujan Center for thermal energy neutrons
- High-intensity irradiation facility
- Blue Room: Variable energy proton beams. Large impact on operation of LANSCE neutron sources
- **“Low” intensity (< 100 nA) variable-energy (200-800 MeV) proton beam in Area-A**

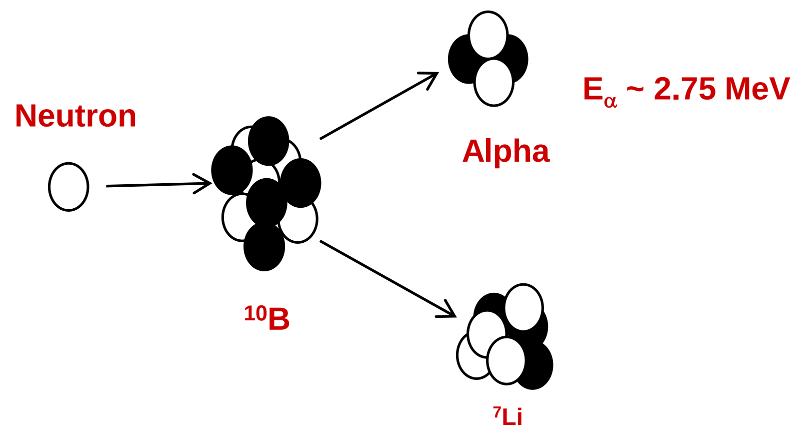


- **Development of thermal neutron beam at LANSCE**

Measurement of thermal neutrons in aircraft

- Recently the avionics community has become concerned about the effects of thermal neutron on flight control electronics
- High-energy neutrons are thermalized in the aircraft fuel, passengers and aircraft materials.
- These thermalized neutrons can interact with ^{10}B that is in the semiconductor parts. ^{10}B can capture a neutron and produce an energetic alpha particle which can deposit enough charge to cause a single-event upset.
- To understand the effect of thermal neutrons in aircraft need to know:
  - Thermal neutron intensity in airplane—Airplane dependent- Tinman
  - Effect of thermal neutrons on semiconductor devices- measure at Lujan Center
  - Model / simulations of thermalization of neutrons in aircraft- MCNP calculations

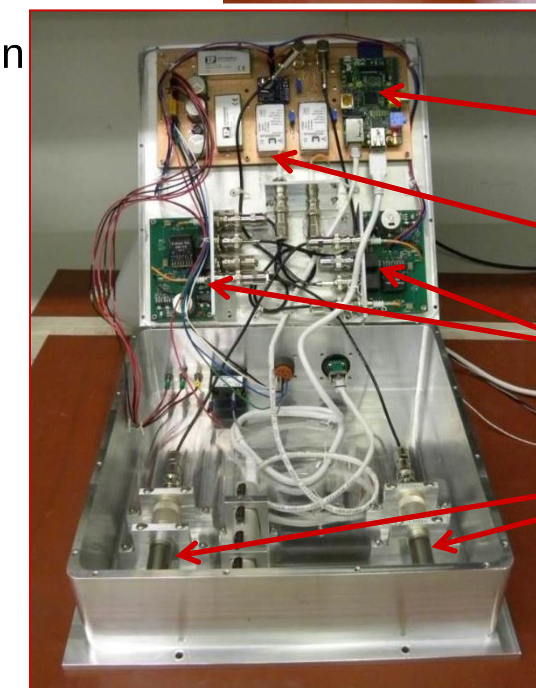




Measurement of thermal neutron intensity in aircraft--Tinman

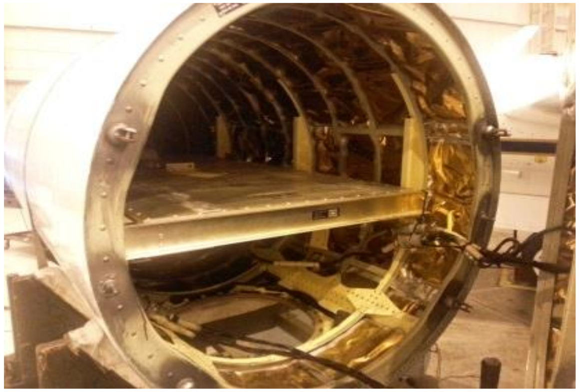
- A detector was designed in LANSCE-NS to measure thermal neutrons in aircraft
  - Two cylindrical ^{3}He ion chamber detectors. (~1 cm diam 4 cm long)
  - One detector was bare, one detector was shielded with cadmium to block thermal neutrons
  - The difference in count rates between these two detectors gives the thermal neutron rate
- Final detector was fabricated by ISR Division to space specifications.
- Uses a Raspberry Pi computer for DAQ

Vibration damping springs

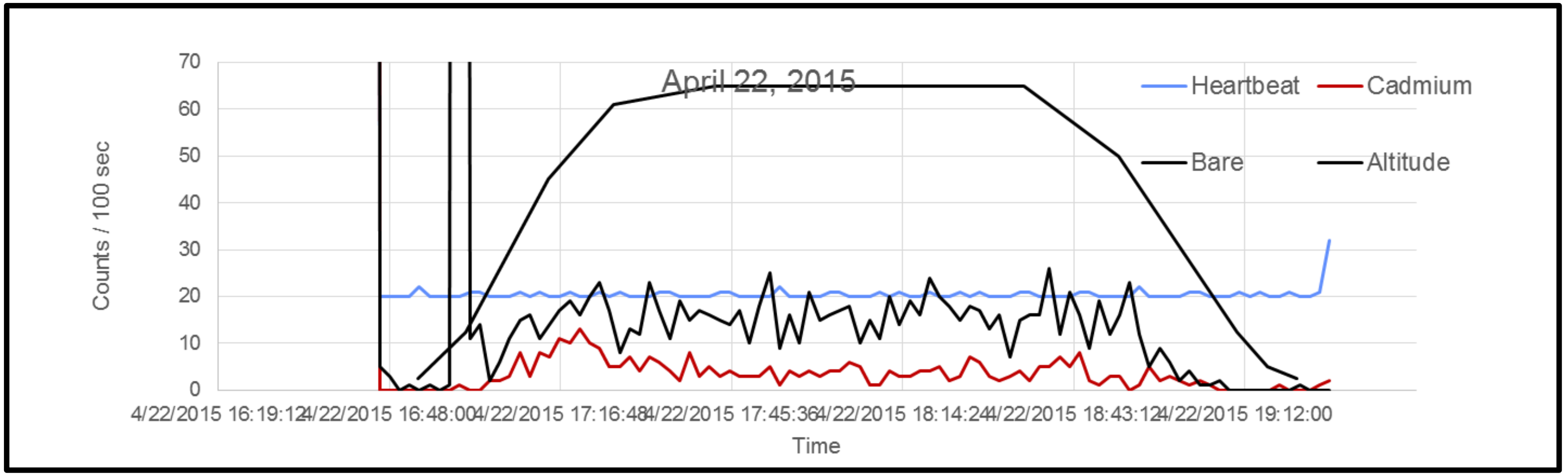


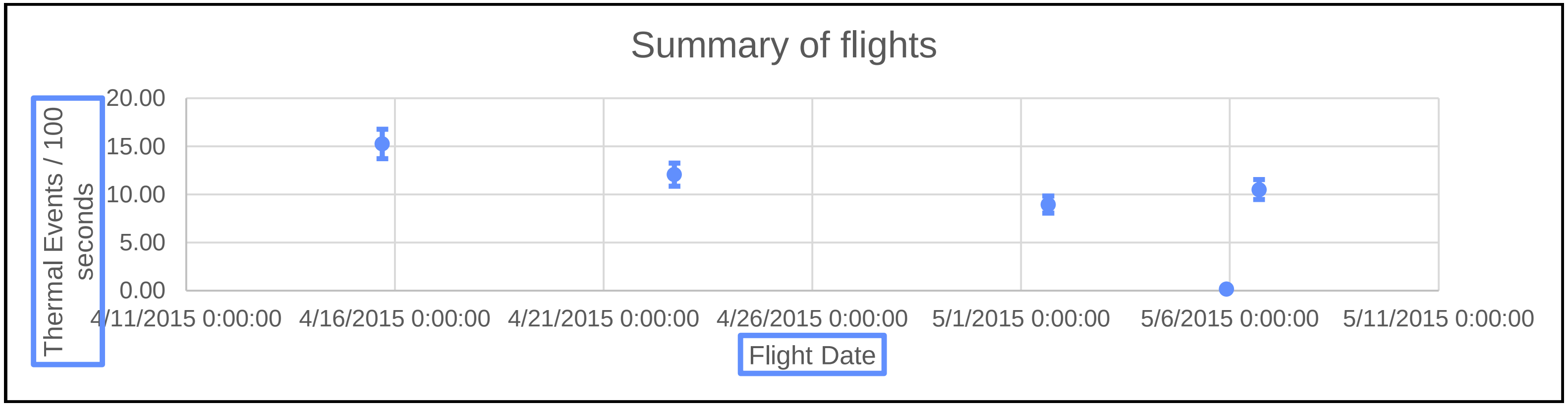
Tinman flew in an ER-2 airplane

- **ER-2 is civilian version of U-2 spy plane**
- **Maximum altitude is classified**
- **Flew on 4 flights from NASA Armstrong Flight Research Center in Palmdale Ca**



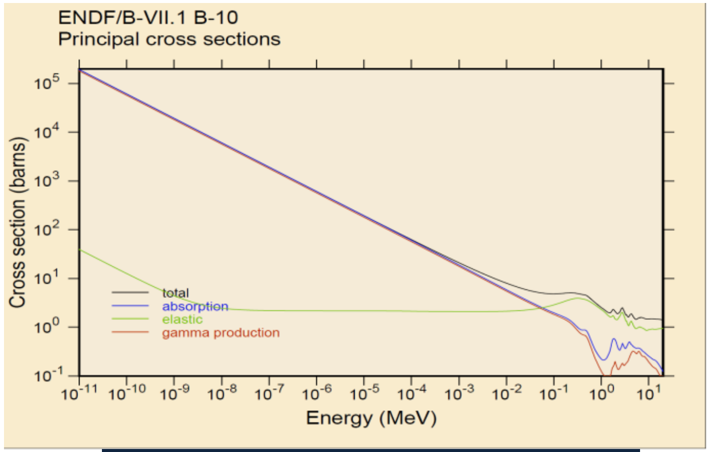
Preliminary results look like detector operated correctly

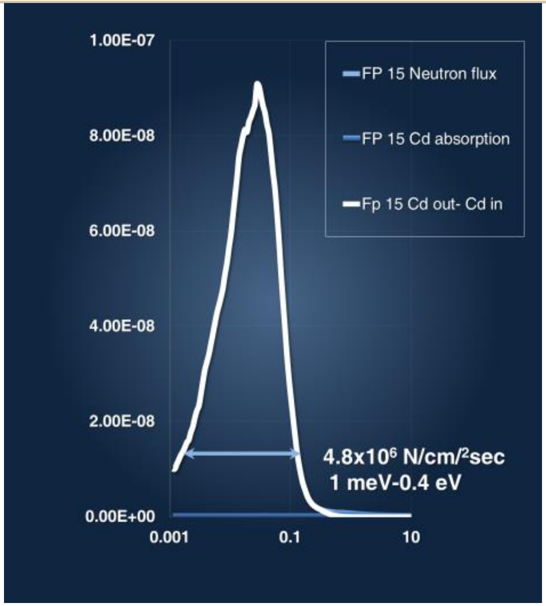




Thermal neutron testing at Lujan Center

- First measurements of thermal neutron SEE were performed 2014 cycle at Lujan Center on FP 12
- Used Cd filter technique to get a pure thermal spectrum
- Problem was FP12 had liquid hydrogen moderator which was not prototypic of temperature of neutrons in aircraft
- DAQ was made for very low energy neutrons. Integration time was on order of several microseconds.
- Next run cycle
  - Develop a room temperature FP probably FP 15 (PCS), FP16 (Pharos) or FP 12 with water moderator
  - Upgrade signal processing electronics. 100 ns integration times





Next Steps

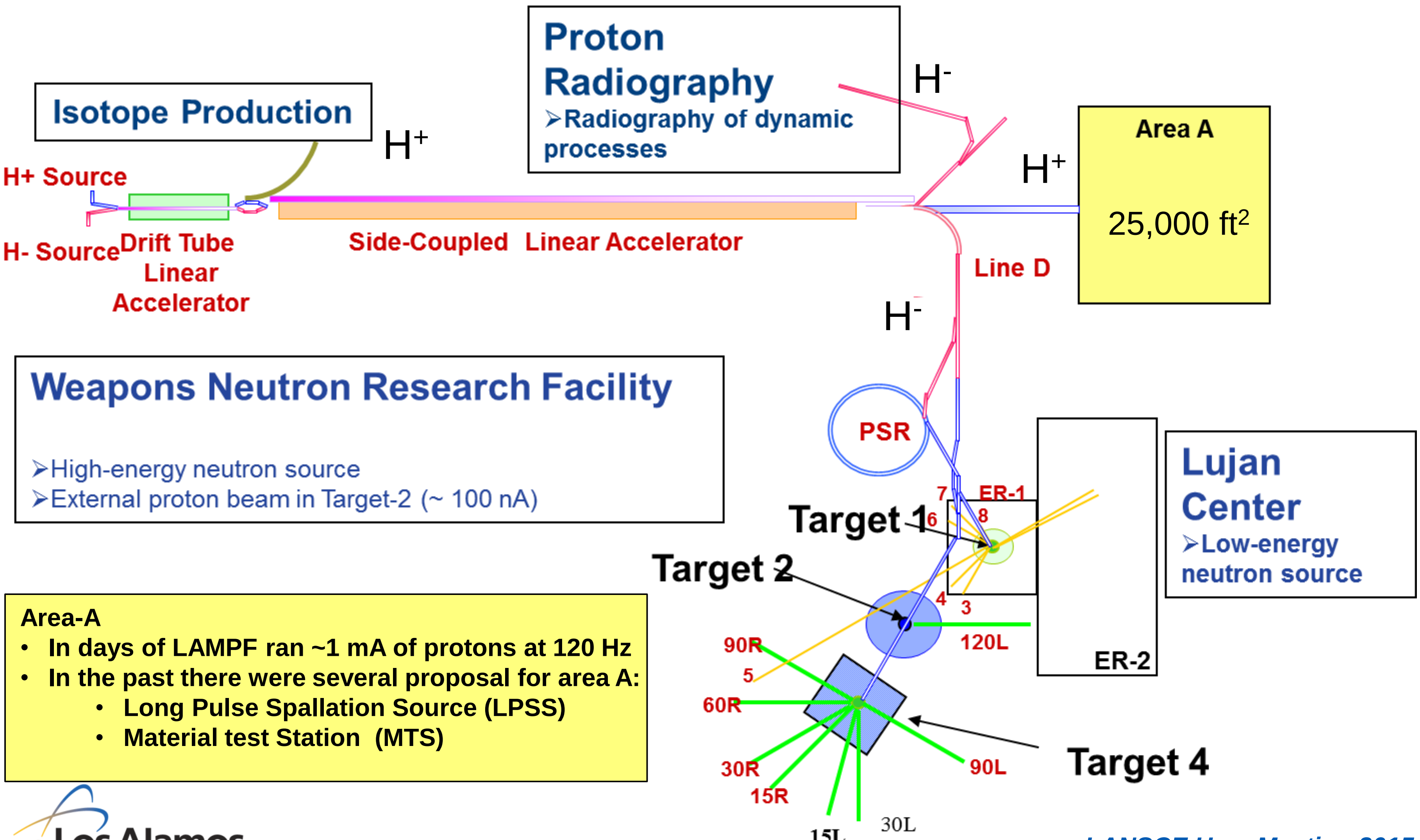
- **Measure thermal neutron intensity on commercial (larger) airplane**
- **Measure effect of thermal neutrons on semiconductor devices at Lujan Center → new flight path**
- **Develop Monte-Carlo model of airplane and compare predictions of MC simulations with measurements**

- **Development of proton source at LANSCE**

Low-intensity proton beam in Area A

- With the closing of IUCF, there is a serious national need for low-current proton beams in the energy range from 200 – 800 MeV. Last year IUCF had 1500 hours of irradiations at ~$500-$800 / hour= ~ $1M. Other places charge more.
- Although such beams are available in the Blue room, the impact is large for Target-4 and Target-1 when running at other than 800 MeV or using the PSR beam
- A low-power (100 nA) experimental area could be established in Area A, which would meet the needs of NASA, ISR, Isotope production, Industry, Universities, detector materials irradiation and other users **without impacting the present research program at LANSCE**
- 1 Hz of H+ beam delivered to this area would produce as much as 1 mA/120Hz=8 uA of average beam current. 1 Hz operation would have insignificant impact on other beam users.
- 100 nA (=6x10^{11} protons/sec) is roughly the current presently delivered to Target-2. Target-2 is shielded with approximately 22 feet of dirt. This is roughly the same as 4 feet of steel. I believe we have sufficient shielding on hand to construct a small experimental cave (~15' X 20') in Area-A.
- Establishing a of low-power experimental area in Area-A will be a step towards high-power operation and other applications

LANSCE accelerator and experimental areas

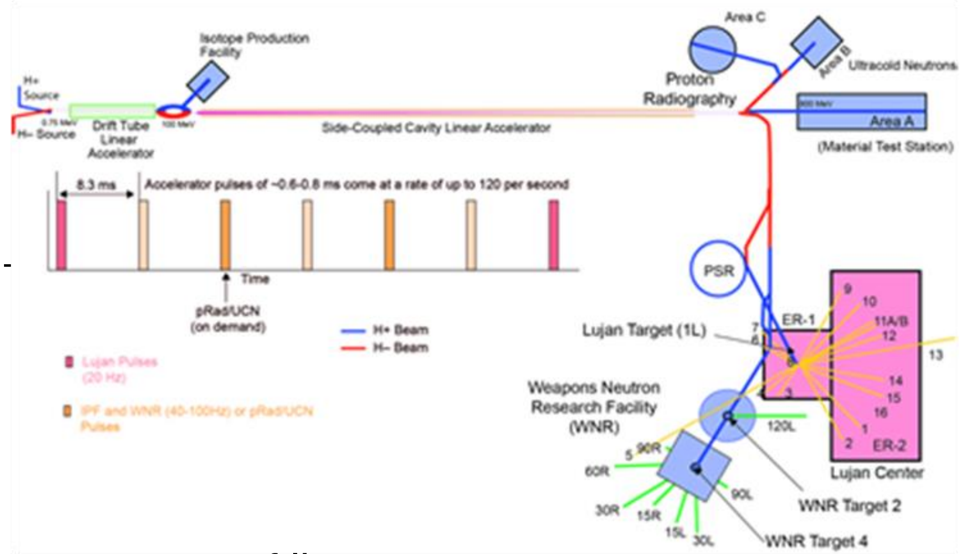


Area-A
- **In days of LAMPF ran ~1 mA of protons at 120 Hz**
- **In the past there were several proposal for area A:**
  - **Long Pulse Spallation Source (LPSS)**
  - **Material test Station (MTS)**

Low-intensity proton beam in Area A (2)

- Developing this experimental area will exercise several capabilities that will be necessary for any future use of Area-A. These include:

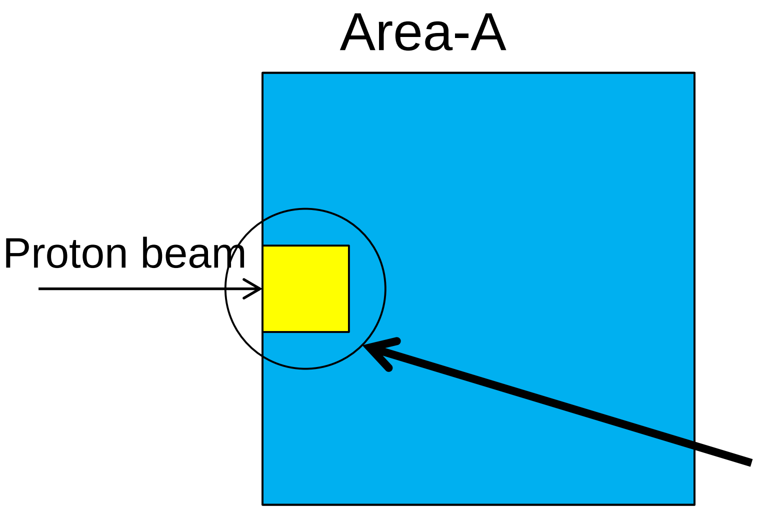
- Simultaneous transport of both H+ and H⁻ beams through 805 MHz part of the linac
  - Alignment needs to be checked
  - Haven't sent beam down to Area-A in ~15 years

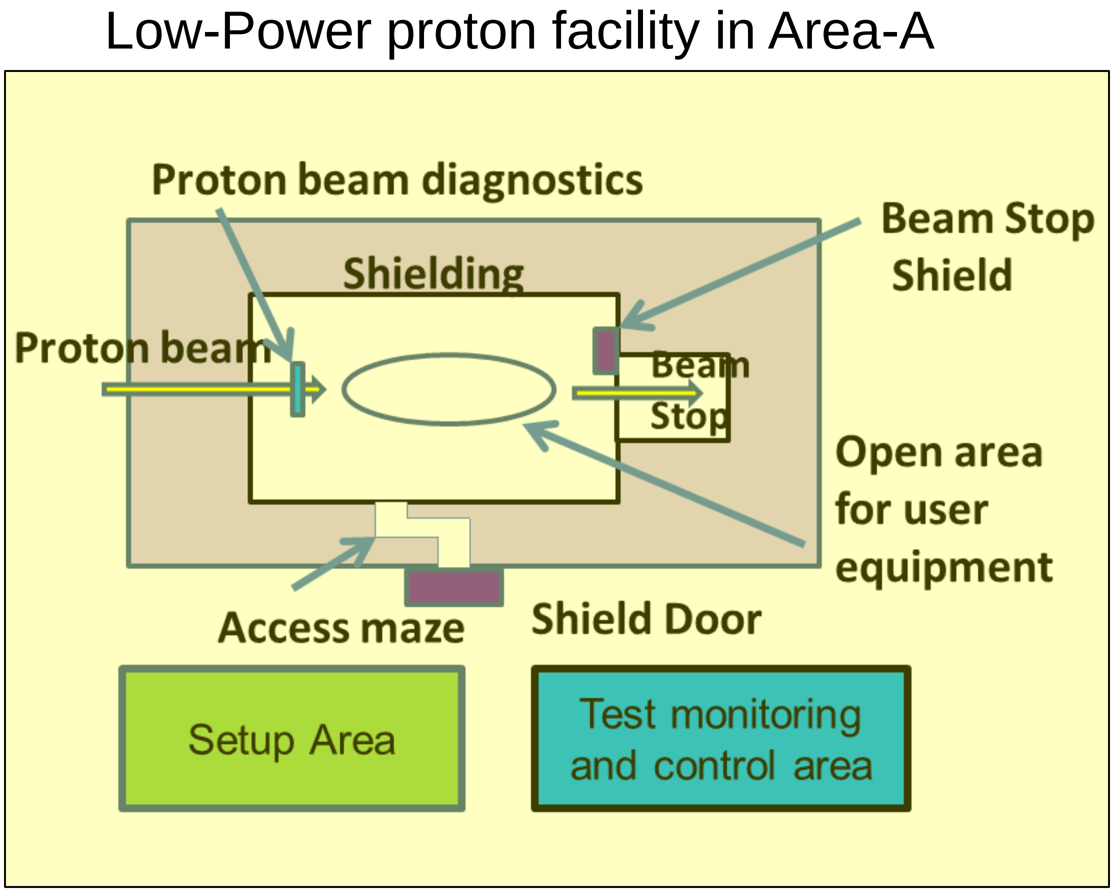


- Switching the beam between IPF and 800 MHz part of linac-
  - Need glass beam line (~$100K)
  - Have pulsed magnet, modulator
  - New lattice parameters for IPF and Area-A operation

- Operating dual energy in the accelerator
- All the other issues with beam transport to Area-A (magnets, beamlines, etc.) that have developed since Area-A was last used.

New facility for proton irradiations in Area-A





- **Area-A has excellent infrastructure**
  - Overhead crane
  - Electrical power
- **Area beyond experimental area can be used for other activities**

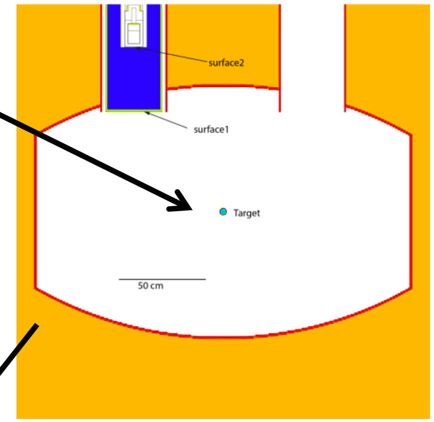
Next steps for protons in Area-A

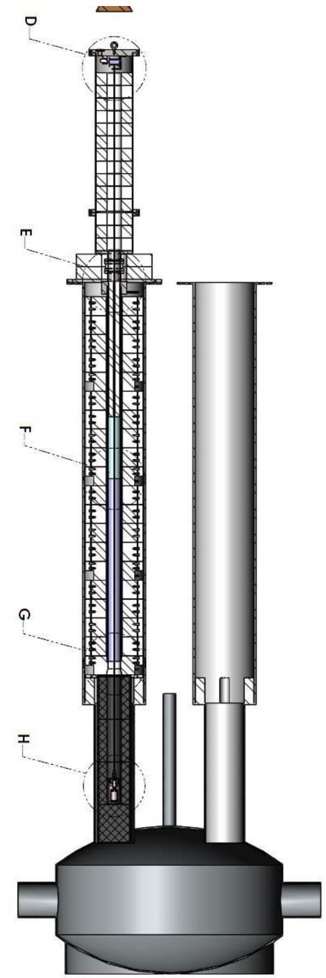
- **Explore the interest of possible users for low-intensity proton beams**
- **Engage community in design and specification for new facility**
- **Develop cost and schedule estimate for installing target area in Area-A**
  - Beam transport, control systems
  - Experimental area design, shielding, beam stop, etc.
  - Proton beam diagnostics
  - Everything else
- **Write proposal and give to Lab management**

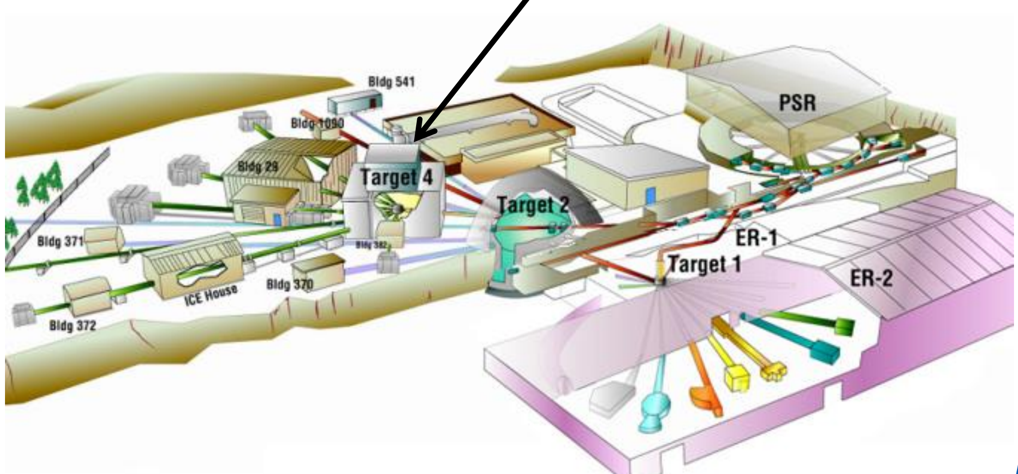
High-intensity neutron irradiation at Target-4 “East-Port”

High-fluence neutron irradiations are performed at the Target-4 “East Port”

- **0.9 m from neutron production target**
- **Neutron flux ~3x10^{13} n/cm^2/day for 1-100 MeV & 100-800 MeV**
- **Sample holder – 8.5 cm dia., 20 cm length**
- **Now irradiating**
  - LYSO (Cerium-doped Lutetium Yttrium Orthosilicate) - rad-hard scintillator studies (Caltech+LANL)
  - GaN, SiC photodiodes, LEDs, HEMT, MOSFET - semiconductor radiation hardness studies (UNLV+LANL)



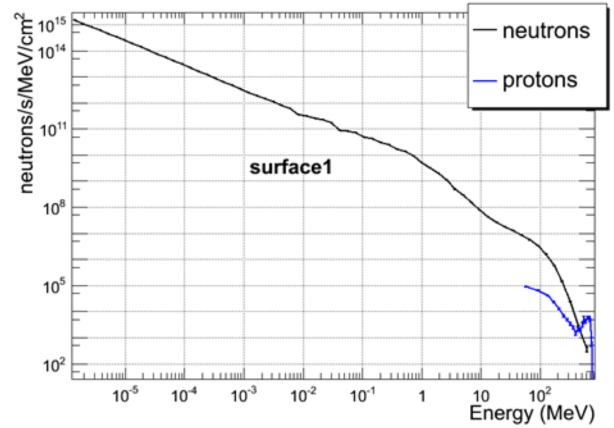


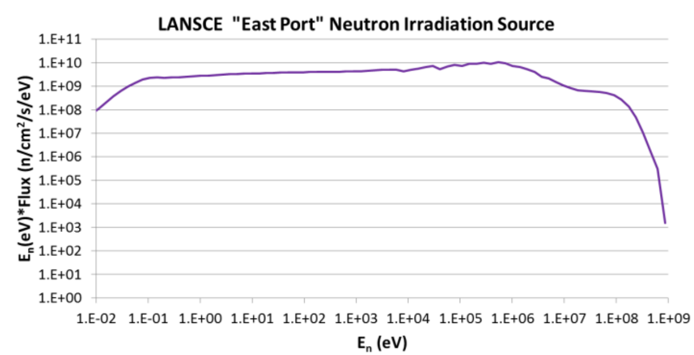


East Port Neutron Energy Spectra Cover a Wide Range

Energy	Neutrons/cm²/day
1eV-1keV	5.9E+13
1keV-1MeV	1.1E+14
1MeV-100MeV	2.5E+13
100-800MeV	2.9E+13

- The neutron spectrum can be moderated for greater thermal neutron flux
- Designed and implemented for ^{99}Mo production from ^{235}U fission
- Present applications are
  - Electronics for NIF diagnostics and space applications
  - Scintillators for LHC future detectors and MaRIE
- Future – Potential for Isotope Production, Materials Damage, High-Energy Dosimetry





Conclusions

- **There are several exciting new capabilities that we are considering for electronics and materials irradiations at LANSCE**
  - Room-temperature thermal neutron irradiation capability
  - Low-intensity proton beams (250 MeV – 800 MeV, ~ 100 nA)
  - High-intensity neutron irradiations
- **We are looking for comments and input from our user community on these upgrades**