Overview of Imaging at LANSCE and LANL

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Introduction – Neutron Imaging Advances at Los Alamos

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- Many types of imaging are in use at LANL
  - Photon (Microtron – to 15 MeV, DARHT)
  - Proton (800 MeV) short pulse, dynamic imaging, primary beam
  - Neutron (thermal-epithermal, high-energy), secondary beams
  - Muon – using natural cosmic ray background
- Goal is to observe properties of objects and phenomena that can't be seen with other probes – non-destructive evaluation (NDE)
- Photons (x-rays) scattering depends on atomic number
- Protons are sensitive to material density
- Neutrons have a scattering dependence that varies widely with energy and element/isotope
- All of these probes are complementary, combined "multi-probe" imaging can be a very powerful technique

Imaging comparison

- X-Ray – good for small higher-Z objects in lower-Z materials e.g. bones or metal in the human body
- Thermal neutrons – good for hydrogenous materials in heavier materials e.g. a rose in a lead shielded container, water or oil in metal systems
- High-energy neutrons – hydrogenous materials in dense, fissionable materials
- New – epithermal neutrons with energy-selective imaging, e.g. fission products in uranium fuel rods
- Muons – sensitive to high-Z materials, good for large objects and radiation sensitive objects (or people) that are not amenable to other techniques

1896 x-ray image
of William Crooke’s hand.

Comparison of Imaging Characteristics of Different Probes

Probe	Source example	Typical Imaging Time Scale	Sensitive to	Resolution	Comments
Photon	LANL Microtron	s	Electrons, density	100 μm	High intensity, economical
Proton	LANSCE Area C	ns – μs repetition	density	10-100 μm	High Intensity, fast, repetitive, focusing
Thermal Neutron	NIST/PSI	ms - s	nuclei	10-100 μm	Good intensity
Thermal+Epithermal Neutron	LANSCE Target 1 Lujan Ctr	10-100s	nuclei	55-100 μm	Fair intensity, nuclear resonance selection
High-Energy Neutron	LANSCE Target 4 WNR	10-100s	nuclei	100 μm – 1mm	Fair intensity, very penetrating, energy range selection
Muon	Cosmic Rays	Hours/Days	Electrons, density	cm	Low intensity, very penetrating, large objects

Technical Details

- Beam Resolution L/D
  - D = collimator diameter
  - L = distance from collimator to sample
- Field of View – beam spot size
- Intensity – time to get an image with enough counts
- Detectors – resolution (pixel size), efficiency, energy response, timing
- Neutron converters – scintillator screens

Neutron Imaging at LANL – History and Recent Developments

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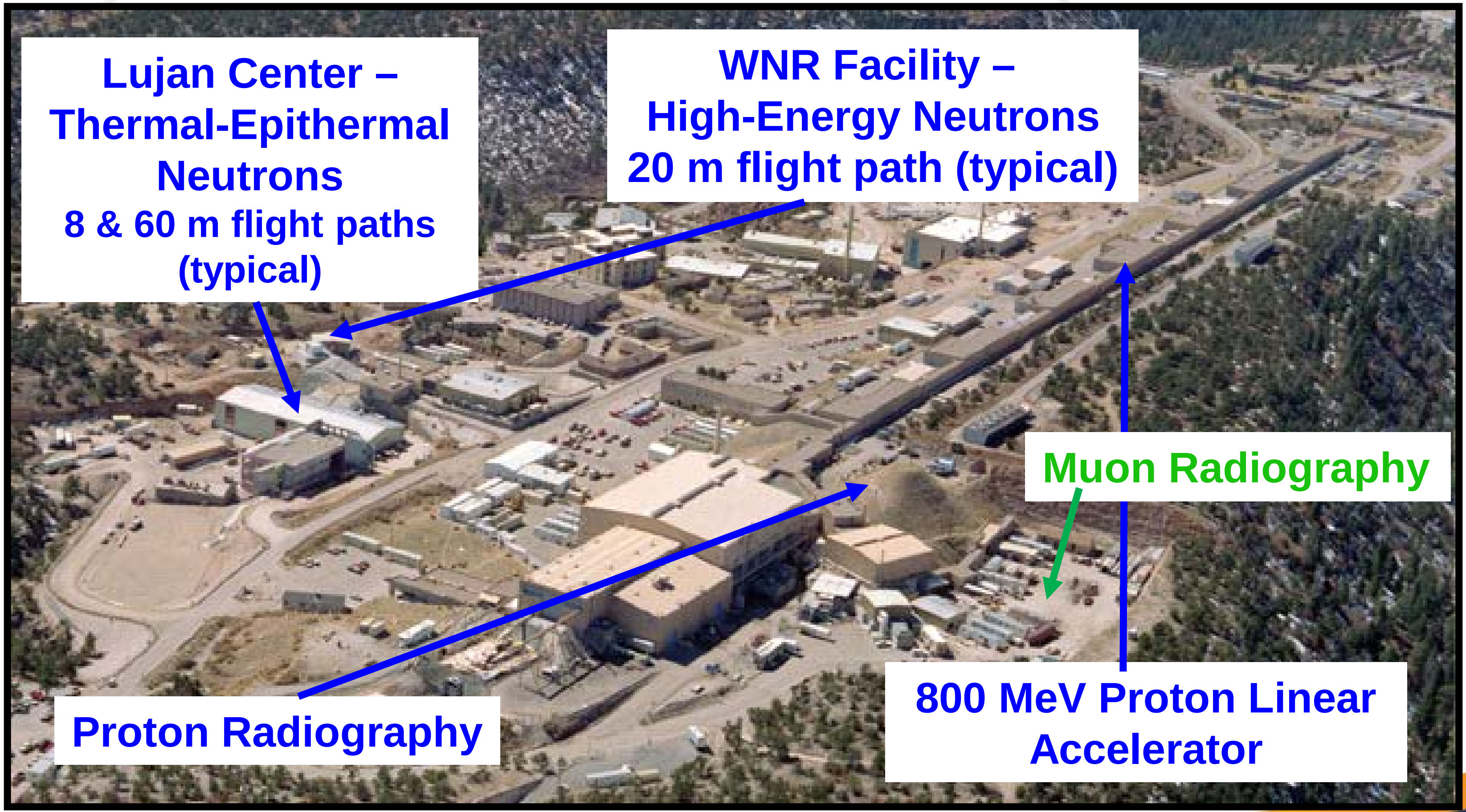
- At LANSCE, thermal, epithermal, and high energy neutrons are available from two spallation sources at the 800 MeV proton accelerator
  - Neutron imaging was investigated using these sources in the 1990s
  - Good and useful images were obtained, but for a variety of reasons the capability was not continued
- Improvements in detectors and computing have enabled new capabilities that use the pulsed beam properties at LANSCE
  - Time-of-flight (TOF) neutron energy selection

Accelerator Layout Showing Imaging Locations

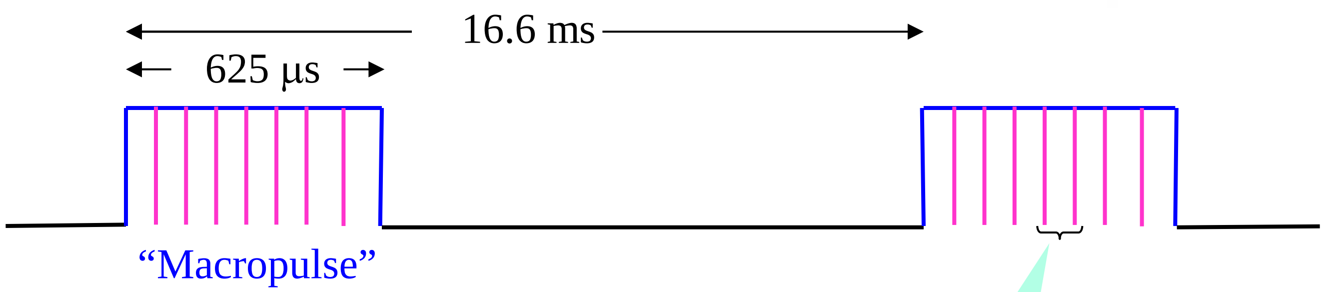


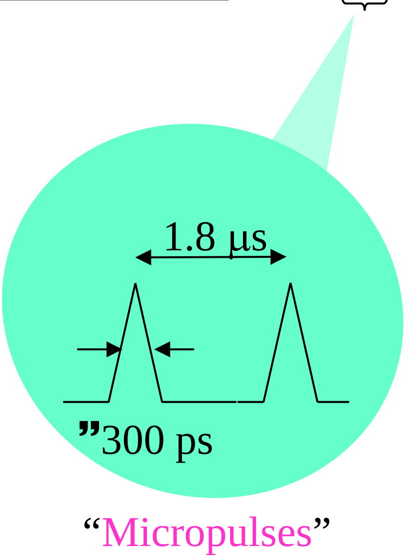
Proton Beam Time Structure and Pulse Widths

- WNR Facility (Target 4)
  - Width micropulses < 1 ns (FWHM) typical
  - Spacing 1.8 μs (typical) variable but greater spacing reduces time-averaged intensity
  - Macro pulses 650 μs (typical), 8.3 ms spacing
- Lujan Center (Target 1)
  - Width ~ 125 ns (FWHM)
  - Spacing 50 ms (typical)

The WNR Pulsed Proton Beam

Typical WNR Proton Beam Parameters





Energy = 800 MeV

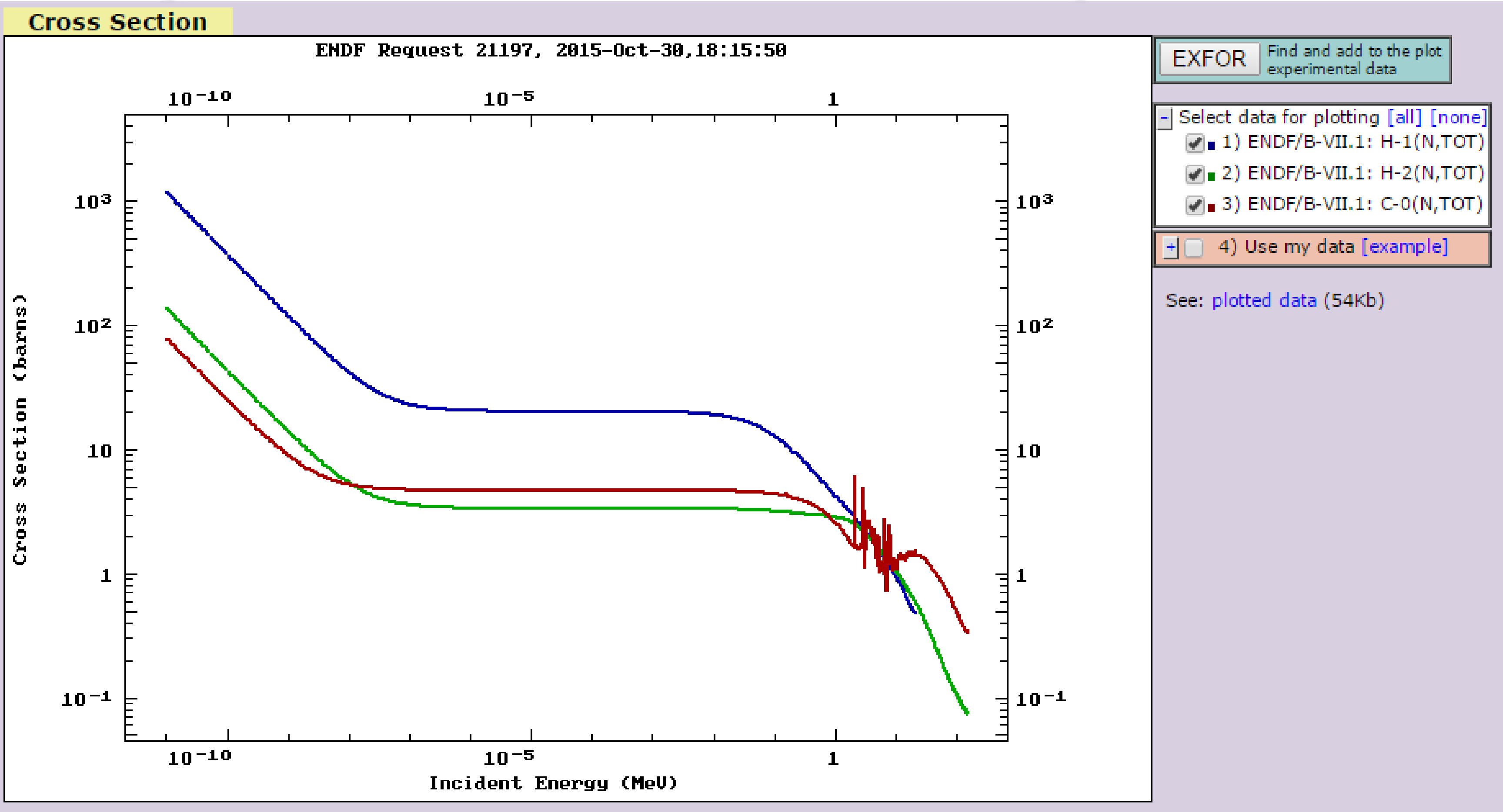
Average Current ~ 5 µA

Protons/Micropulse ~ 7×10^8

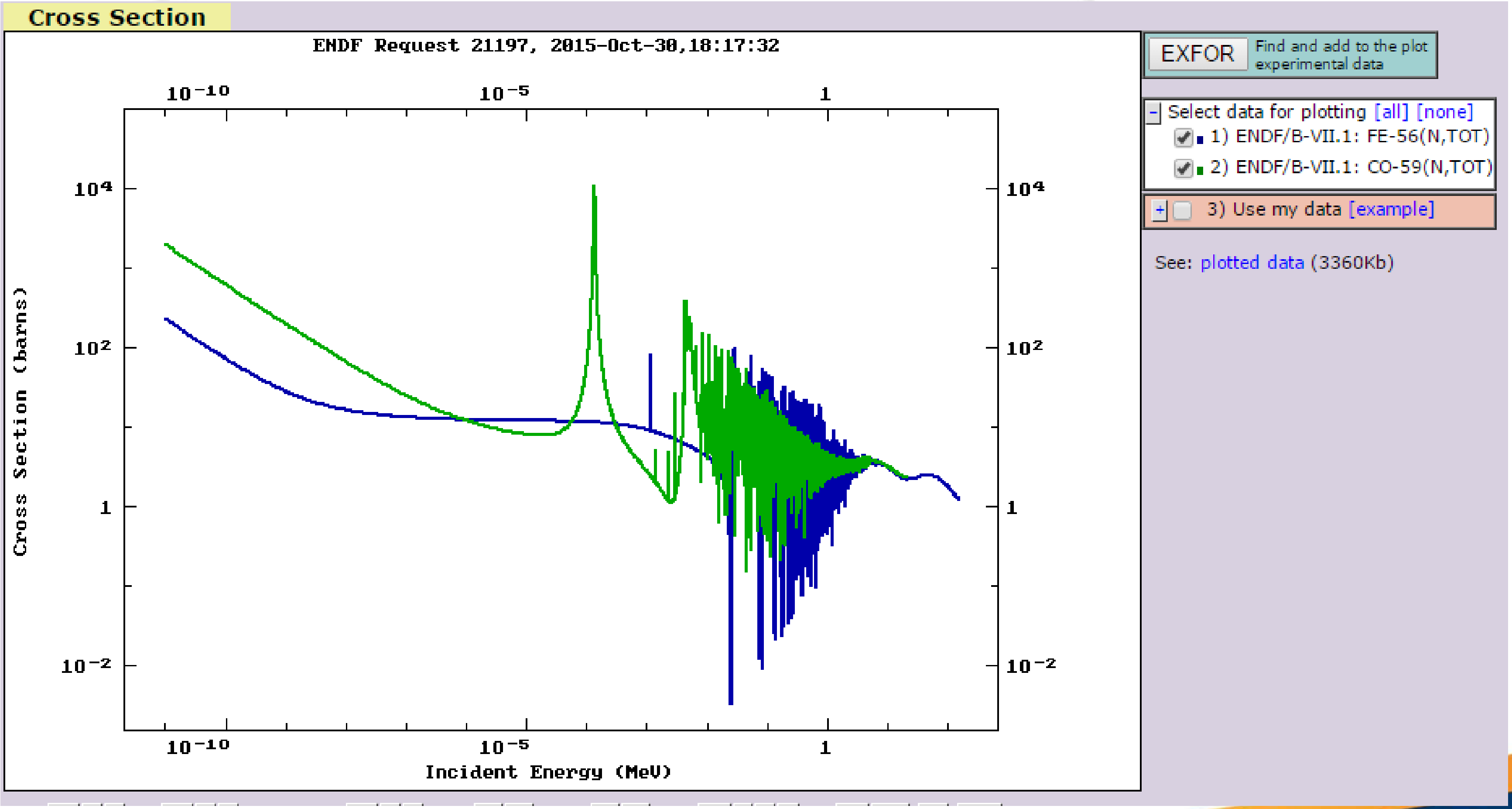
Time Structure of High-Energy Proton Accelerators in Operation

- SINQ (PSI, Switzerland) – CW – thermal and cold neutron beams
- J-PARC (Japan) – 3 ns or chopped, but chopped operation is limited due to intensity demands
- ISIS (RAL, United Kingdom) – double-pulsed
- LANSCE (LANL, U.S.) Single pulses
  - Advantages in pulse width and spacing for energy-selective neutron imaging

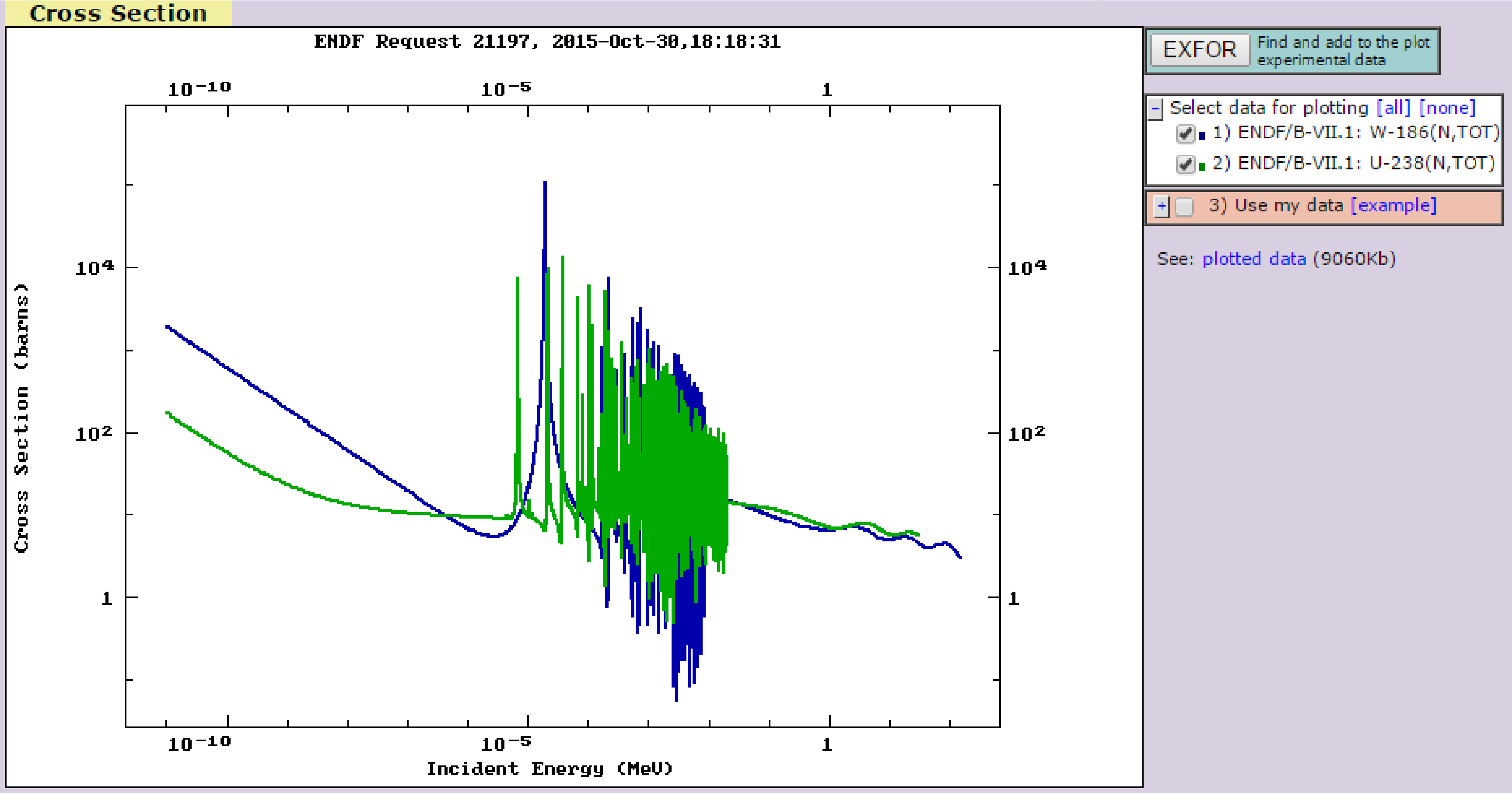
Neutron Total Cross Section Comparisons – H, D, C



Neutron Total Cross Section Comparisons – ^{56}Fe, Co



Neutron Total Cross Section Comparisons – ^{186}W, ^{238}U



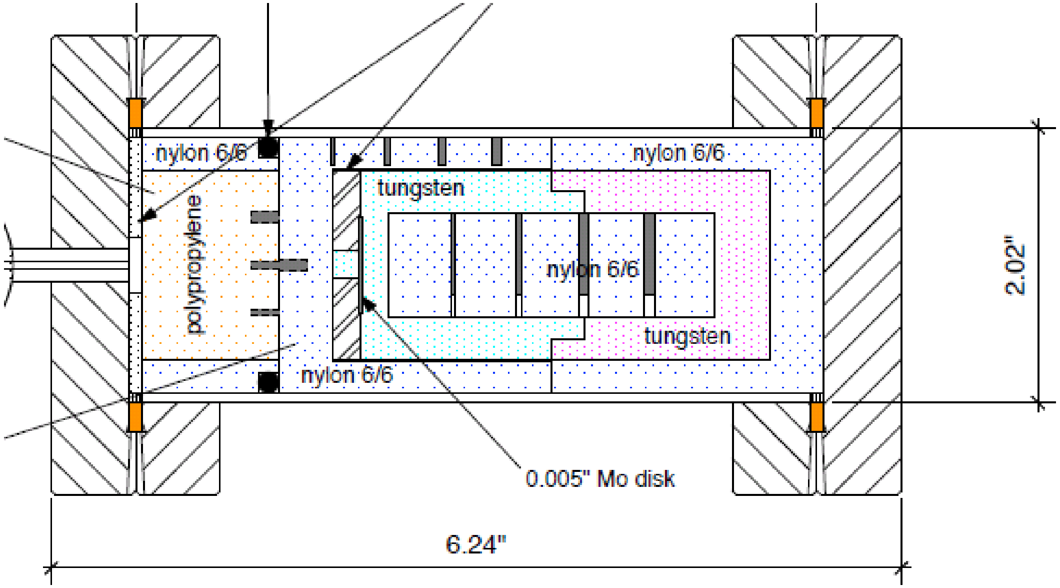
Detectors in Use at LANSCE

- The following give highest intensity in our experiments
- (1) Medical X-ray image flat panel amorphous silicon (aSi) detector with PP+ZnS(Ag or Cu) neutrons – no TOF but short imaging times, gamma-ray-insensitive

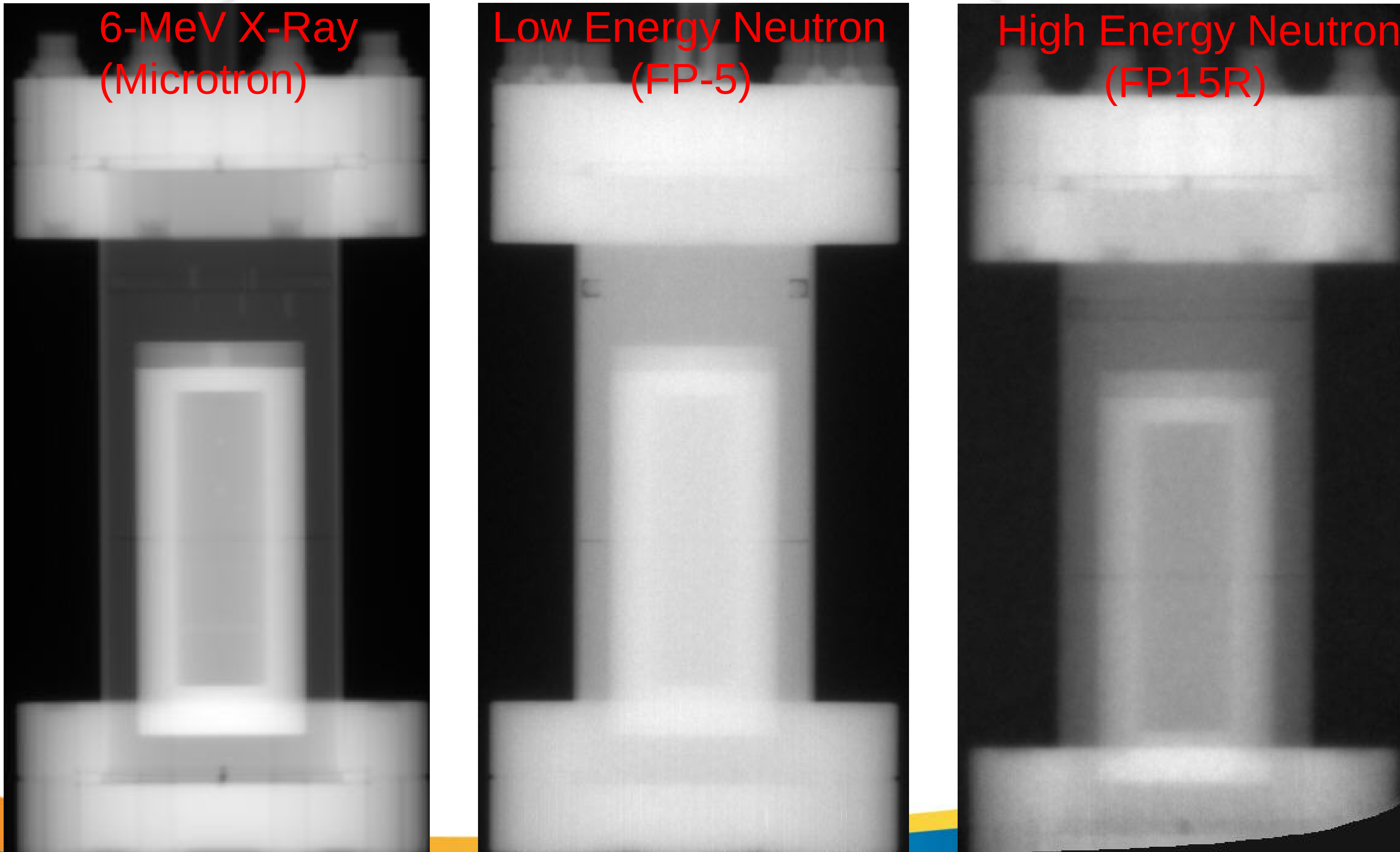
- (2) aSi flat panel with Gadolinium Oxysulfide (Gadox) scintillator screen for thermal neutrons
- (3) intensified Charge-Coupled Device (iCCD) c plastic scintillator and mirror – gives large field of view and TOF or scatter rejection (mono-energetic source), used for high-energy neutrons at present
- (4) B/Gd-doped Micro-Channel Plate (MCP) with Time-Pix (CERN) fast readout - measures data for all neutron energies of interest at the same time, used at the moderated source at present

A Multi-Element Object Used to Compare Images from Photons, Low-Energy, and High-Energy Neutrons

- Object is a cylinder consisting of steel, tungsten, molybdenum, nylon and polypropylene parts



Radiograph Comparison for a Multi-Component Object about 16 cm tall



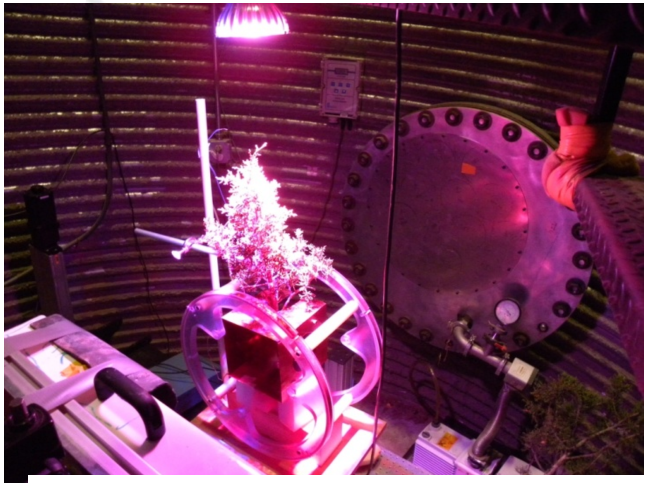
Note: Radiographs are not at identical angular orientation or scale

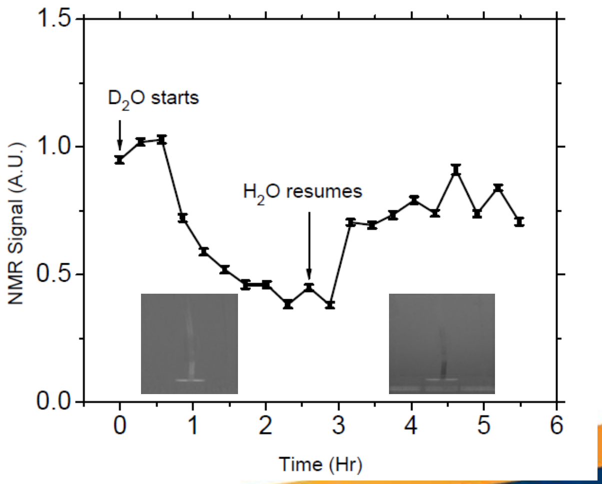
Three examples demonstrate some of the applications of neutron imaging

- (1) Trees
  - Water flow in living specimens
- (2) Nuclear reactor fuel rods
  - Inclusions and fission products in uranium oxide
- (3) Phantom in thick uranium metal
  - Aluminum, steel, and polyethylene of varying thicknesses behind a thick uranium plate

Combining Capabilities to Reveal How Trees Transport Water

- Using the Lujan Center Flight Path 5, 60 meter station (the Silo) simultaneous NMR and neutron radiography measurements were made with low RF background.
- The neutron images were acquired over periods of up to ~12 hours while the pinon and juniper branches soaked up H_2O or D_2O
- Analysis of the neutron images allows calibration of the NMR signal



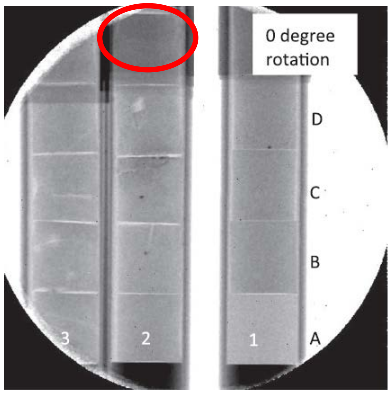


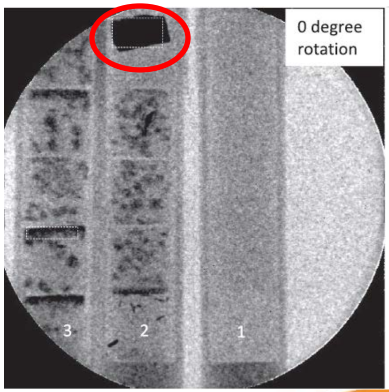
Liquid Flow in a Juniper Branch

- D_2O and H_2O flow in a juniper branch
- ~6 hours experiment duration
- NMR probe
- Not amenable to x-ray imaging

Energy-Resolved n-Rad and n-CT Can Select Elements and Isotopes

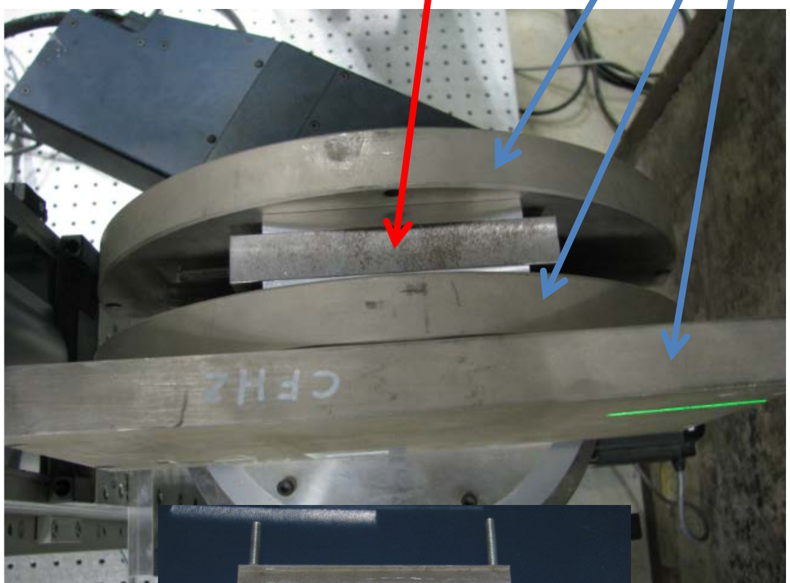
- **A new capability under development at LANSCE exploits the short (~125 ns FWHM) proton beam pulses that produce epithermal neutrons**
- **Detector: Micro Channel Plate**
- **Resolution: < 100 um**
- **Techique uses nuclear resonances that are isotope specific**
- **Nuclear fuel pin mockups with W inclusions demonstrate technique**

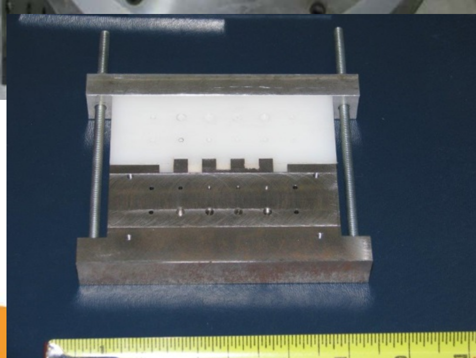




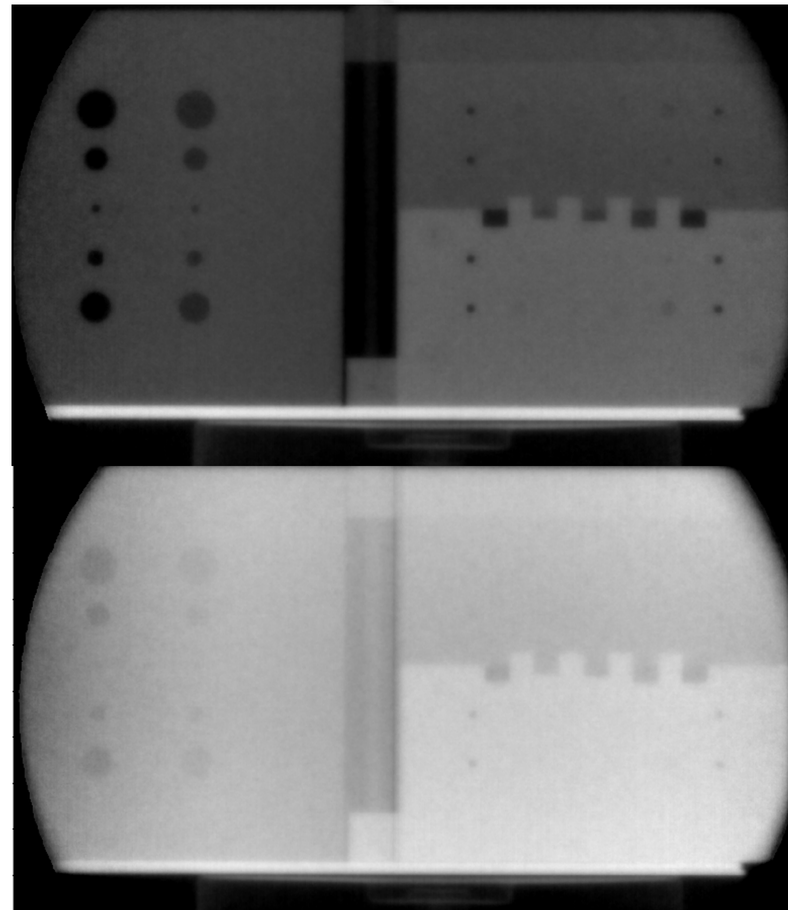
High-Energy Neutron Imaging at WNR Using aSi Flat Panel with ZnS(Ag) Scintillator Screen

Steel, Al, poly phantom in dU slabs



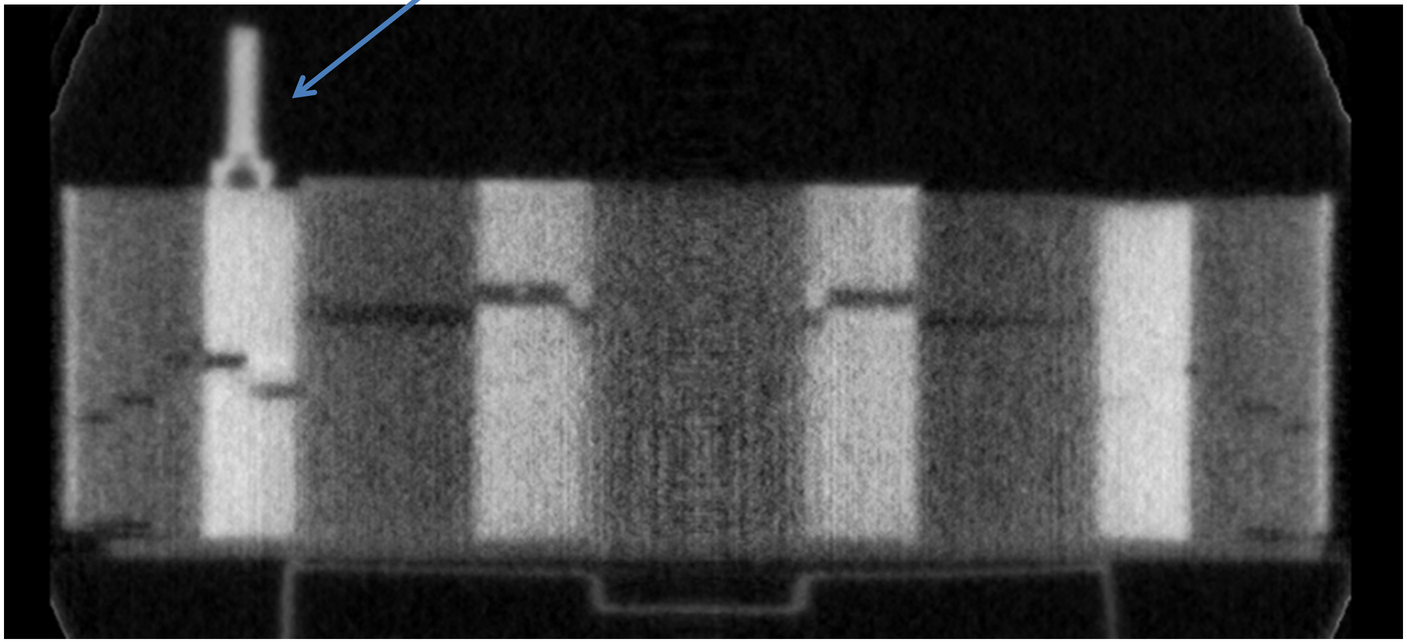


Neutron image of phantom in U through no poly (top) & 4 inches of poly

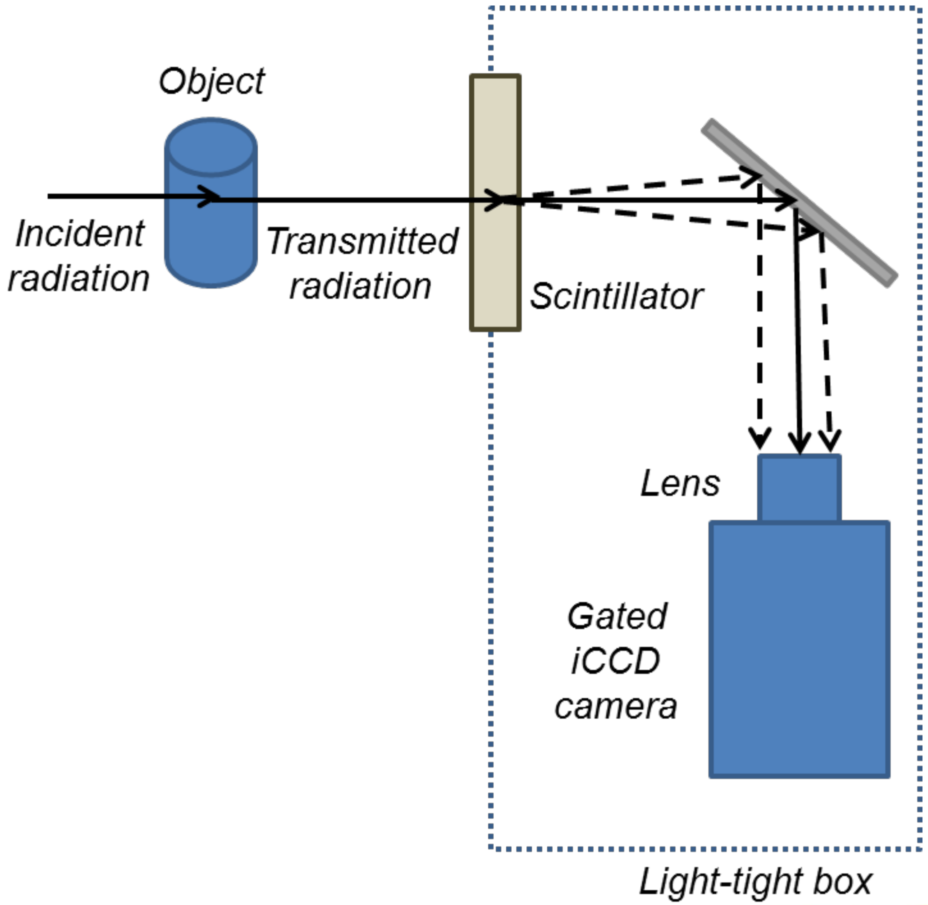


High-Energy Neutron Computed Tomography (CT) Scan of a Multi-Element Item with W, Polyethylene, etc.

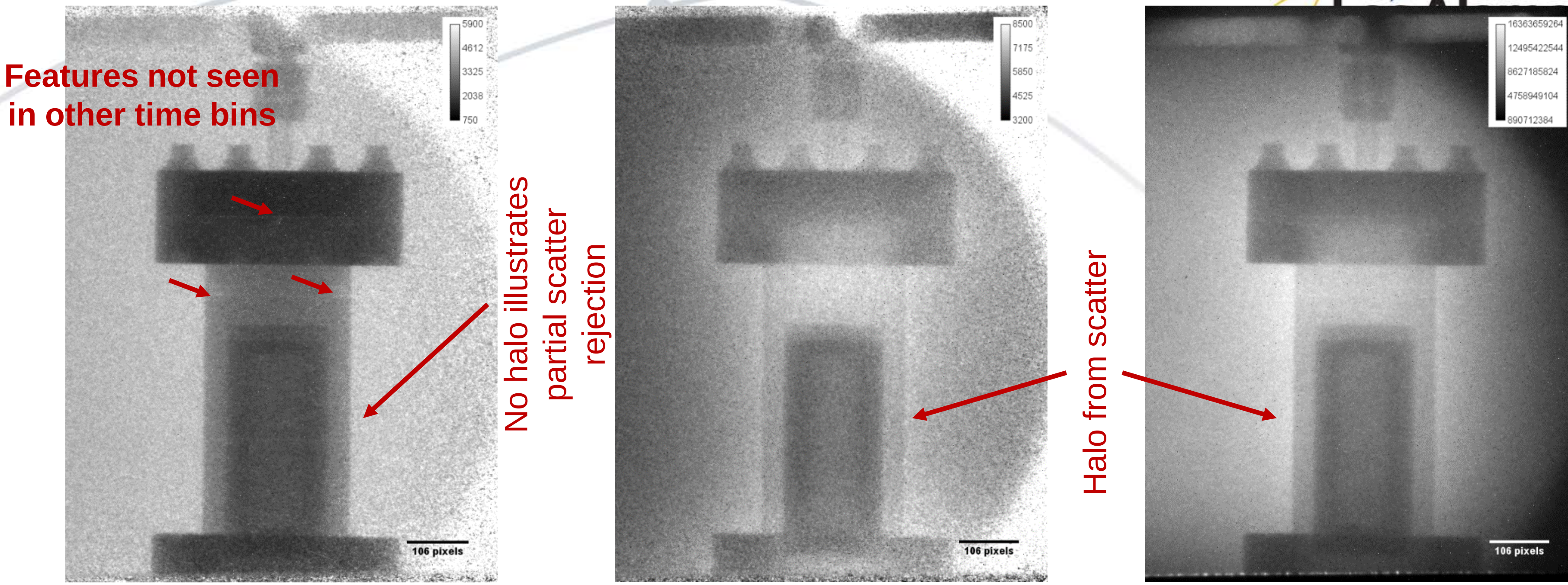
Bolt for position reference



First Results Using the Time-Gated iCCD Camera Setup



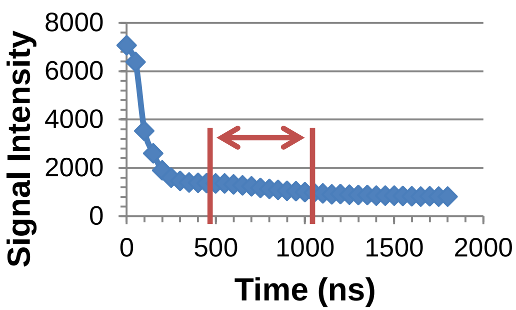
Energy-Selective High-Energy Neutron Imaging

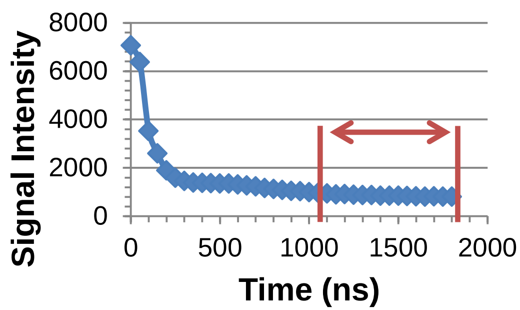


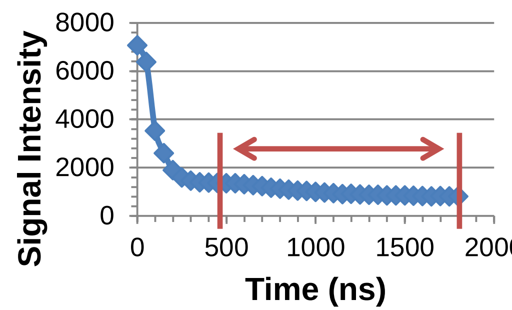
Mid energy neutrons
t = 476.5 to 1059 ns
E = 10 to ~2.5 MeV

Low energy neutrons and scatter
t = 1059 to 1784 ns
E = 2.5 MeV to 100s of keV

Total low energy neutrons
t = 476.5 to 1784 ns
E = ~10 MeV to 100s of keV







High Energy Neutron Radiography Work in Progress

- Improved neutron converter/scintillator screens for faster tomography with flat panel and iCCD imagers
- Continuing studies of water transport in plants – both roots and stems (pinyons & junipers at present)
- CT scans of objects for defense program needs
- iCCD camera (< 10 ns time gating) with fast scintillator screen and mirror enables selection of neutron energy range for optimum contrast and penetration
  - Determine useful and best energies for imaging objects of interest before construction of a full test accelerator and imaging system

Examples of Uses for Energy-Resolved Neutron CT

- Selectively image carbon using MeV range resonances to find diamonds in bulk ore
- Determine the structure and chemical composition of meteorites and geological samples
- Examination of a high-power, heavy duty cathode assembly for failure mechanisms
- Non-Destructive Evaluation of a Variety of Dense, Thick Objects
- Determination of chemical element and isotope distributions in materials, e.g. nuclear fuel rods, scintillator crystal doping, semiconductor device fabrication, …
- More

LANSCE has Unique Advantages for Energy-Selective Neutron Imaging

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- Fast proton pulses for good neutron energy resolution – Targets 1 (moderated) and 4 (high-energy)
- Good L/D ratios for spatial resolution, intensity
- State-of-art detectors and computing
- Proposed Target 1 modifications further enhance capabilities for Energy-Selective neutron imaging in the important keV resonance region
- X-ray & neutron images combined are even more powerful for non-destructive evaluation (multi-probe imaging)

Thank you for your attention!