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Title: Active Proton Interrogation

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Form 836 (7/06)

Active Proton Interrogation

Steven J. Greene, for the Proton Interrogation collaboration

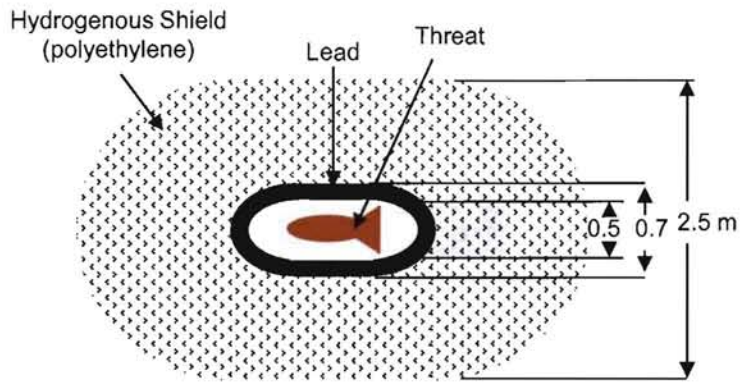
LANL, P-25

APS APR10 Meeting

Proton Interrogation Motivation

- **Goal**
  - Reliable interrogation of lightly shielded cargo.
- **Requires**
  - Unique fissile material signature
- **The signature**
  - Intermediate energy protons (800 MeV-4GeV) produce a distinctive delayed neutron time signature (10s of seconds) from fissionable materials.
  - Backgrounds of delayed neutrons from ^{17}N complicate detection of delayed neutrons.
  - In fissile targets delayed neutrons produce fission neutrons with amplification factors ~5.
  - ^{17}N delayed neutrons are all below 2 MeV, 50% of fission neutrons are above 2 MeV.
  - Spectroscopic neutron detection at long delay times can provide a distinctive signature.

Why use protons for active interrogation*?



Detection=10^6 fissions from a 10×10 cm target

$\mathrm{Dose(p)}=w_r \times 6.24 \times 10^9/(dE/dx)$

$\mathrm{Dose}(n,\gamma)=w_r \times 6.24 \times 10^9/[E/\lambda]$

w_r=10 for n; 1 for γ; 2 for p

Particle	Energy MeV	σ fission barn	Transmission	Dose MeV/cm^2	Dose/detection Rad
n	14.1	2	1.74 E-04	1.57 E+04	25.148
γ	15	0.5	2.08 E-04	6.28 E+03	1.007
p	800	1	1.19 E-01	8.96 E+00	0.003

- Intermediate energy proton fission cross section is large.
- Proton mean free path is long.
- Proton transmission is large.
- Protons provide dose amplification in the target: 1 neutron/30MeV

Neutrons of interest

- Fission neutrons
  - Fission spectrum with tail above 2 MeV
- Delayed neutrons
  - Fissile elements <1 MeV, long half-lives
  - Fissionable elements <1 MeV, long half-lives
  - Lighter elements <2 MeV, short half-lives

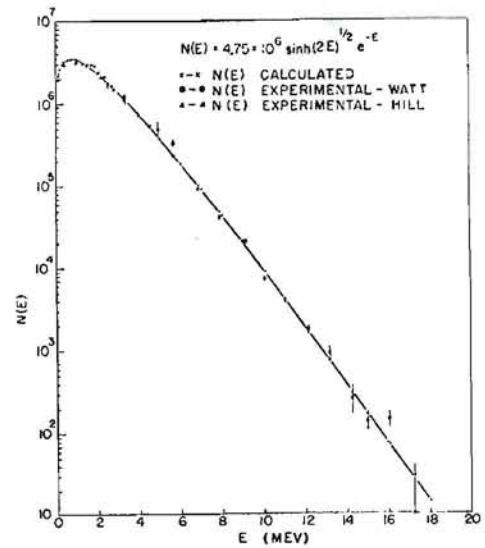


FIG. 4. Energy spectrum of fission neutrons. The calculated curve is based on the assumption of a Maxwellian distribution in the center-of-mass system for the neutrons emitted by a fission fragment.

Fission fragments

Approximate Half-life (sec)	Number of fission neutrons delayed per fission			
	^{233}U	^{235}U	^{239}Pu	Energy (MeV)
56	5.7 E-04	5.2 E-04	2.1 E-04	0.25
23	19.7	34.6	18.2	0.46
6.2	16.6	31	12.9	0.41
2.3	18.4	62.4	19.9	0.45
0.61	3.4	18.2	5.2	0.41
0.23	2.2	6.6	2.7	-
total delayed	0.0066	0.0158	0.0061	
total fission neutrons	2.5	2.43	2.9	
fraction delayed	0.0026	0.0065	0.002	

Glasstone & Sesonske

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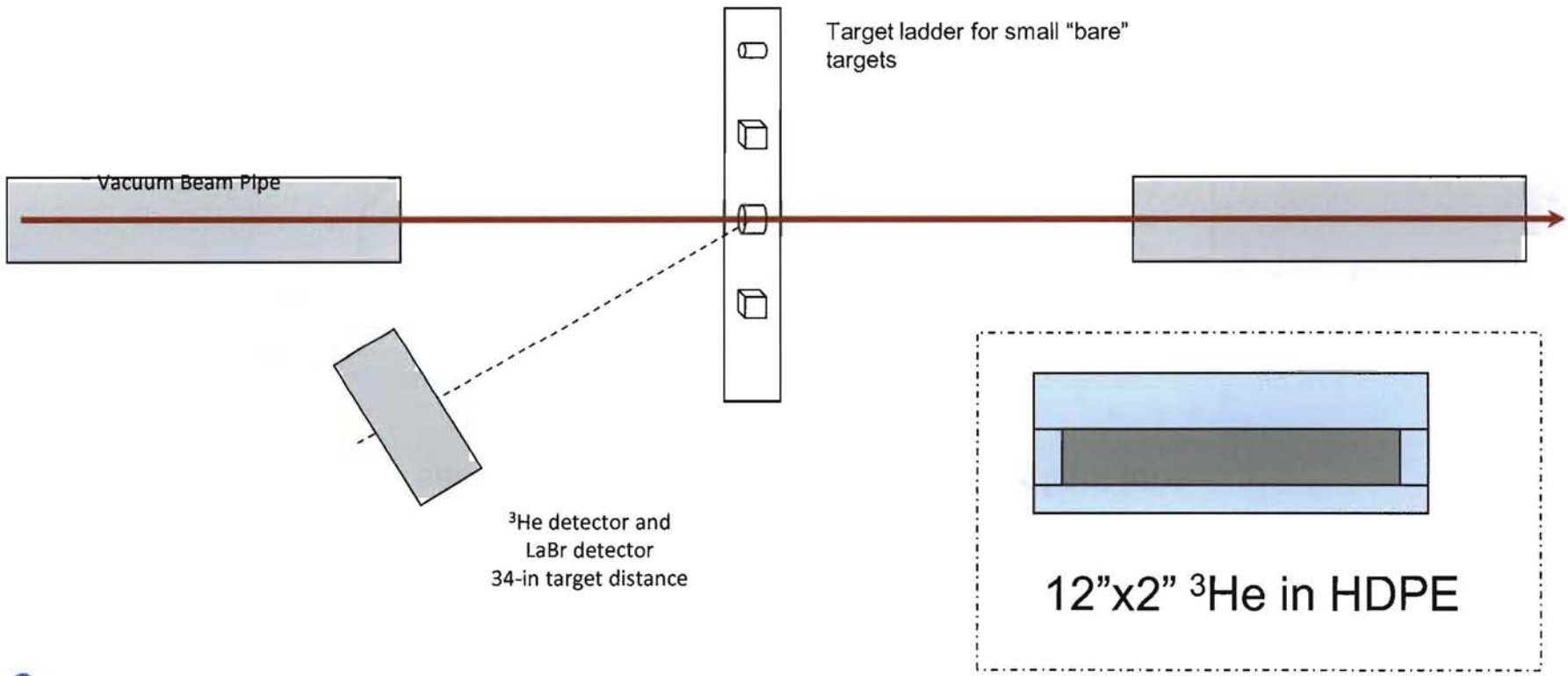
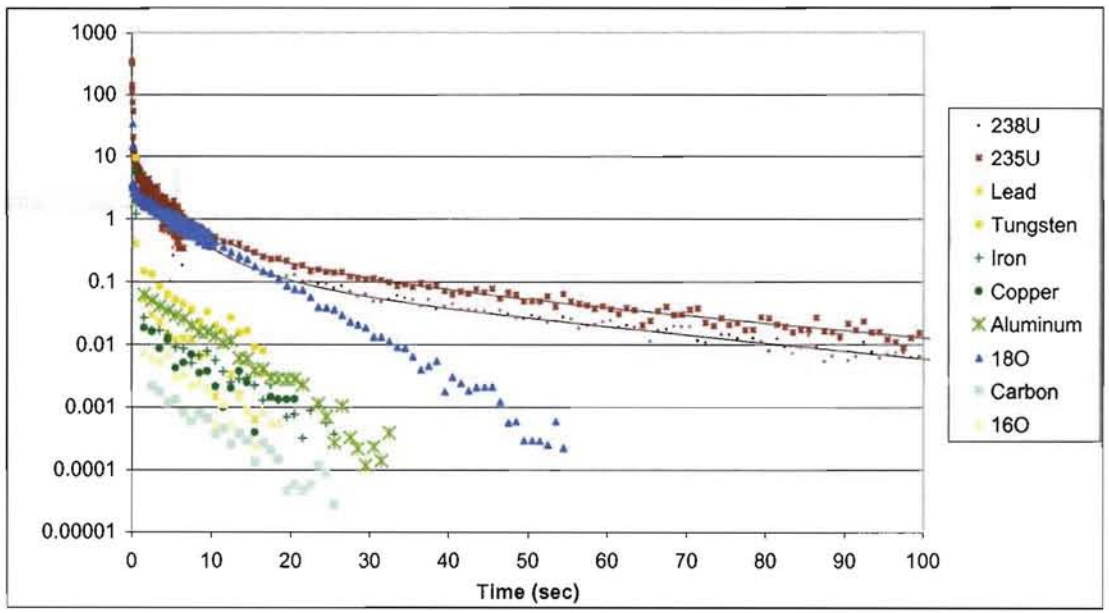
Experimental Setup - Cross Sections

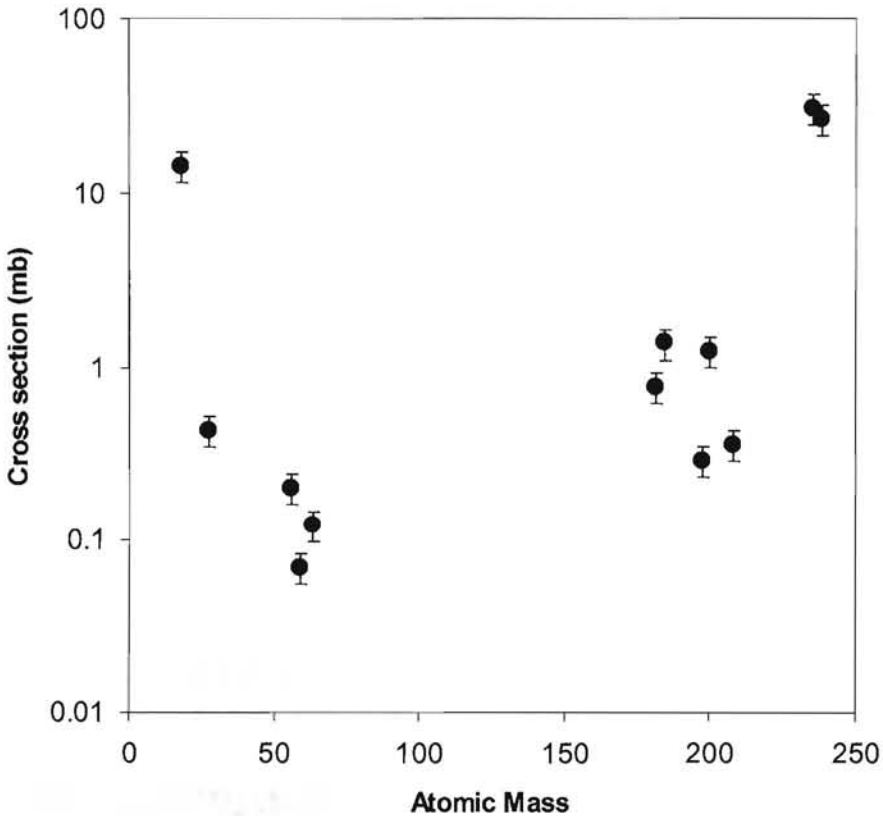


800 MeV cross section results

- **Distinct long-time signature of fissionable/fissile materials**
  - Delayed neutrons from 56 second half-life fission fragments
  - Ubiquity of 4.17 second ^{17}N delayed neutrons & other light ions



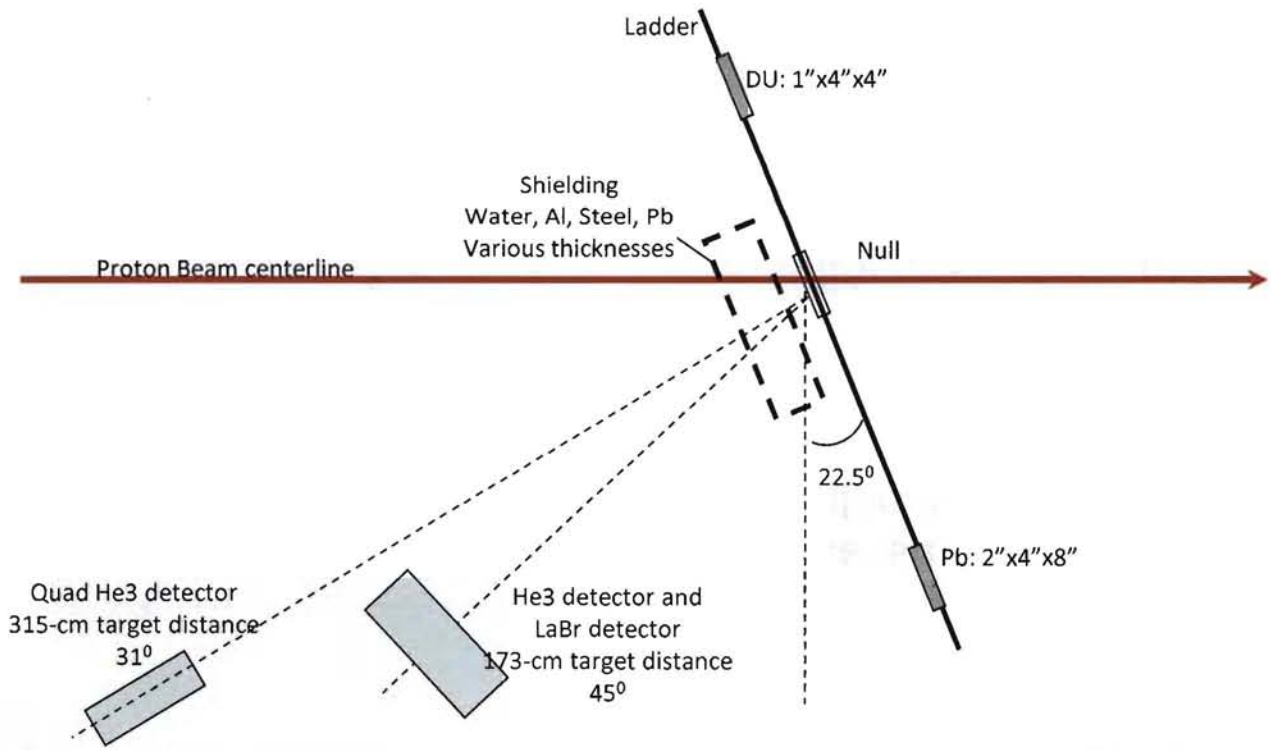
800 MeV summed neutron cross sections



- **Typical structural material, like iron and aluminum, have cross sections of ~1% of uranium**
- **Except for uranium, most delayed activity appears to be from short half-life precursors, notably ^{17}N (4.17 sec) and ^{9}Li (0.178 sec).**

800 MeV bulk shielding study

- **Penetrating bulk shields with proton beam and neutron signal**
  - Probe multiplication
  - Signal degradation



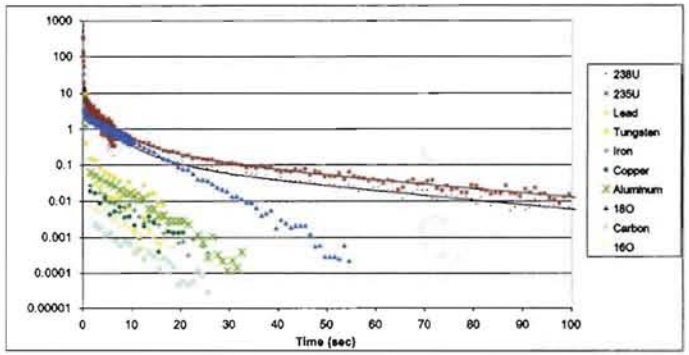
800 MeV bulk shielding materials

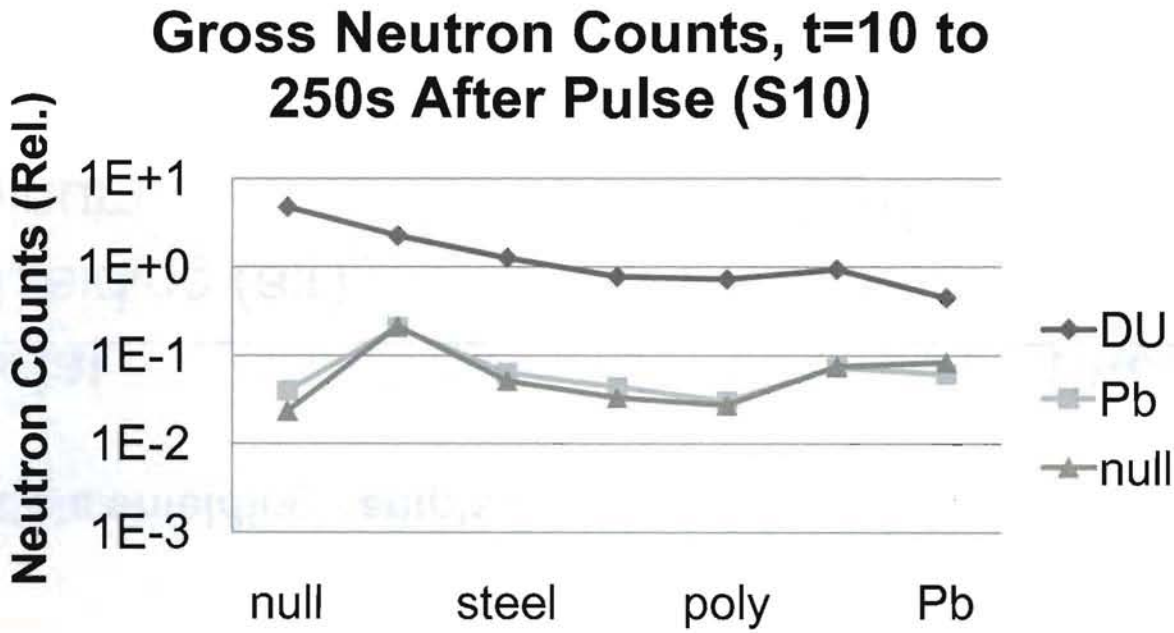
- **Multiple shielding samples**

•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	229.6 g/cm^2	8”

800 MeV bulk shielding results

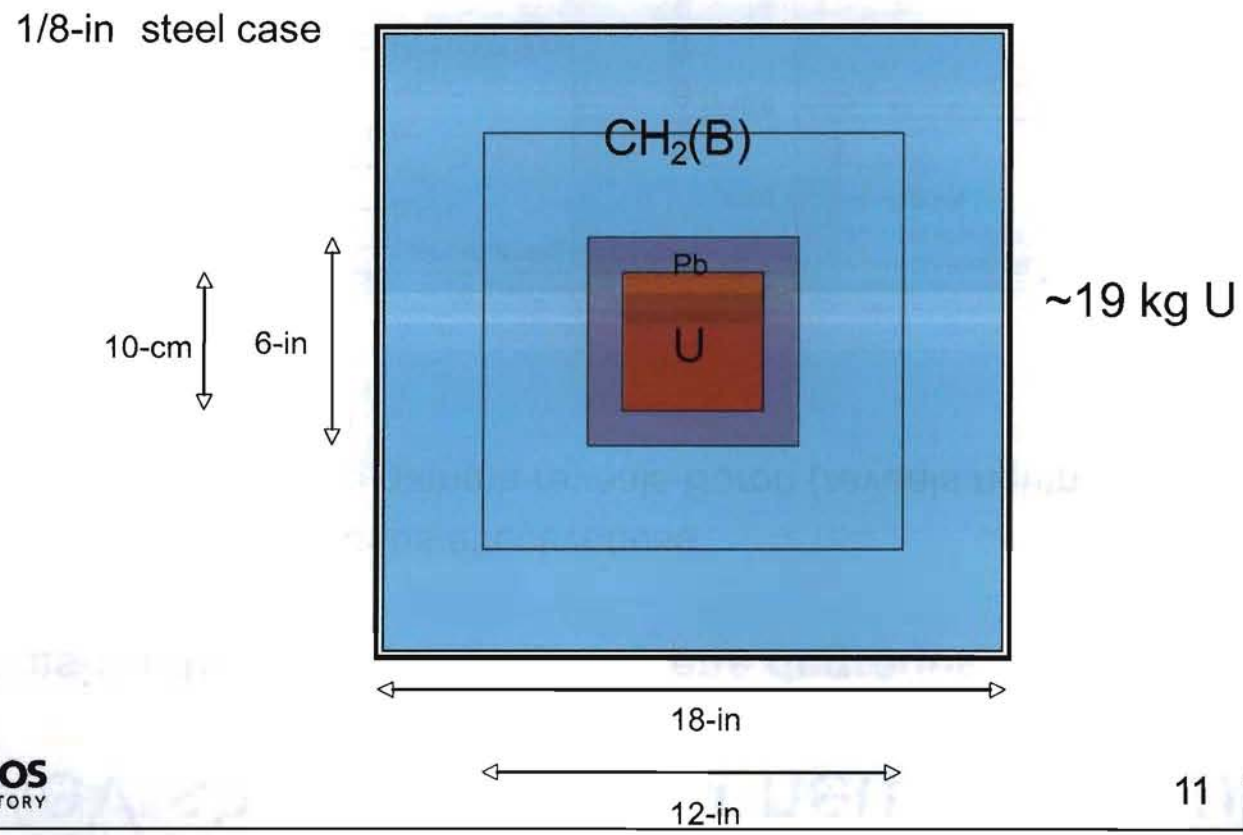
- **Beam and signal can penetrate**
  - Probe multiplication
  - Shielding can have an effect
  - Shielding modifies signal





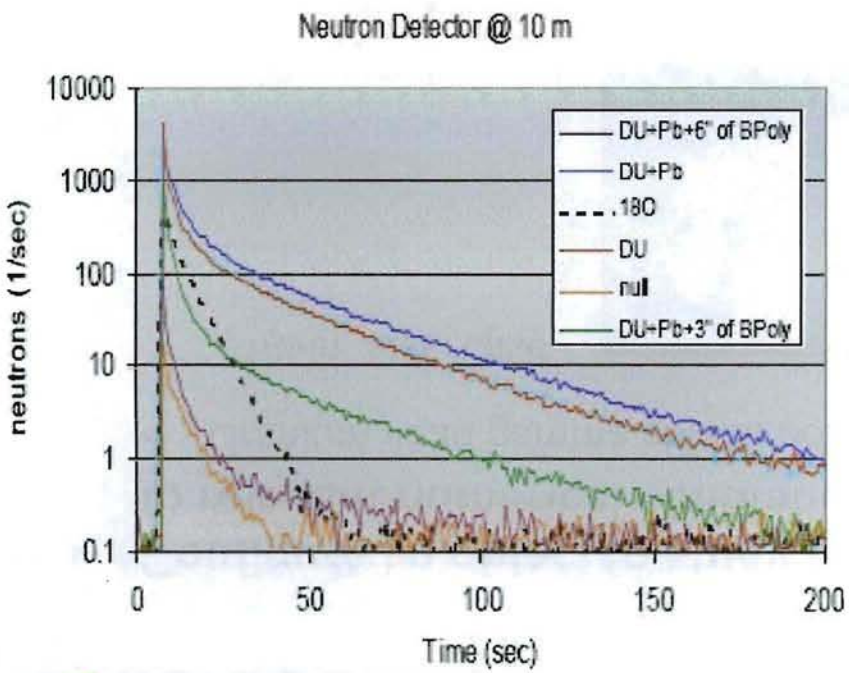
Shielded Object

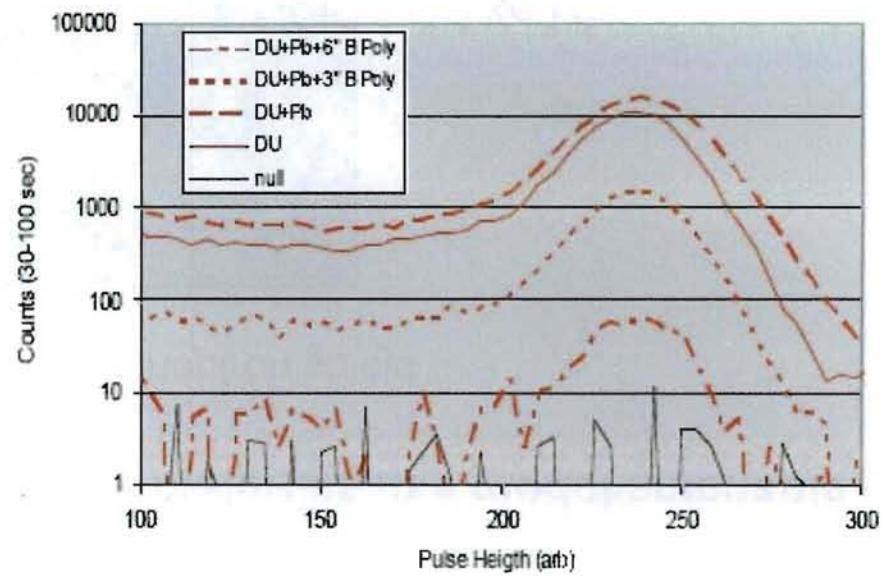
- **Configure an object to study effects of materials in a model amenable to relevant numerical simulation.**
  - Uranium, lead gamma shield, polyethylene neutron shield



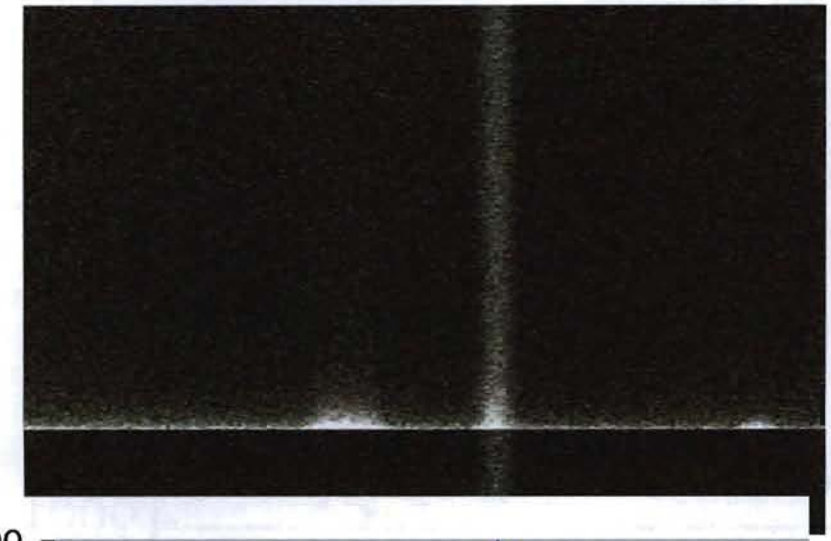
800 MeV shielded object neutron results

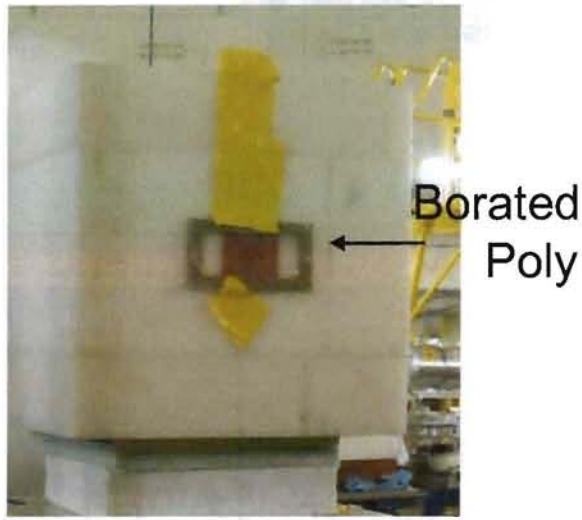
- **Increasing thickness of polyethylene degrades low-energy neutron signal**
  - Adding Boron increases effectiveness
  - 478 KeV n-γ capture gamma reveals Boron (reveals neutron decay time)
  - Probe multiplication

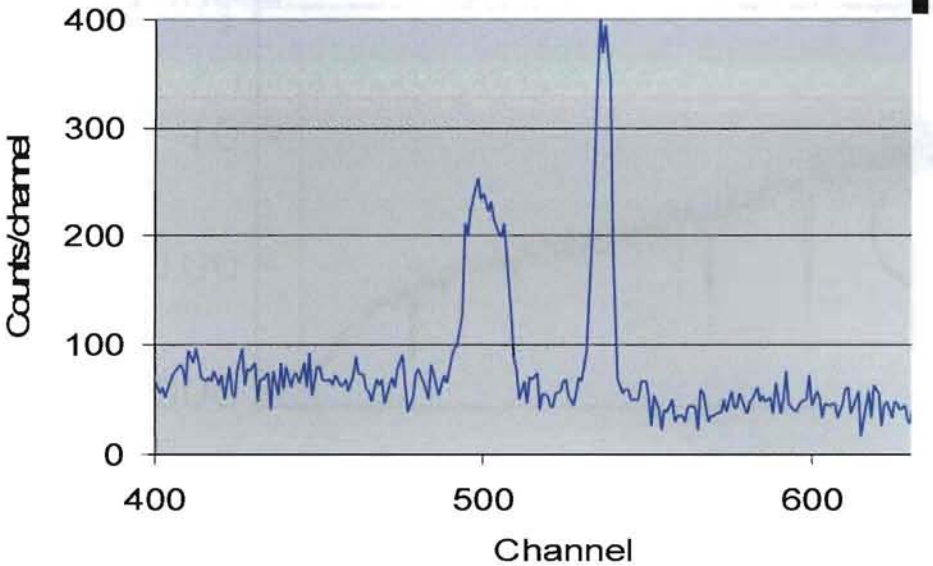


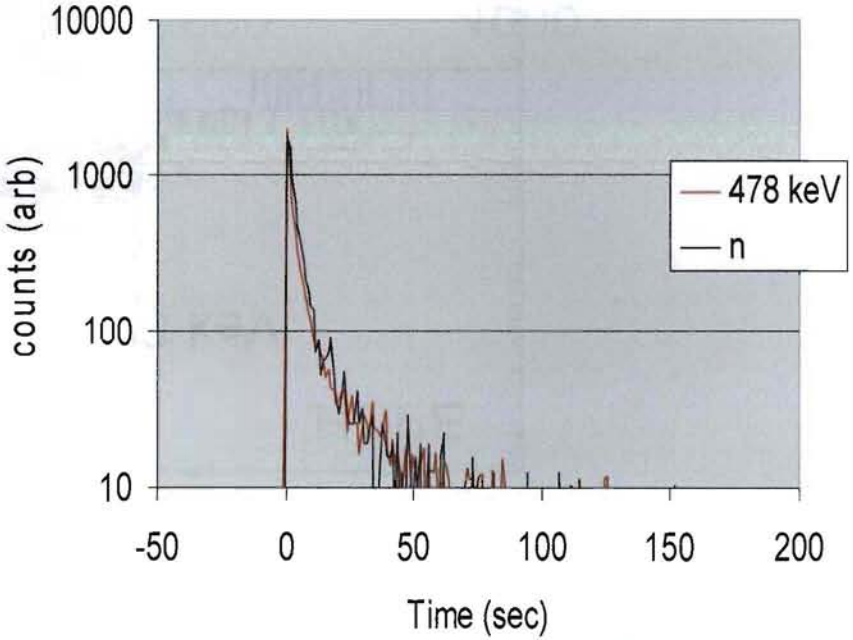


800 MeV TO gamma results

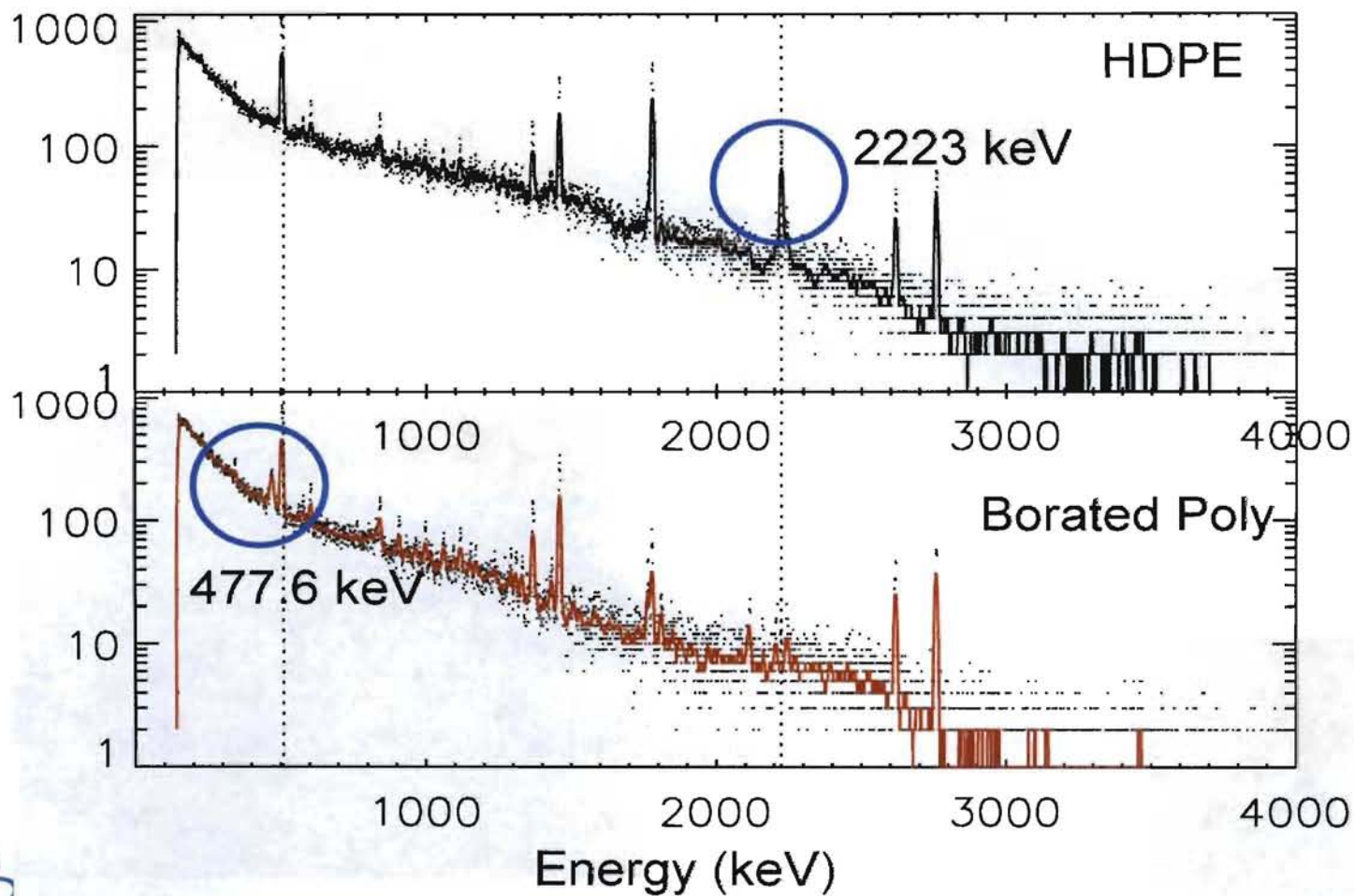








Neutron-capture γ's



4 GeV experiments

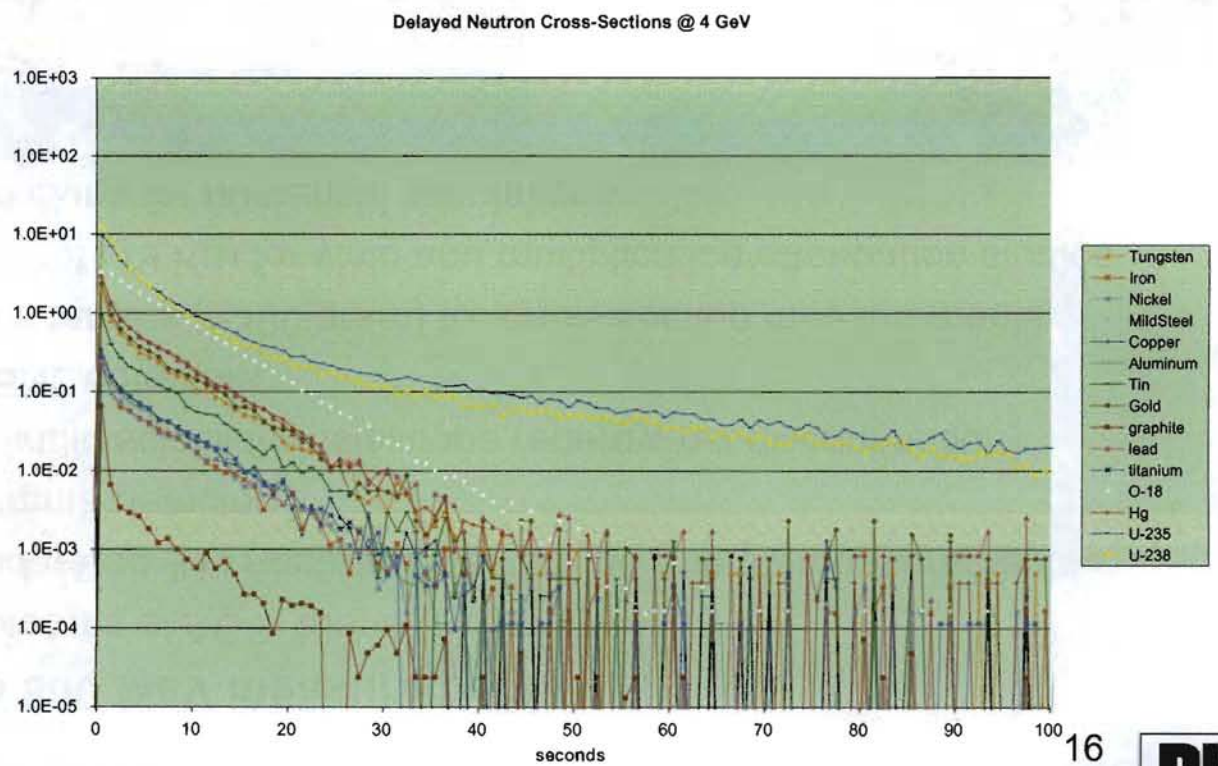
- **Similar to 800 MeV measurements**
  - 4 Gev protons at AGS, tunnel environment
  - CH_2 moderated ^3He neutron detector - no energy measurements
  - LaBr gamma detector
  - EJ-301 liquid scintillator telescope (energy, n-γ discrimination)
  - SNL & BNL detectors
  - Moderate targets (~300 gram) for cross section measurements
  - Large target (19 Kg) for yield and multiplication/attenuation studies
  - Benchmarking for numerical simulations

Cross section station

Threat object station

4 GeV delayed neutron cross sections

- **Similar behaviors**
- **Needs careful background subtraction @ 4 GeV**
  - Return from beam stop
  - Multiple scattering return from tunnel structure
- **Some increase in cross section**
- **^{9}Li & ^{17}N appreciable**



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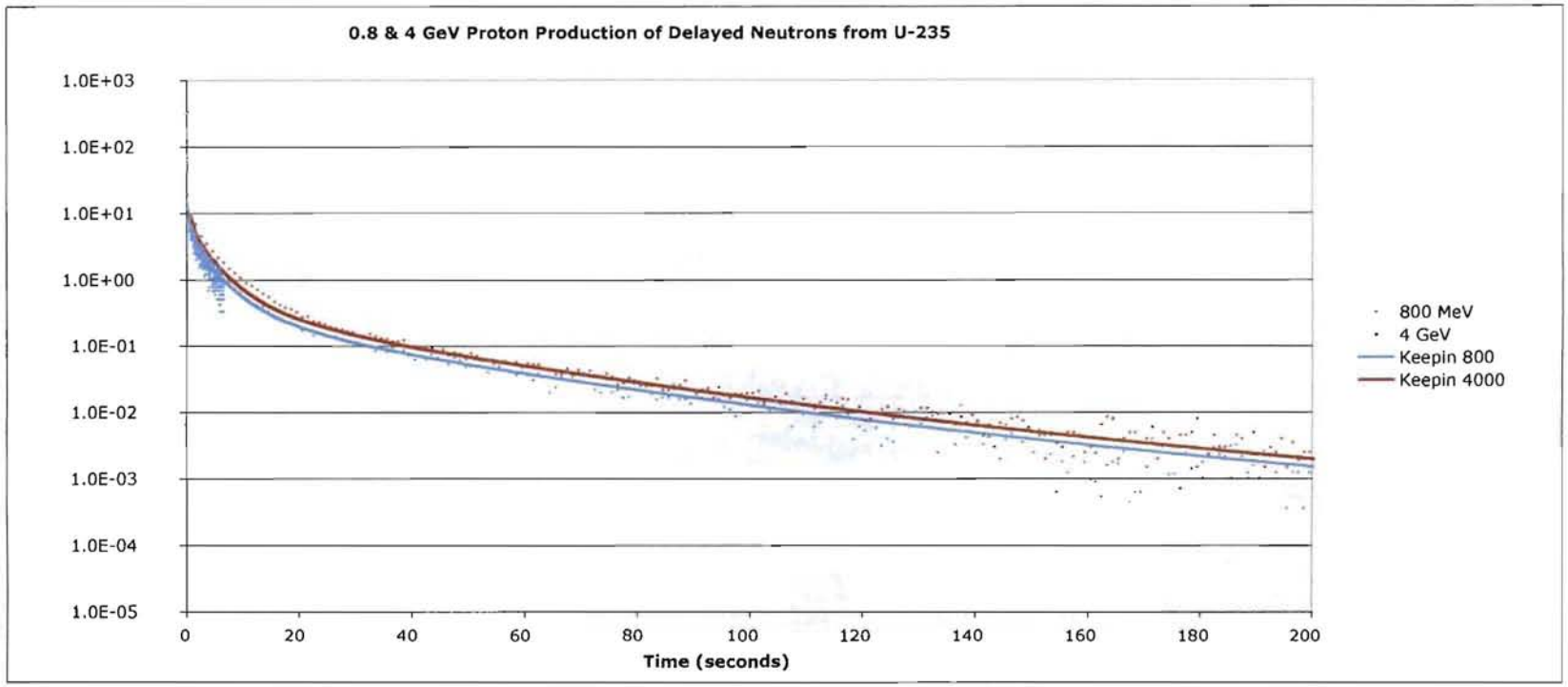
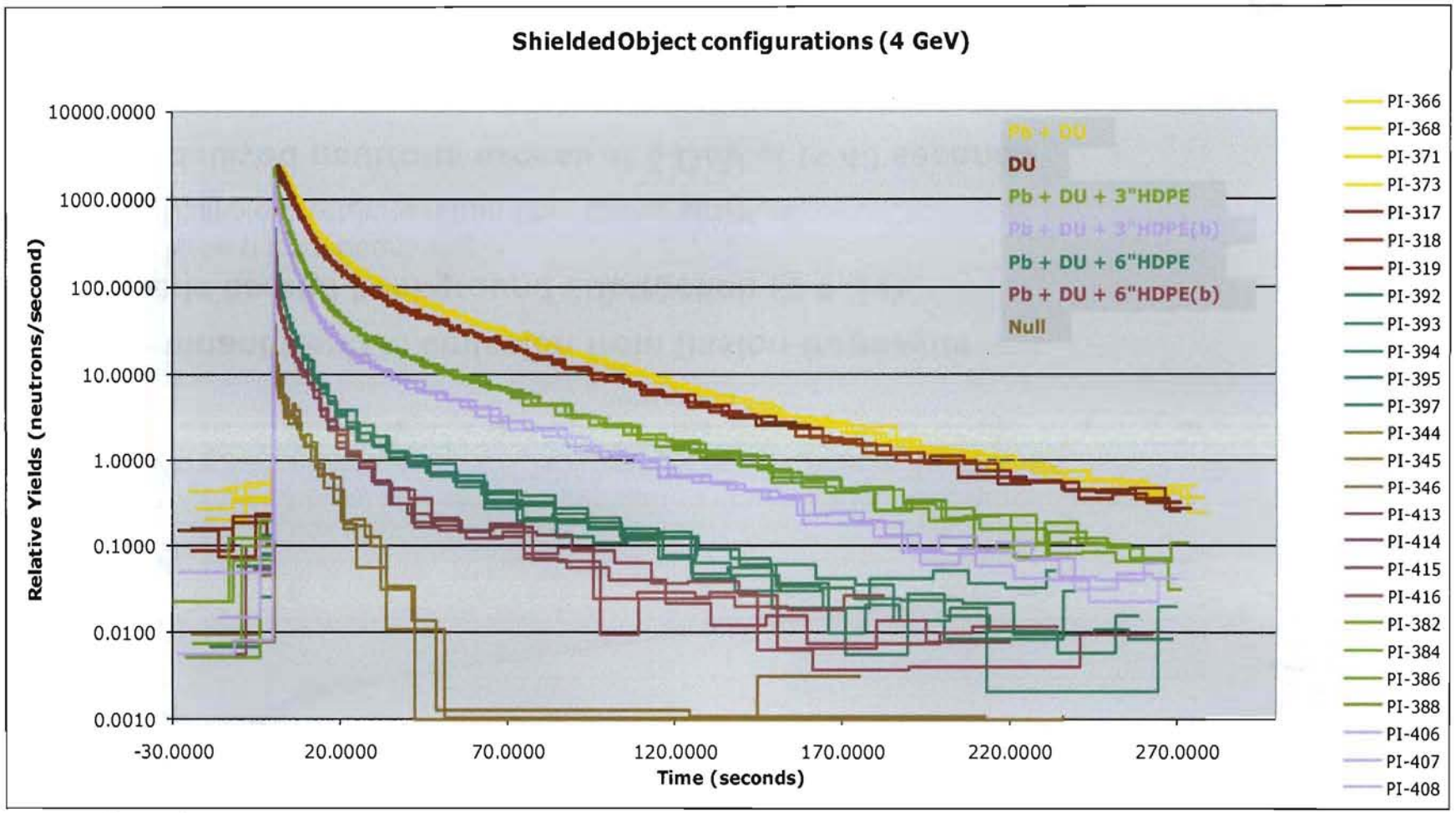
Relative delayed neutron cross sections - U235



- **Dominant trend is emission from fission fragments**
- **Needs careful background subtraction @ 4 GeV**
  - Return from beam stop
  - Multiple scattering return from tunnel structure
- **^{17}N delayed neutrons excess at 4 GeV at t< 40 seconds**

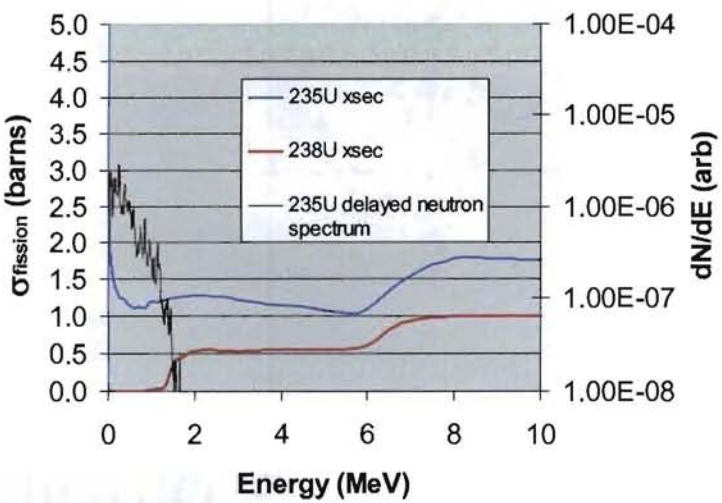
4 GeV shielded object delayed-neutron yields



- **Similar to 800 MeV**
  - ~ factor of 2 between borated and non-borated poly

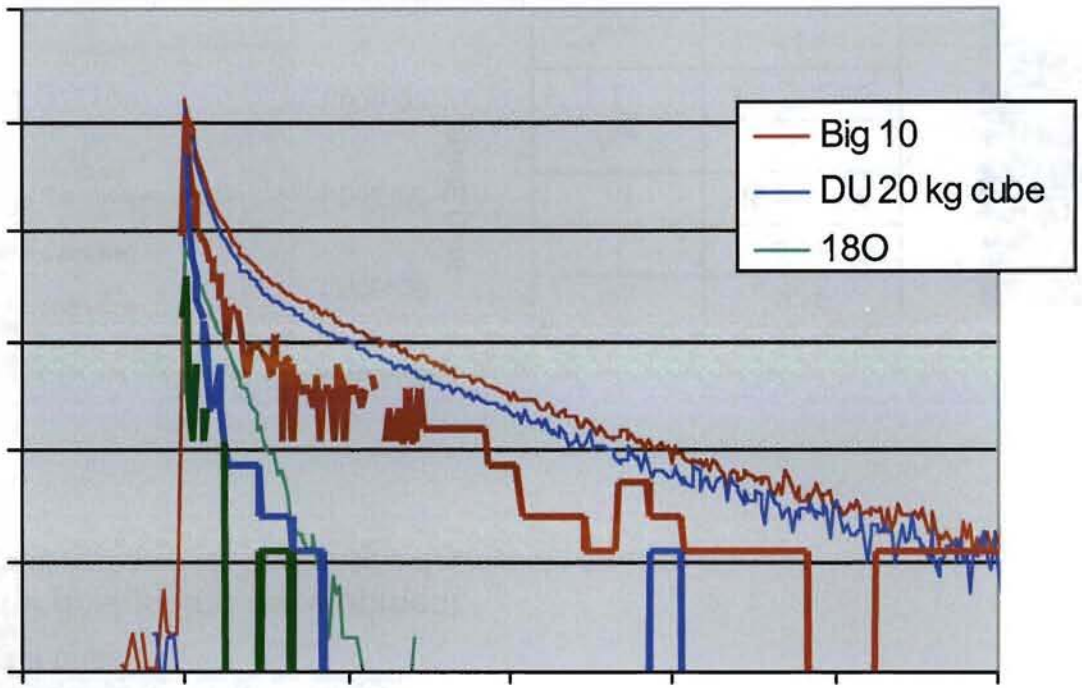
Future plans

- Spectral neutron measurements with enriched (19%) U.
  - Verify improved signal to noise.
  - Verify higher penetration.
- Longer interrogation paths.
  - Enables end to end demonstration.
  - Detector tests
- Accelerator design and development.
  - Essential research for designing a deployable system



f_{235}	0.19
l	5 cm
ρ.l	19 gm/cm2
n_{bar}	2.5
λ	325 gm/cm2
$f_{fission}$	14%

Observation of Delayed-n Induced Fission (liquid scintillator telescope)



Some Conclusions

- **Neutron time signature identifies fissionable/fissile actinides**
  - Delayed neutrons from fission fragments
- **Neutron energy signature essential for unique fissile identification**
  - Higher energy neutrons from prompt fissions initiated by fission fragment delayed neutrons
- **Shielding/overburden provides probe multiplication**
  - Neutron knockout
- **Significant neutron backgrounds can be dealt with**
  - Principally short half lives (~4 sec)
  - Generally low energy (<2 MeV)
- **Neutron capture gammas can be revealing**
  - Reflect time structure of delayed neutrons
  - Potentially identify shielding and nearby materials
- **Most basic physics and effects available with 800 MeV protons**
- **LEU studies critical**
  - Time, energy, shielding effects