Application of Antineutrino Detection Technologies to Other Areas of Nonproliferation and Nuclear Security

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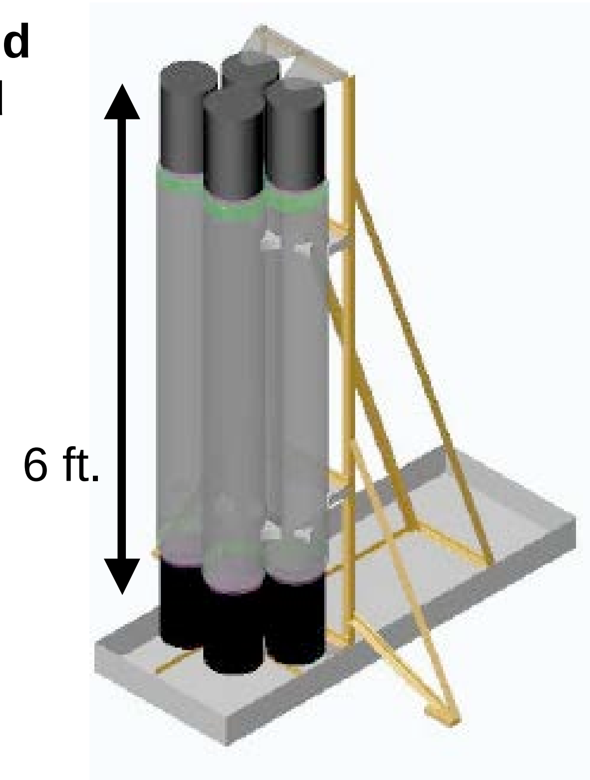
Antineutrino Detection Technology Has A Direct Impact On Other Areas Of Nonproliferation And Nuclear Security

Doped liquid or undoped plastic scintillator detectors



Active interrogation of cargo for HEU and Pu

Passive Pu/HEU detection and characterization

Gd-doped water Cerenkov detectors

Low-cost large neutron detectors for various portal and monitoring applications

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“Nuclear Car Wash” Detectors Are Being Tested at LLNL for Active Interrogation of Cargo

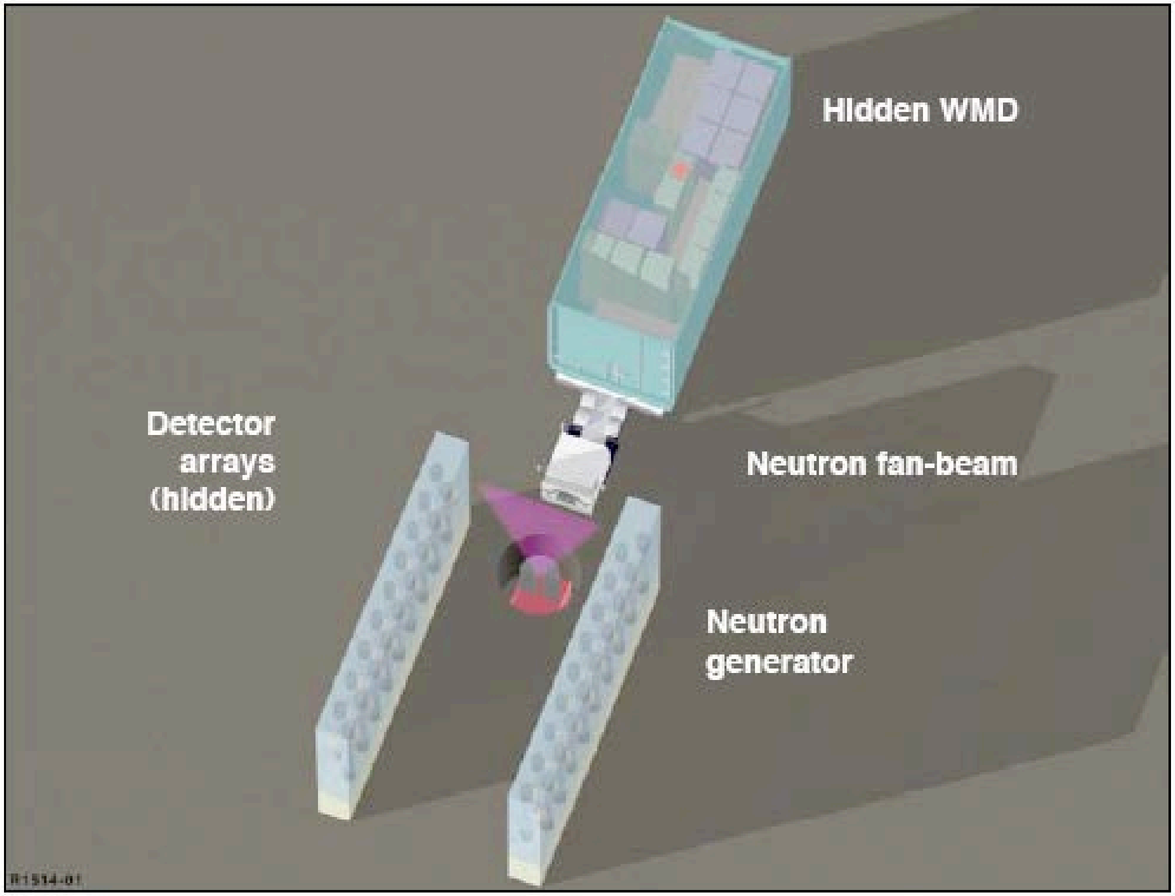
90% of the world’s trade moves through sea-going containers

More than 6,000,000 containers enter the U.S. annually

Cargo material is diverse

Containers are large

Need tscan < 1 min / container

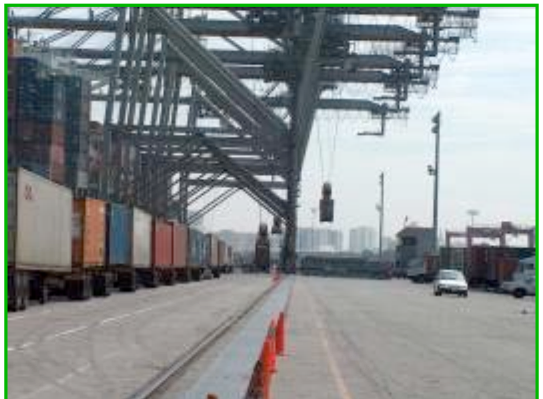


This is a formidable problem - cargo scanning is one element in a global nuclear control regime

Active interrogation is one element in a cargo scanning system

Arrival at port → Document screening → Passive screening → Radiography screening → **Active interrogation** → Unload container → Response

Passive screening / Radiography screening / Active interrogation → Cleared for delivery



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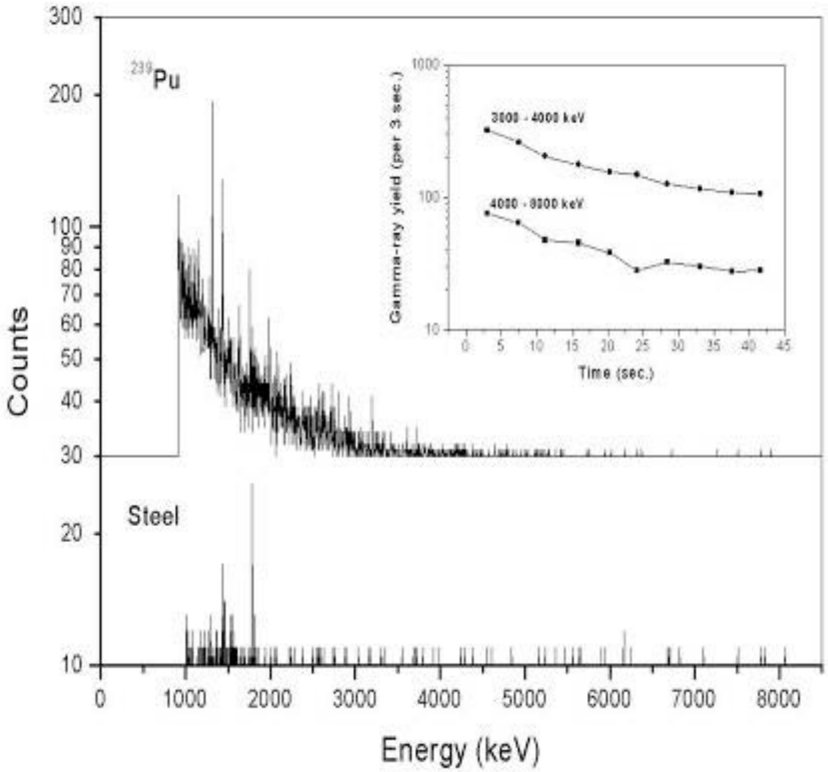
Thermal neutrons are known to induce β-delayed γ-rays above 3 MeV in U, Pu

<u>Experiment by Norman *et al*. 2004 [1]</u>

- E_n = thermal
- Separate neutron irradiations of ^{235}U (93%), ^{239}Pu (95%), wood, polyethylene, aluminum, sandstone, and steel.
- Cycles of 30 s irradiation and 30 s counting.
- 10 sequential 3-second gamma-ray spectra were acquired with a single coaxial 80% HPGe detector.



<u>$^{235}U(n_{th},f)$ and $^{239}Pu(n_{th},f)$:</u>

Significant gamma-ray intensity above 3 MeV.

Short effective half-life (approximately 25 s).

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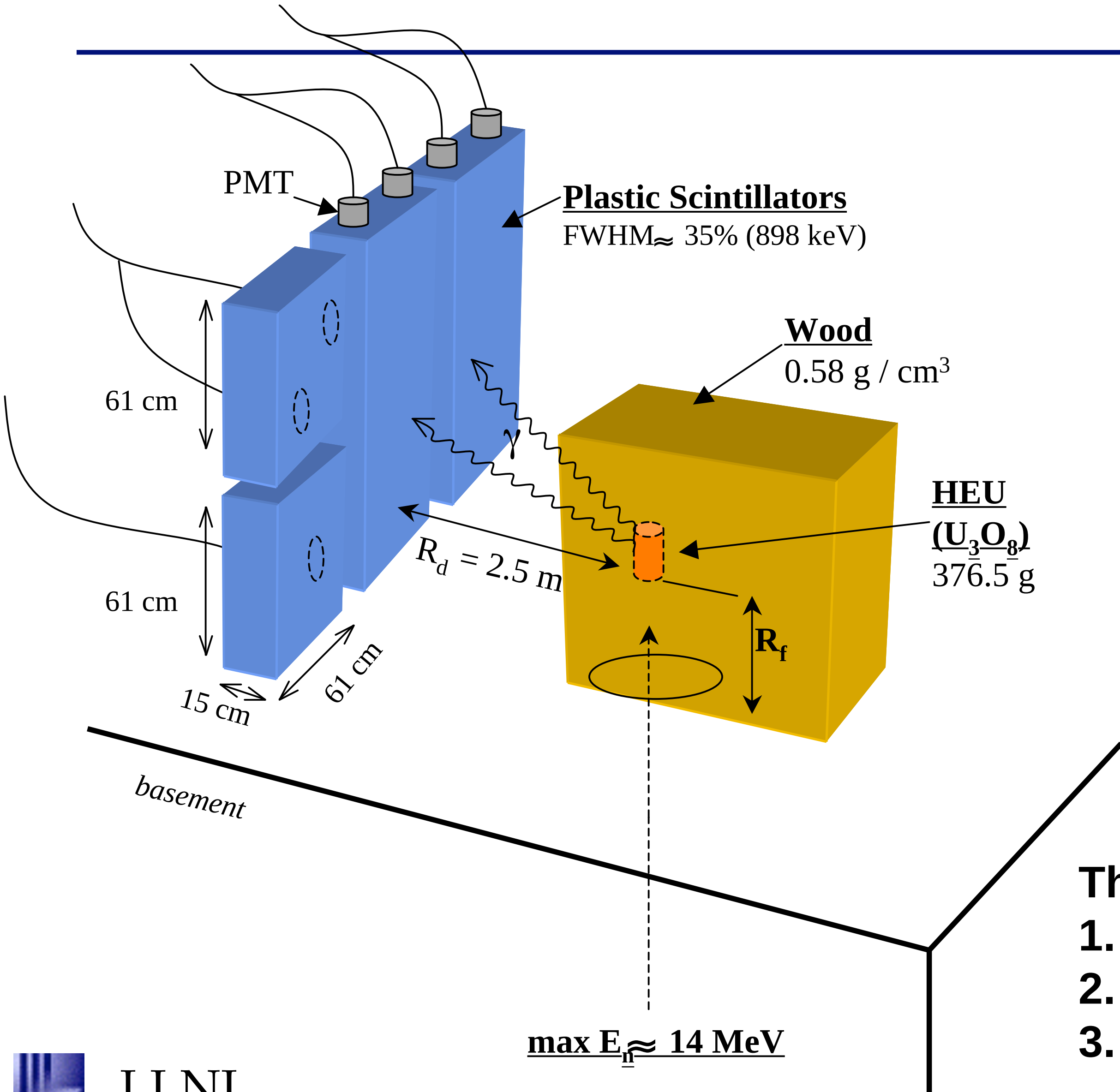
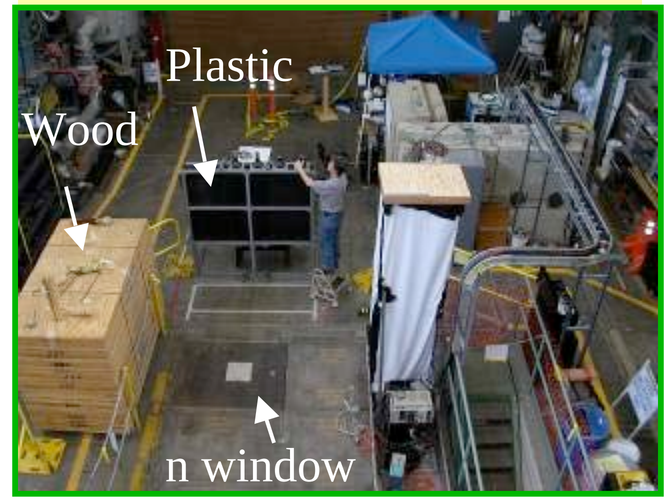
[1] E.B. Norman et al., NIMA 521 (2004) 608-610.

Cargo experiments with HEU and 14 MeV neutron beam



HEU embedded in plywood
R_f = 61 cm (40 g / cm^2 wood)
R_d = 2.5 m (60 g / cm^2 wood)
Y_n ~ 6x10^{10} n/s initial
Φ_n ~ 6x10^4 n/s/cm^2 at target



The Experiment:
1. Turn on beam for 30 sec
2. Turn off beam
3. Acquire counts for 100 sec

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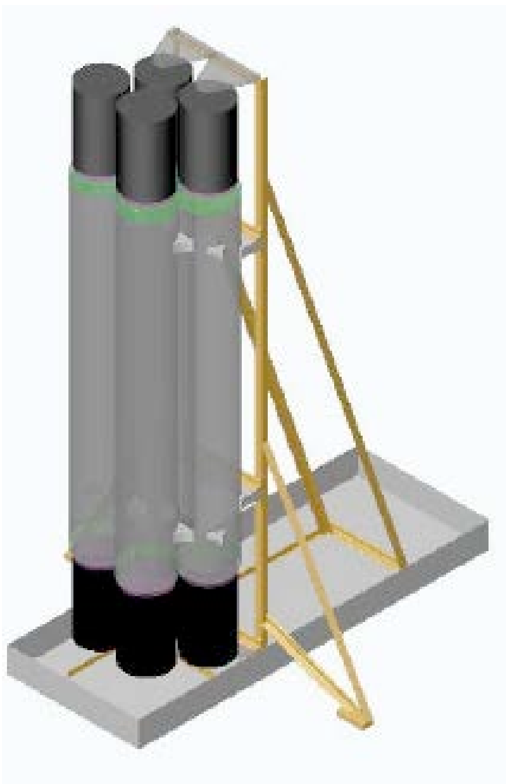
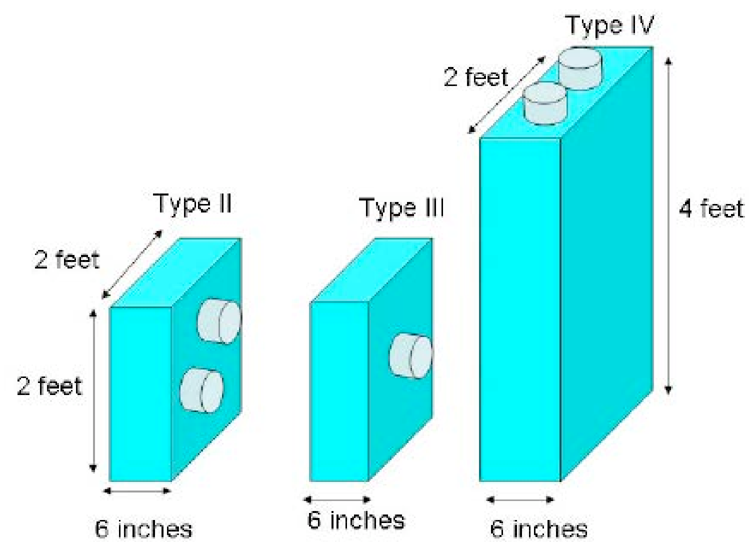
Detectors Used Are Very Similar in Scale and Design to San Onofre Detector



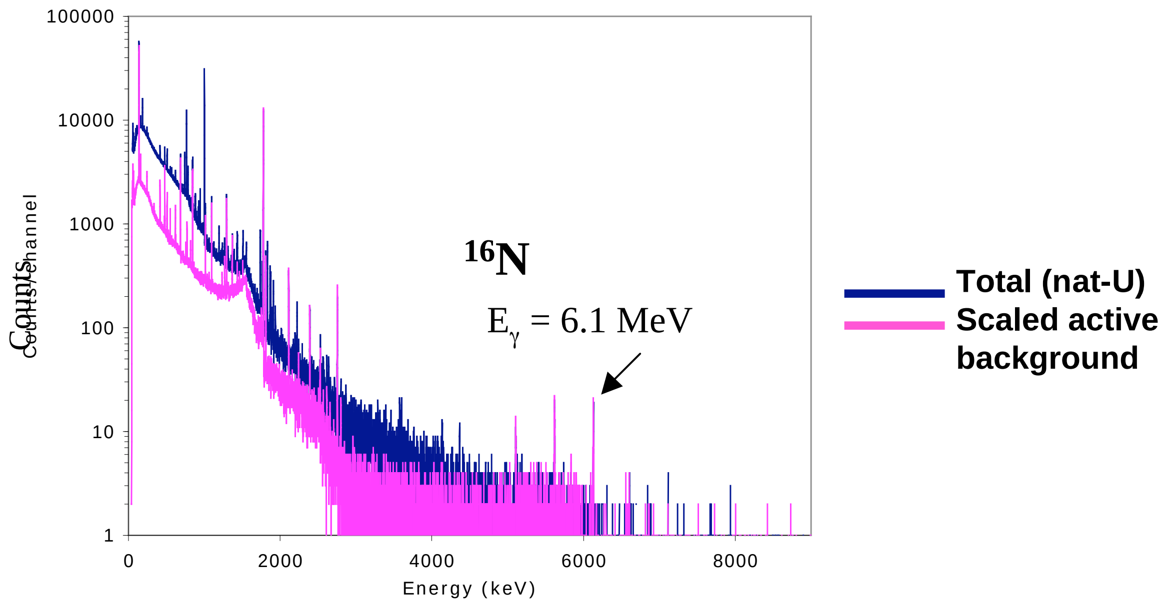
4 ganged liquid scintillator detectors 6 foot tall, 8” diameter



Total of 8 plastic scintillator 6-10” deep, 2-4 feet wide

14 MeV beam induces a troublesome background for E_γ > 3 MeV

Nat-U and background pulse height spectra



^{16}O(n,p)^{16}N:

Threshold = 10.24 MeV

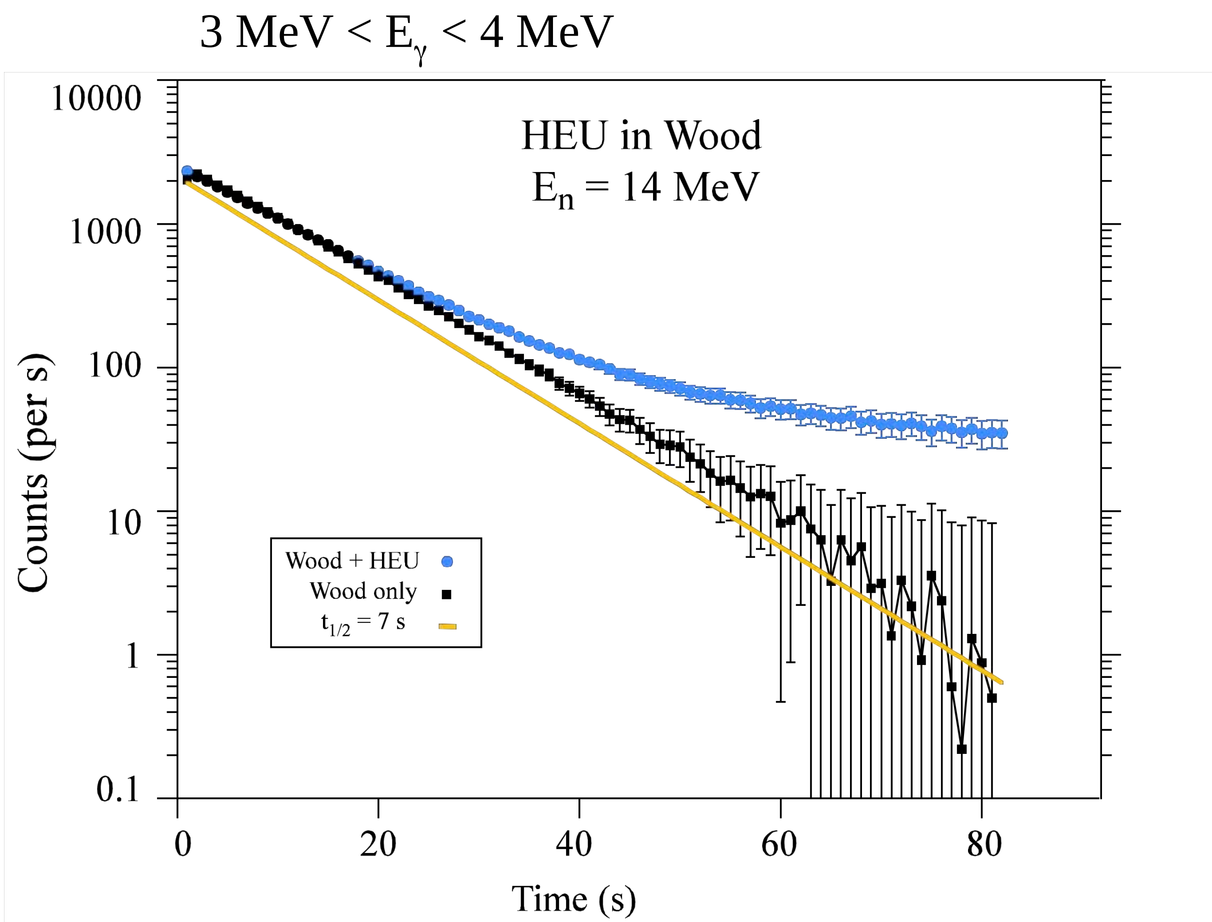
Q = -9.63 MeV

^{16}N E_γ = 6.1 MeV

^{16}N $t_{1/2}$ = 7.1 s

50% HPGe spectra after irradiation with 14 MeV neutrons, with and without the 22 kg nat-U target.

First Results in 2005: Decay curves show fission dominates ^{16}N contamination after a few half-lives



$^{16}O(n,p)^{16}N$:

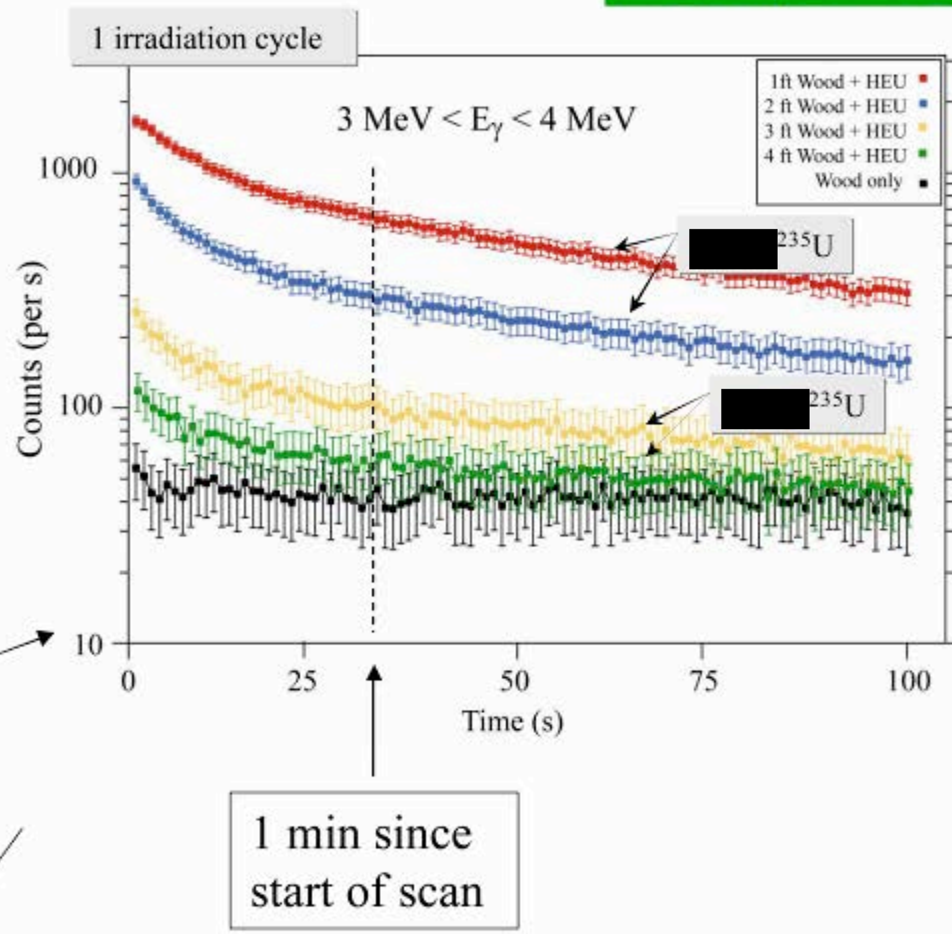
E_γ = 6.1 MeV

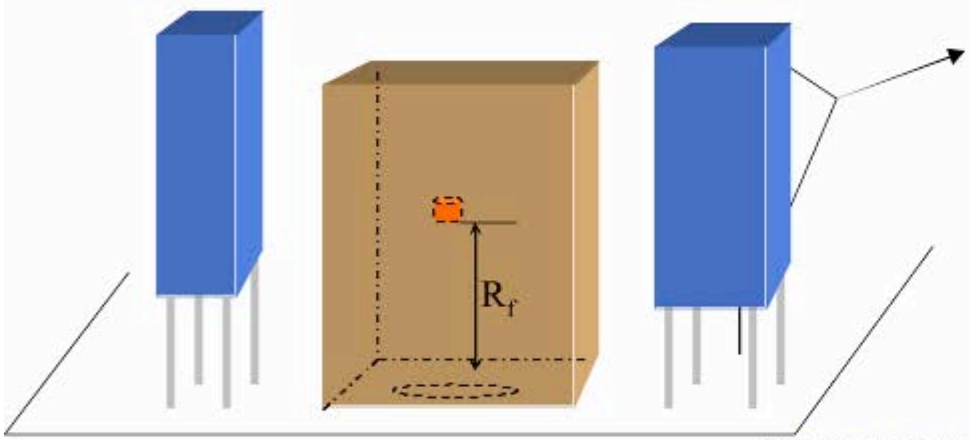
$t_{1/2}$ = 7.1 s

- E_n = 14 Mev
- 1 plastic detector
- 376.5 g HEU (U_3O_8)
- 50 irradiation cycles
- 3 MeV < E_g < 4 MeV

Delayed γ-ray signal stands out to 5σ in wood

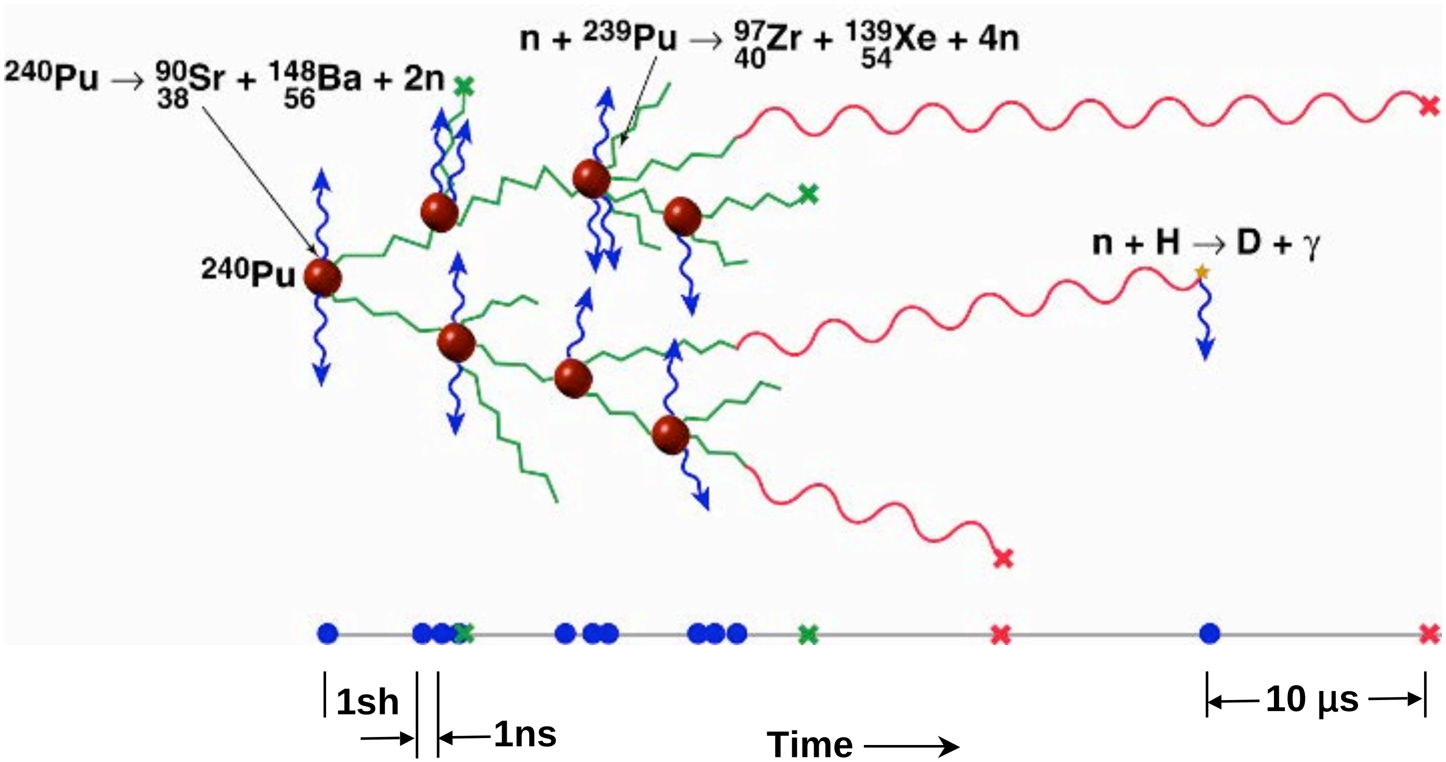
- Single cycle decay curves are shown for R_f = 1,2,3 and 4 ft. plywood.
- Normalized to 25 μA (100 W) into the d_2 gas target.
- 'Passive' background has been subtracted.
- 2σ Poisson uncertainties shown.
- Integrating to 30 s shows a signal 5 σ (actual) above the active background at Rf = 4'.





Improving Passive Detection of HEU and Pu using Plastic Scintillator and a Statistical Theory of the Fission Chain

A chain initiated by spontaneous fission of Pu-240



Neal Snyderman, Dan Dietrich, Chris Hagmann, Wolfgang Stoeffl, et. al

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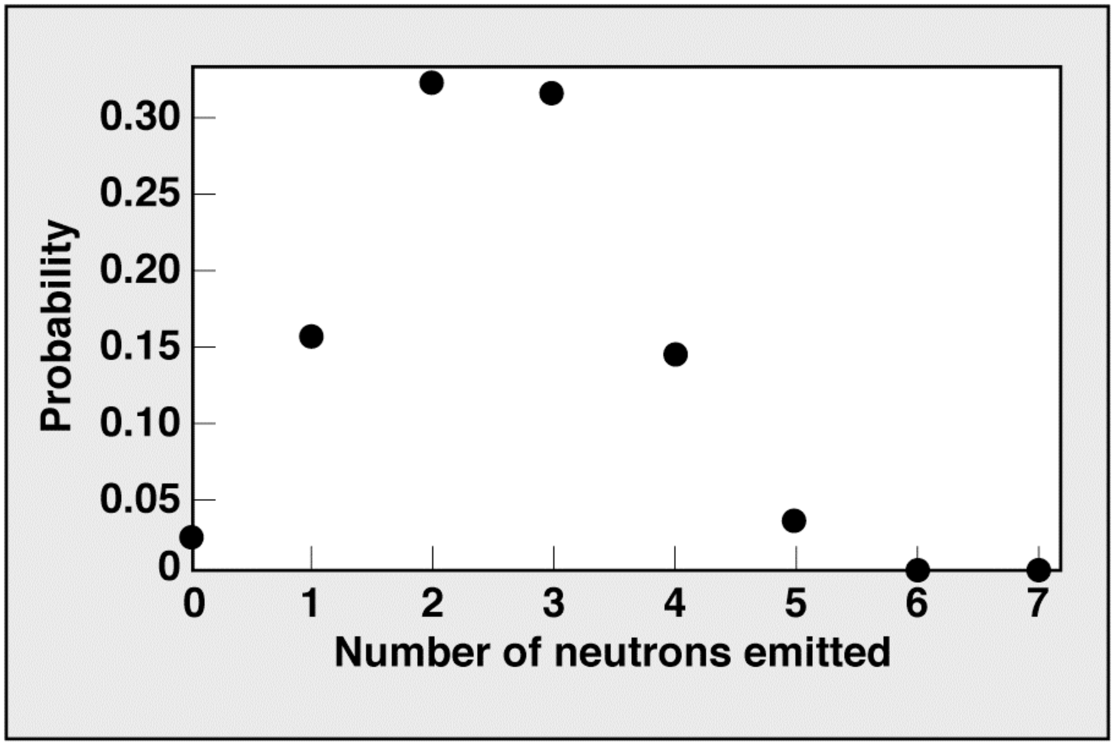
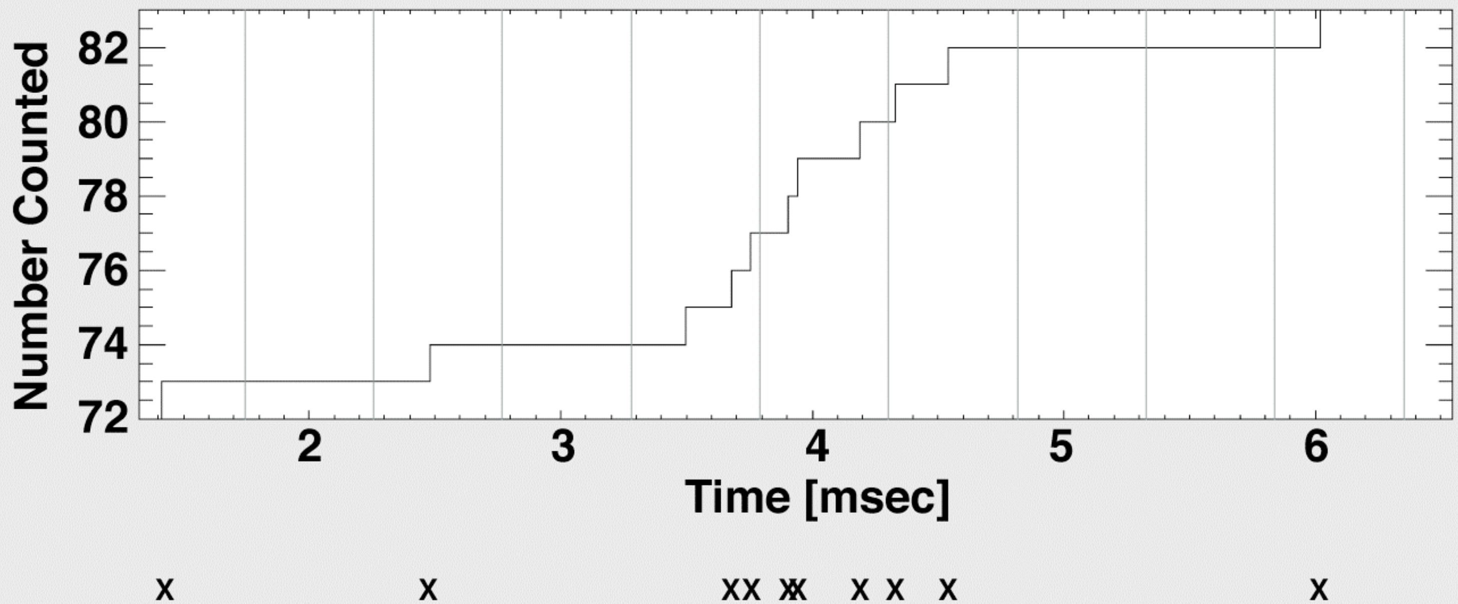
Number of neutrons emitted in fission



A simple time-correlation study: look at time series of counts

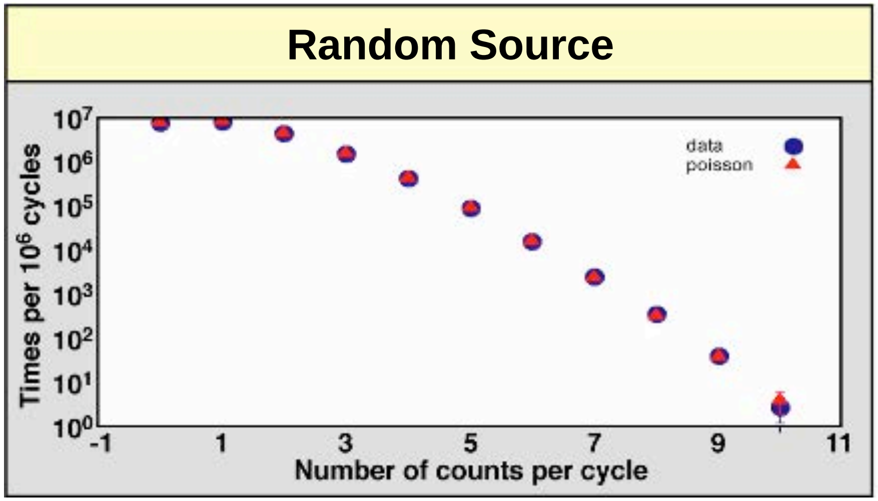
From one 512 μsecond interval to the next, sometimes very different numbers of counts are recorded

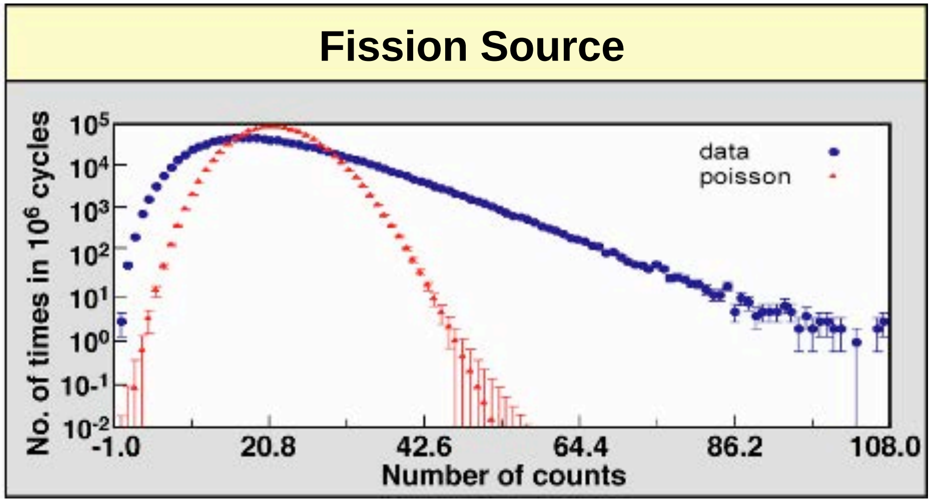


The basic data is the time of arrival of counts

Signature of fission

The increased width of the Pu data distribution over that of a random distribution is due to the very large fluctuations in the number of neutrons emitted from one fission chain to the next





Early data (2004-2005) were taken with He3 detectors

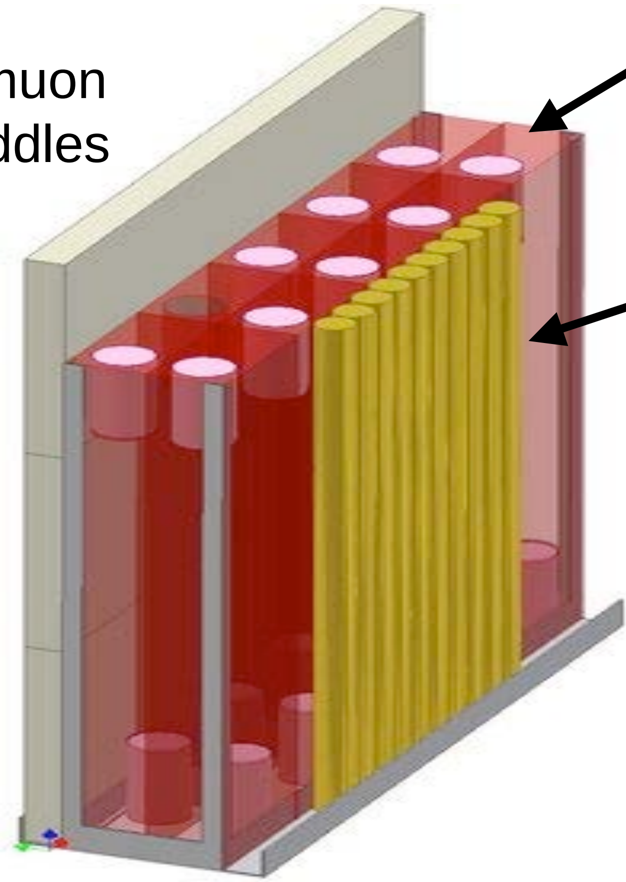
To fully exploit time signatures, we want to measure gamma-gamma, neutron-neutron, and gamma-neutron time correlations within burst-like fission chains occuring at low rates

- **Examples of time signatures**
  - ns to ten ns time correlations in the gamma shower
  - Microsecond time correlations persist even after thermalization of neutrons
  - Microsecond time correlations can persist even after neutron capture and conversion to 2.2 MeV gamma ray
  - Muons can create burst-like events that mimic the signal

- **Doped/undoped plastic or liquid scintillator detectors with a veto fulfill many the requirements for exploiting this rich signature**
  - large solid angle
  - ns timing resolution with waveform digitizers
  - Good efficiency for fast neutrons and gammas
  - with dopants, good efficiency for thermal neutrons
  - pulse shape discrimination may also be useful (depending on detector geometry)

Recent studies: one element of a 5-sided passive HEU detection test bed

5 cm
plastic muon
veto paddles

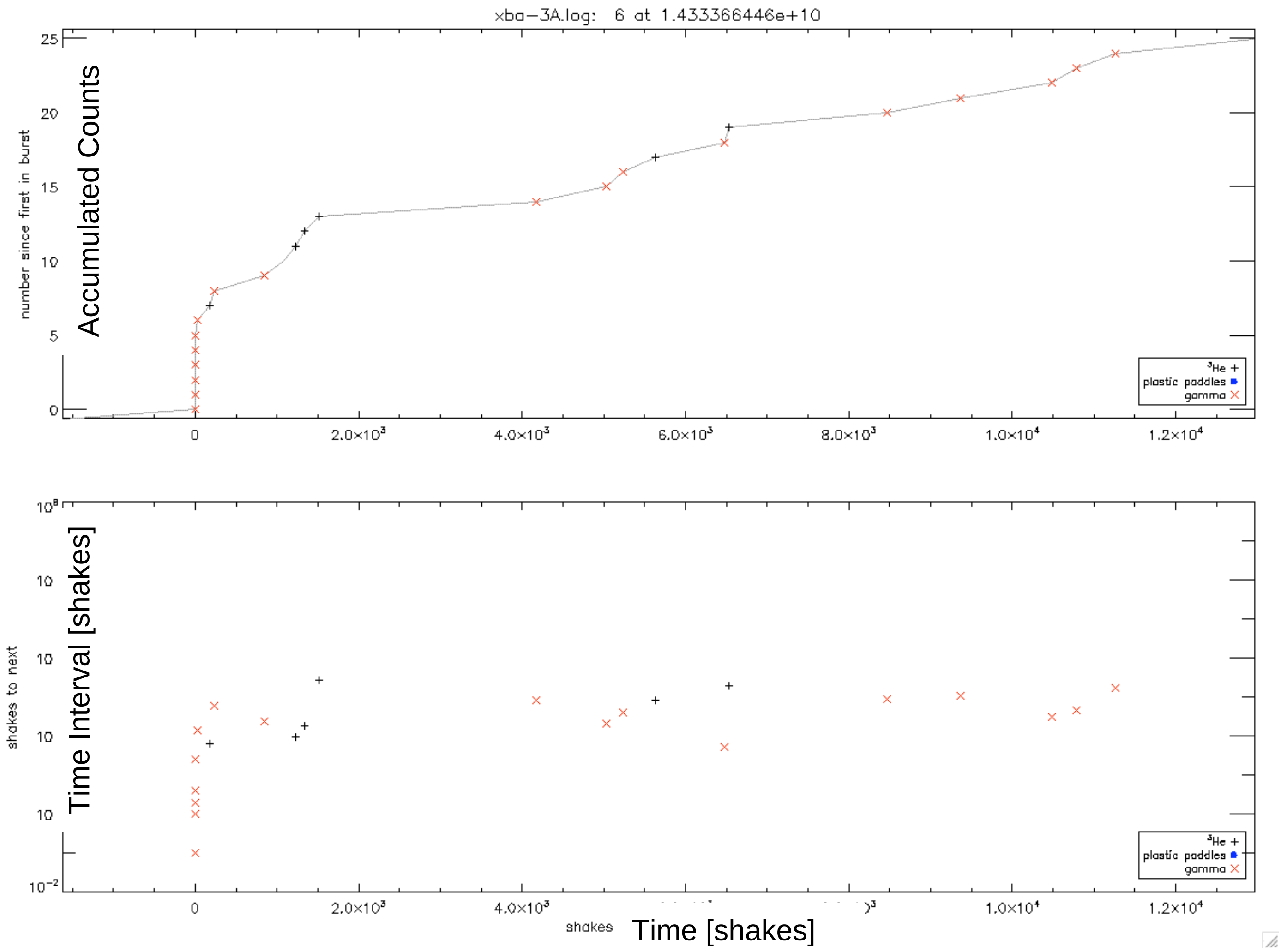


8 each
1 m x 10 cm x 20 cm plastic scintillator
tubes with opposite
side readout

First implementation uses ^{3}He
tubes for thermal neutron detection
- neutron recoil or capture in doped
scintillator can also be used

Detector elements, size
and readout are close
analogs of
antineutrino detectors

Recent data recorded with a scintillator/^{3}He system



Summary of fission chain studies

- **There exists a fission chain signature from high multiplication HEU (and Pu) that can be passively exploited for detection**
  - using large neutron and γ-ray detectors outside a shipping container or other
  - even from low multiplication, if you can wait long enough (as we demonstrated experimentally)
- **Backgrounds from natural radioactivity can blind the (n, γ) signal, but**
  - high multiplication events can be picked out for by statistical techniques
  - with fast timing, prompt fission γ-ray signal can be seen between background counts
- **Background from cosmic ray showers interacting with cargo can create a signal qualitatively similar to the fission chain signal**

Cubic meter scale scintillator detectors with a muon veto hold promise for passive HEU detection

The point(s)

- San Onofre like detectors have wide application outside of basic or applied antineutrino physics
- Other problems in nonproliferation and nuclear security are as interesting as reactor monitoring
- This community and technology can help solve those problems
- Spectroscopy isn’t everything