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Title: PROTON INTERROGATION

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Proton interrogation

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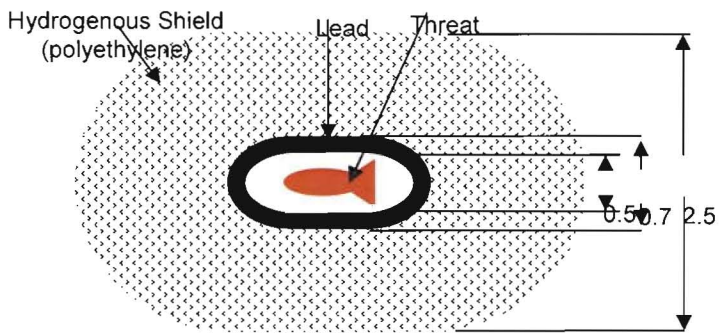
Energetic proton beams may provide an attractive alternative when compared to electromagnetic and neutron beams for active interrogation of nuclear threats because: they have large fission cross sections, long mean free paths and high penetration, and proton beams can be manipulated with magnetic optics. We have measured time-dependent cross sections for delayed neutrons and gamma-rays using the 800 MeV proton beam from the Los Alamos Neutron Science Center for a set of bare and shielded targets. The results show significant signals from both unshielded and shielded nuclear materials. Results will be presented.

Outline

- **Review experiments**
  - Experimental layout
  - Results
- **Discussion of path forward**

Why use protons?



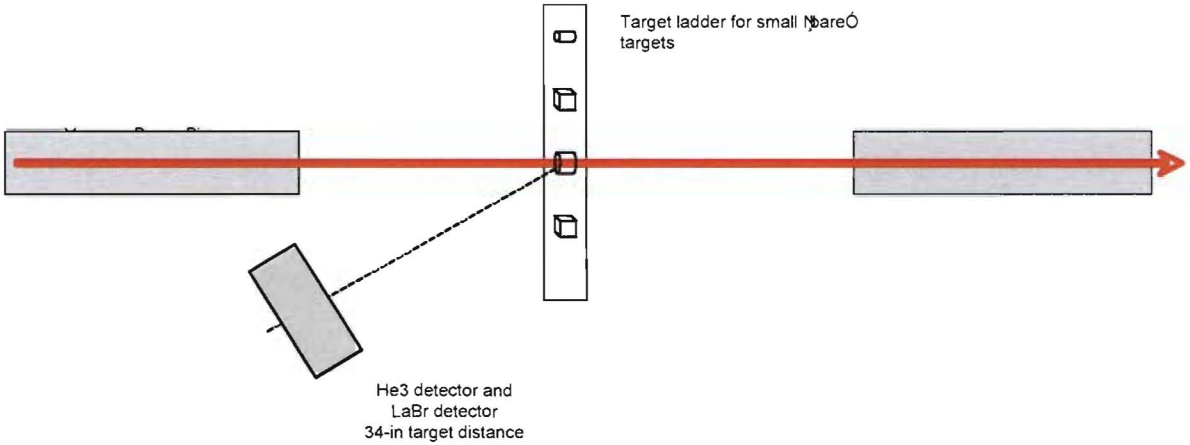
Particle	Energy (MeV)	$\sigma_{fission}$ (barn)	Transmission	Dose (MeV)
n	14.1	2	1.70E-04	1.57E+04
γ	15	0.5	2.08E-04	6.28E+03
p	800	1	1.19E-01	9.0

- Intermediate energy proton fission cross section is large.
- Proton mean free path is long.
- Proton transmission is large.
- Proton interrogation may provide a signal when other probes fail.

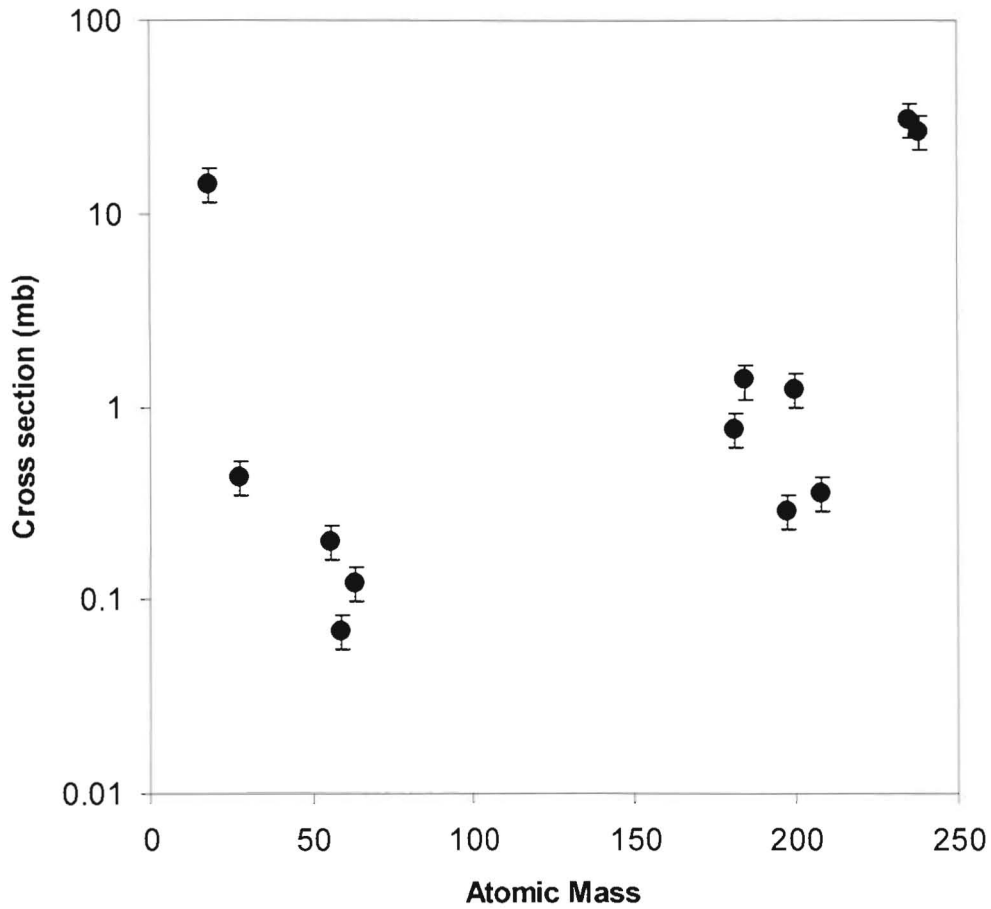
LANSCE 800 MeV proton radiography facility

Delayed Neutron Measurement

- **Materials spanning the periodic tabe - ^{12}C to ^{238}U**
- **Simple targets**
  - 10s or 100s of gram samples
- **Simple counters**
  - ^{3}He gas mixture proportional counter
  - LaBr



Delayed Cross Sections vs Z



- Delayed neutrons from Pb, Hg, Au appear to arise from fission.
- 18O has the highest delayed neutron production of all targets measured.
- Typical background materials like iron and Aluminum have cross sections ~1/100th of Uranium

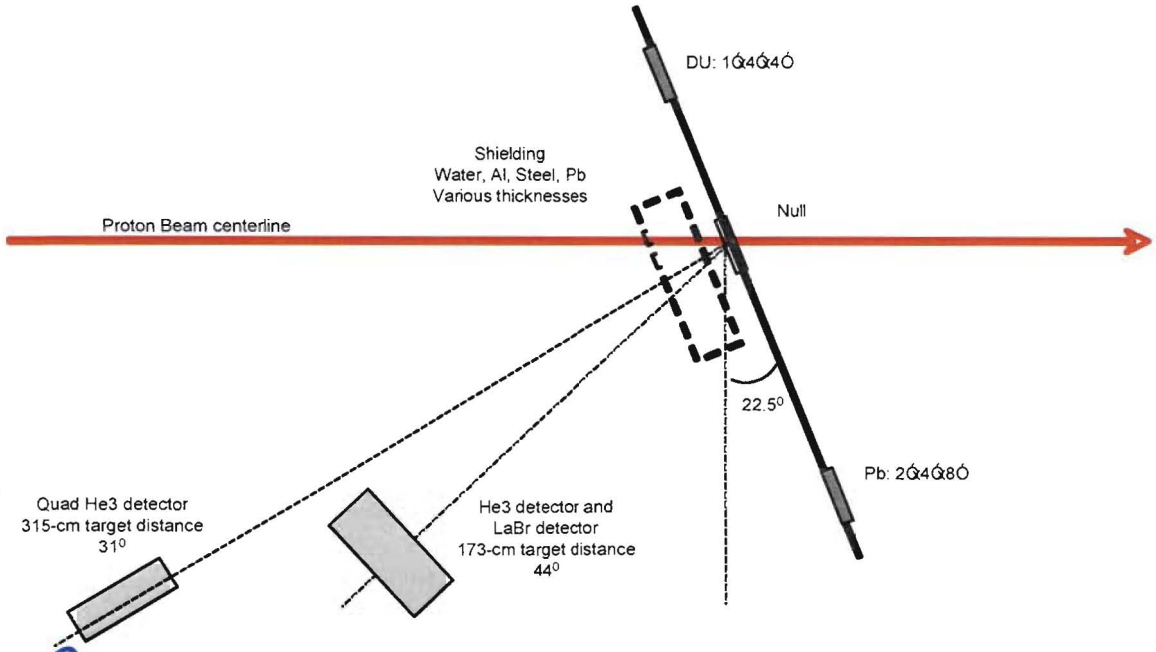
Shielding Configurations Tested

Material	density	thickness*
No shielding (air)	**0.1 g/cm^2**	
Aluminum	**27.4 g/cm^2**	**4”**
Steel	**81 g/cm^2**	**4”**
Water	**30.4 g/cm^2**	**12”**
Polyethylene (CH_2)	**29.5 g/cm^2**	**12.5”**
Sand (SiO_2)	**44.7 g/cm^2**	**8”**
Lead (stops beam)	**229.6 g/cm^2**	**8”**

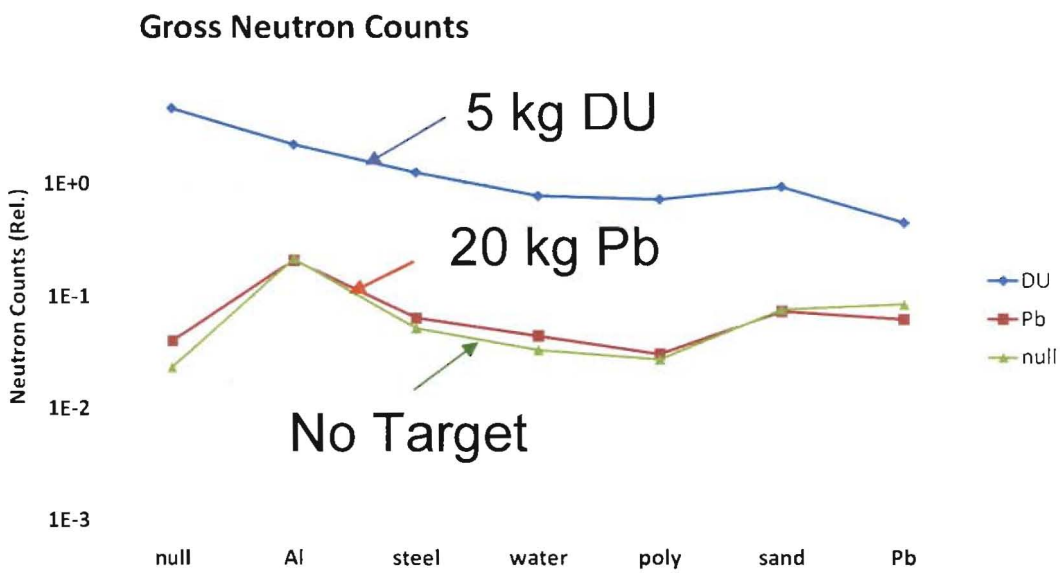
*minimum linear thickness of materials
--protons traveled through materials at an angle of 22.5^0
--neutrons at 45^0

Compound Targets

- **Preliminary investigation of shielding effects**
  - 'Environmental' clutter
  - Intentional shielding



Relative Neutron Yields From Compound Targets

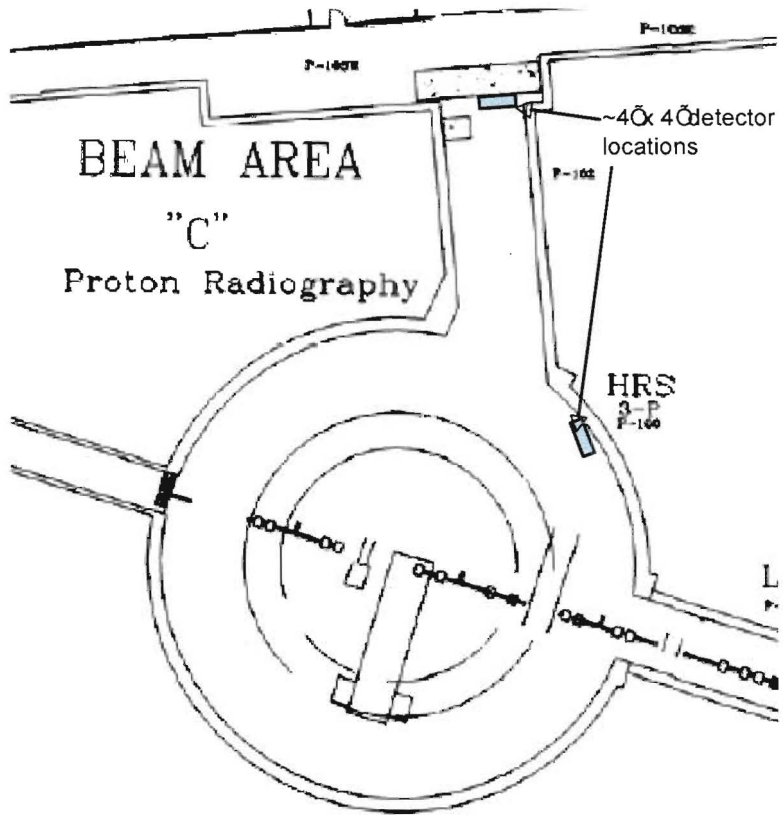


Ongoing Work

- Design, execution, and interpretation of a set of experiments over limited beam and signal flight paths through air on attenuator, target, and shielding materials at the energy of the LANSCE beam.
- Measure delayed neutron & gamma cross sections at 4 GeV.
- Determine a nominal design proton energy based on an optimization between stand-off range, probe and signal propagation, and detector technology.
- Establish an extended, in-air, proton and neutron flight path at LANSCE

Upcoming Measurements

- **Detector development**
  - Multi-layered array
  - Neutron energy binning
- **Gamma signal**
- **Additional targets**
  - Simple, A = 100-150
  - Compound



Experimental Issues

Goal:

Monte Carlo Validation

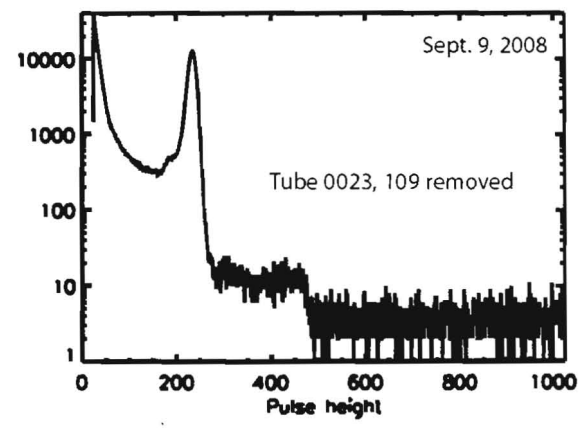
1. Cross section validations
2. Interrogation of complex targets at range

Cross section measurements

- Calorimetry
  - Develop a scintillator calorimeter coupled to a 3He detector

Interrogation

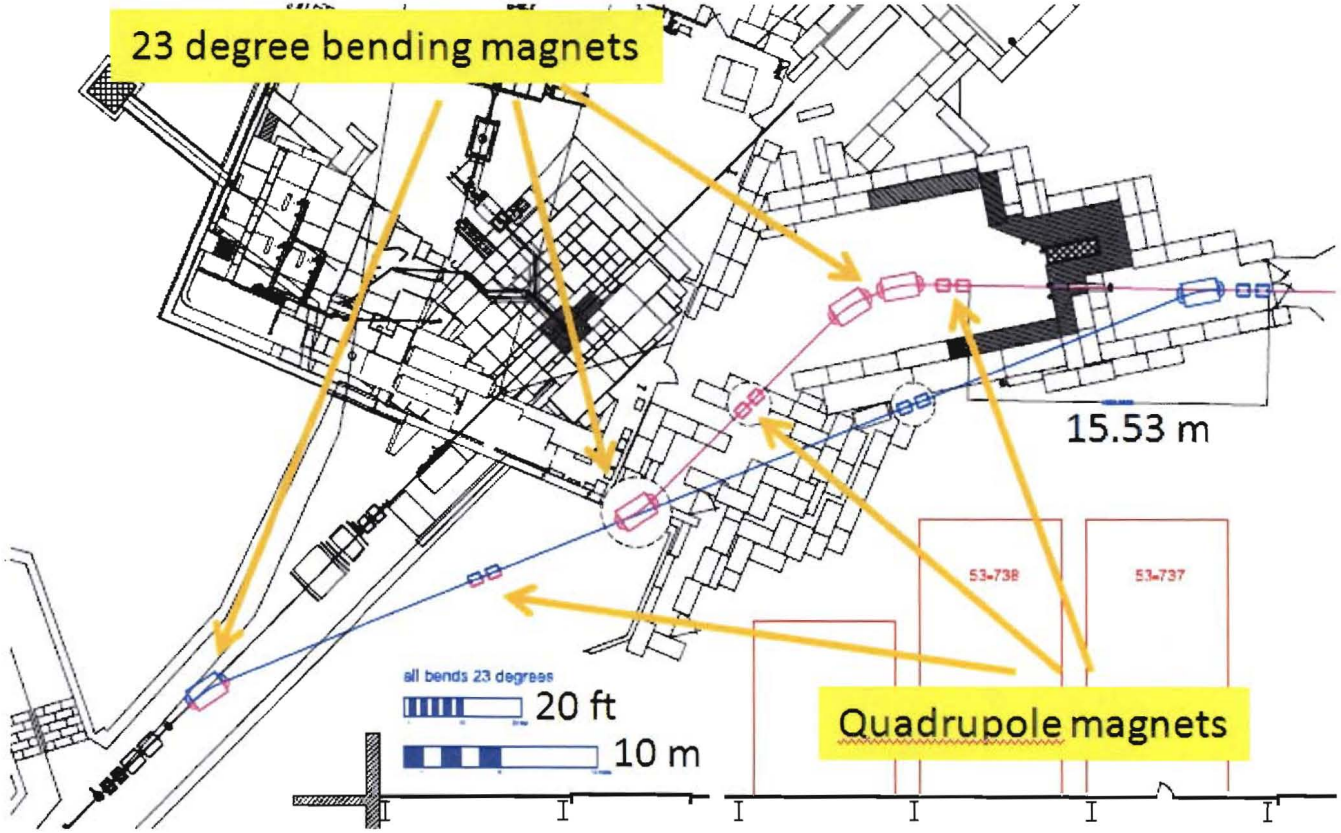
- Larger area efficient detection
- Simple Readout



Superconducting Cavity Development

- 50 MV/m
- 200 MeV

Open Air Proton Flight Path



Summary

- Measurements suggest proton induced delayed neutron provide a significant signal of SNM
- Interrogation through significant overburden has been demonstrated
- Monte Carlo benchmarking under way
- Higher energy measurements (AGS)
- Longer interrogation paths (Line C and NTOF)
- Accelerator design and development