BNL-81308-2008-CP

Office of Nonproliferation Research and Development

SNM Movement Detection / Radiation Sensors and Advanced Materials Portfolio Review

Thermal neutron imaging support with other laboratories BL06-IM-TNI

June 17, 2008

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Thermal neutron imaging support with other laboratories

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Co-investigators:
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Collaborators:
James Jones, INL
Daren Norman, INL
Gus Caffrey, INL
Klaus Ziock, LLNL and ORNL
Tim Brown, SRNL

Budget:	2006	2007	2008
	$150k	$150k	$150k

Project overview

Goals:

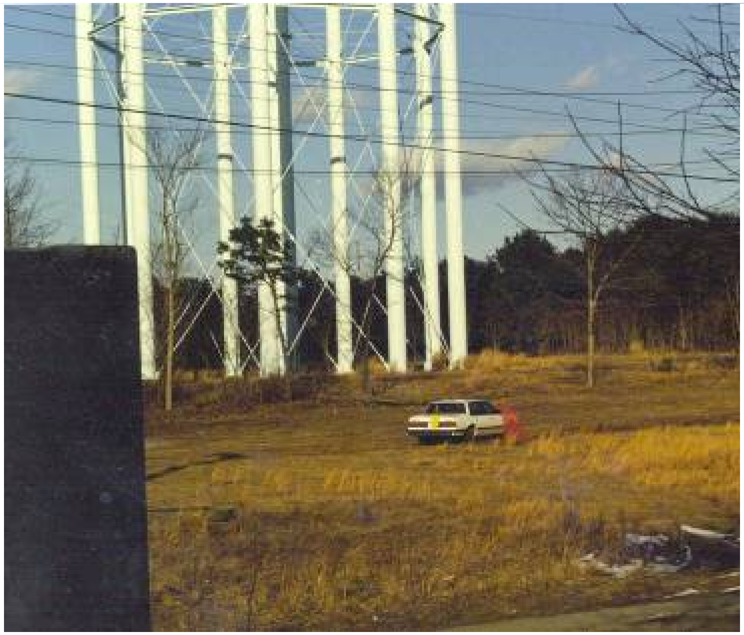
Detect and locate a source of thermal neutrons

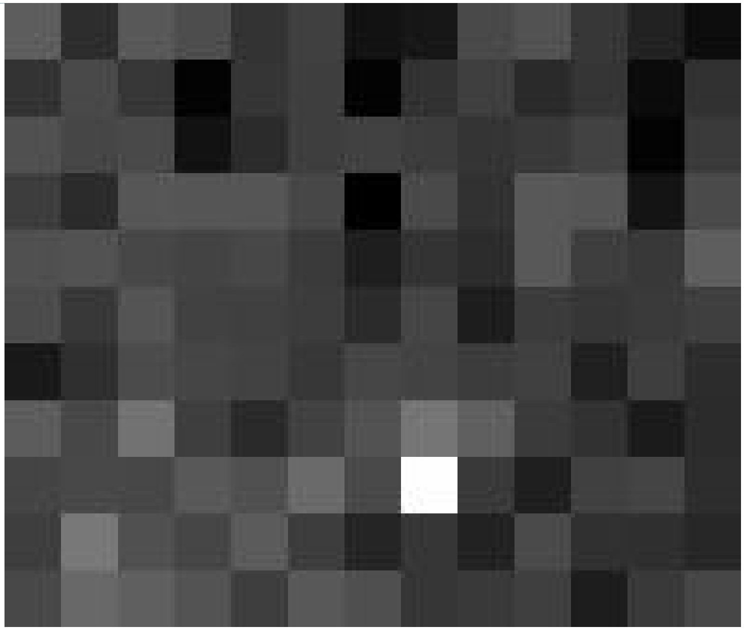
Distinguish a localized source from uniform background

Show shape and size of thermalizing material

Test thermal neutron imager in active interrogation environment

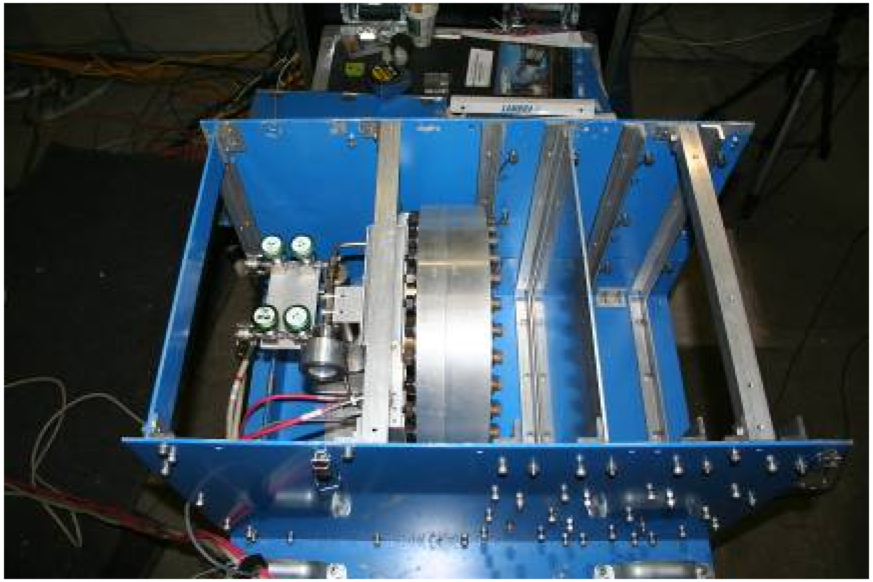
Distinguish delayed neutrons from prompt neutrons

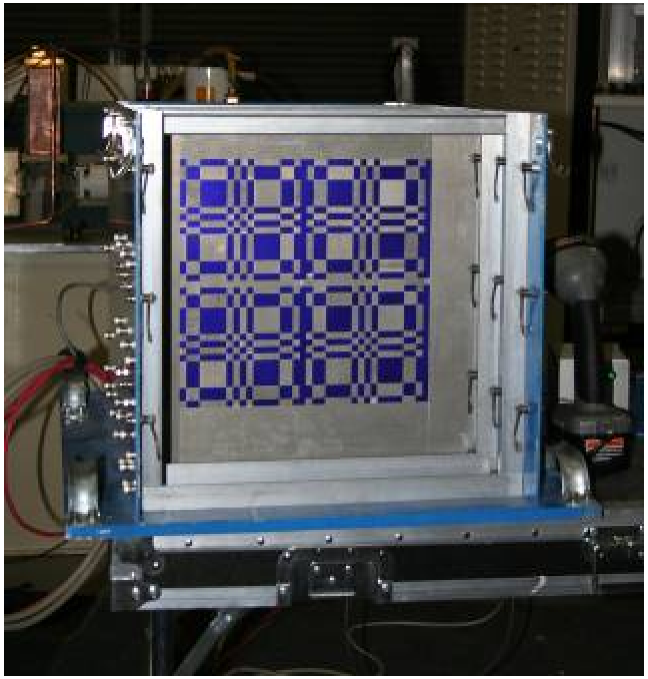




Technical approach

- Compressed He-3 position-sensitive wire chamber
- Cadmium coded aperture
- Continuous acquisition for passive mode
- Time-gated data acquisition for active mode
- Fast Fourier Transform processing





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Early papers on coded apertures

- E.E. Fenimore and T.M. Cannon, “ Coded Aperture Imaging with Uniformly Redundant Arrays, ” *Applied Optics,* **17**, 337-347, (1978)
- E.E. Fenimore and T.M. Cannon, “Uniformly Redundant Arrays: digital reconstruction methods”, *Applied Optics,* **20**, 1858-64 (1981)
- S.R. Gottesman and E.E. Fenimore, “New family of binary arrays for coded aperture imaging”, *Applied Optics,* **28**, 4344-52, (1989)

Thermal neutron imaging support with other laboratories

Deliverables:

- Quarterly Technical Reports
- Quarterly Budget Reports
- Publications
- Presentations at Conferences
- Final Technical Report

Capability improvement addressed by project success (relevant to the non-proliferation mission):

- Improved search capability
- Improved diagnostic capability
- Improved arms control signatures
- Improved active interrogation of shipping containers
- Improved explosives detection capability
- Improved monitoring of dry fuel storage containers

Progress to date

Various neutron sources

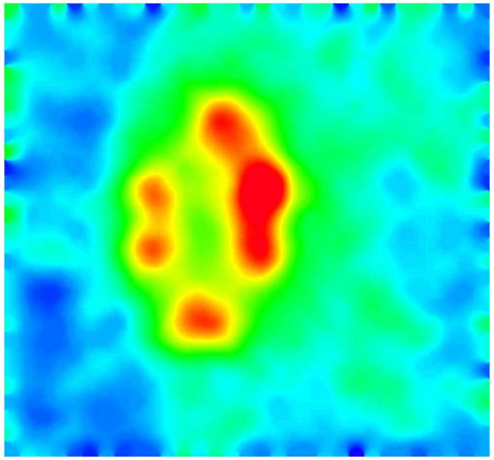
- **Cf-252 (spontaneous fission)**
- **Am-241+Li (alpha,n)**
- **Bremsstrahlung + W or Pb (prompt photo-neutron)**
- **Bremsstrahlung + DU (photofission, delayed neutrons)**
- **D-T generator (14 MeV neutrons slowing to thermal)**

Different moderators

- **Polyethylene**
- **Paraffin wax**
- **Water**
- **Melamine**

Object shapes and sizes

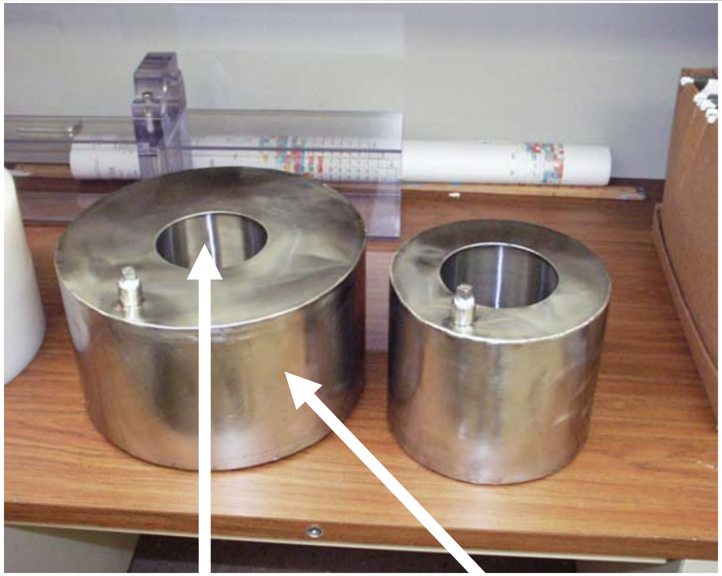
Single pixel
Multiple separated objects
Round, diameter up to 1/3 field of view
Triangle, rectangle, torus



Demonstration of multiple-source counting capability

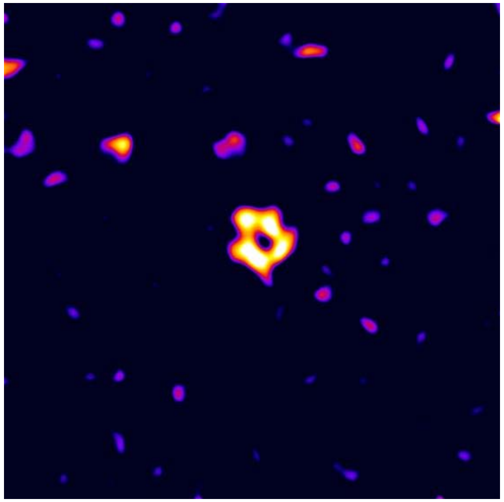
Pu oxide cans in water jackets at SRL

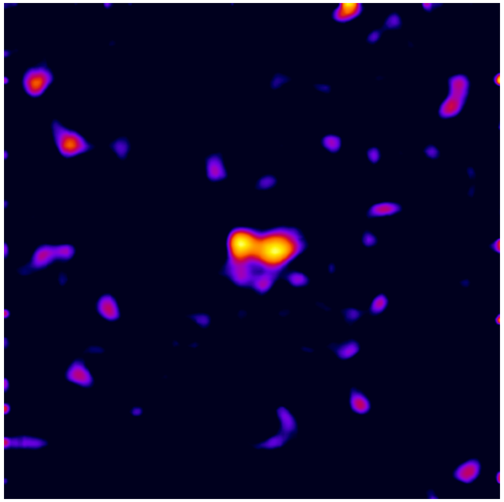
10 cm water gives good thermalization



5 cm water is not enough

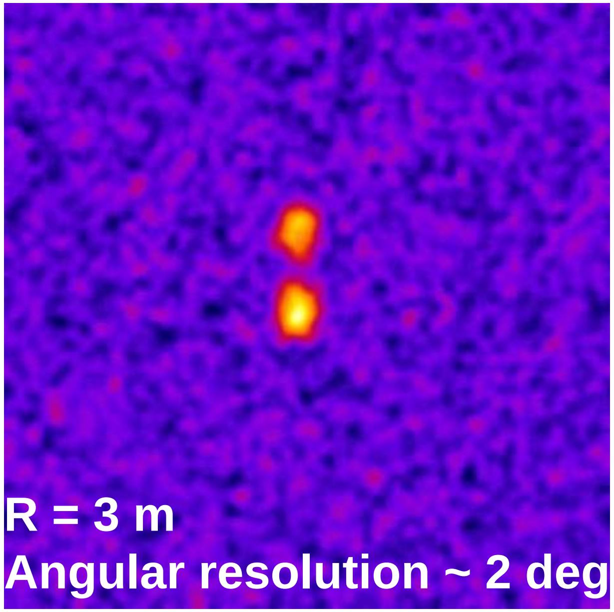
TOP VIEW

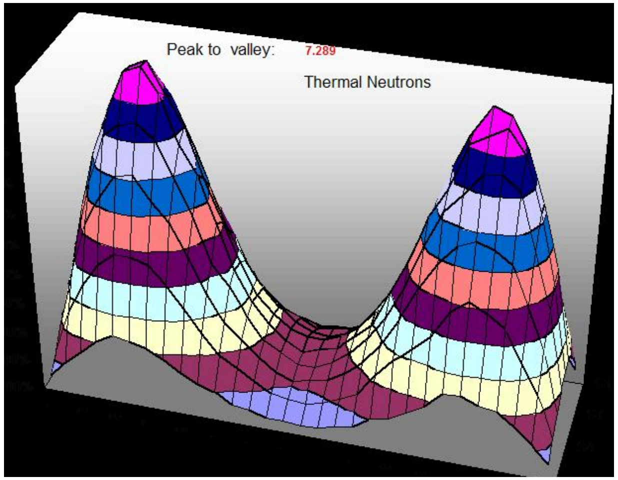




SIDE VIEW

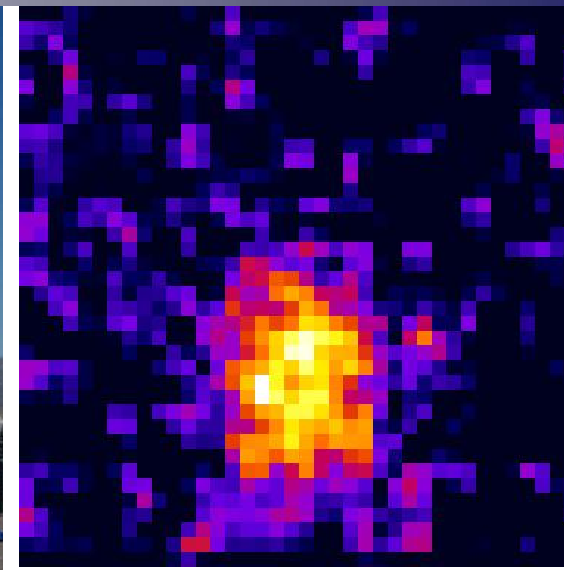
Imaging experiments at INL





- ^{252}Cf sources in three 10 cm polyethylene cubes
- The neutron diffusion length is less than the 10 cm cube size so the center cube is suppressed
- Agrees with Monte Carlo results (right- Alain Lebrun)

Leakage of thermal neutrons from dry storage casks at INL Tech Area North



Thermal neutron image

Examples of storage casks at Idaho National Lab

Klaus-Peter Ziock, Gus Caffrey, Alain Lebrun, Leon Forman, Peter Vanier and Jason Wharton, Conference Record of IEEE Nuclear Science Symposium, 2005, Puerto Rico.

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Back illumination with thermal neutrons

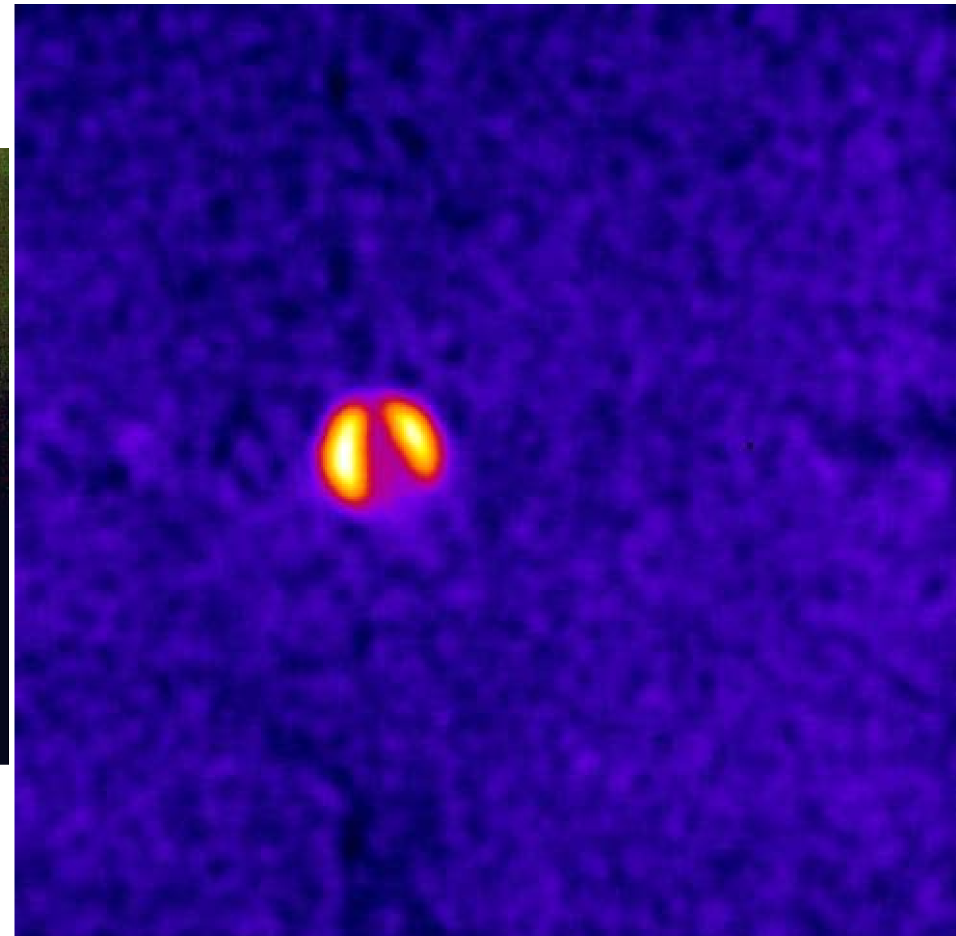
Photograph

BPE Shielding

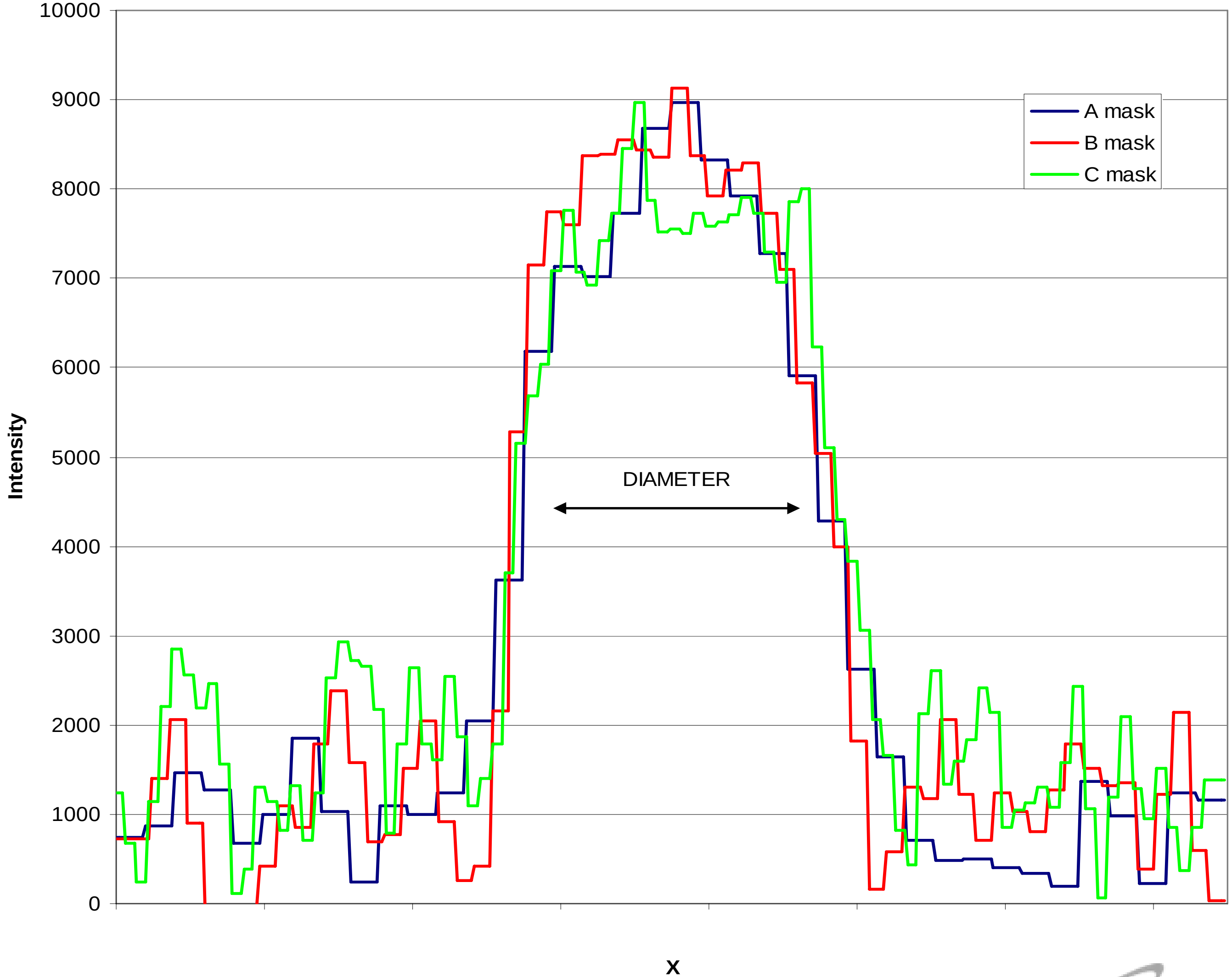
Wooden wedge

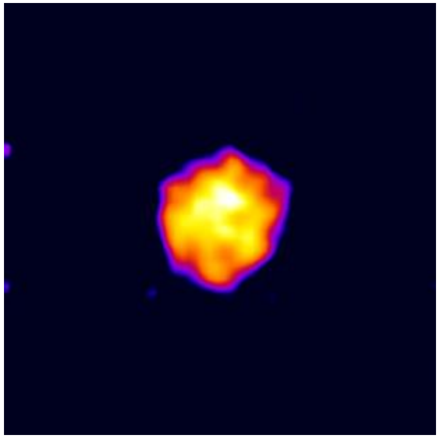
Neutron source behind paraffin cylinder

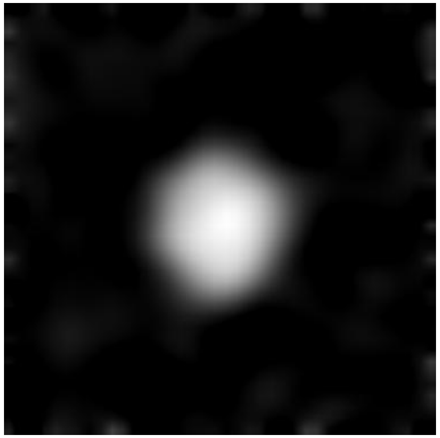
Neutron Image



Cf-252 or Pu in melamine moderators







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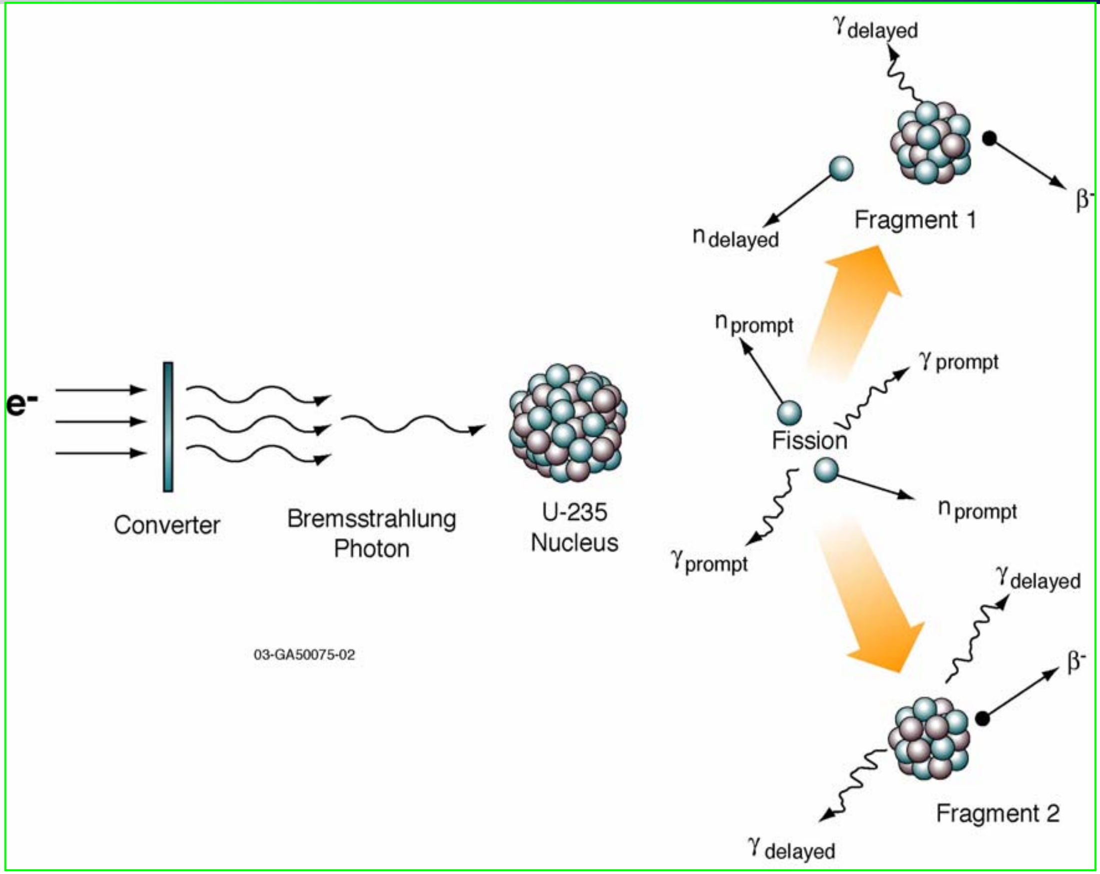
Prompt photoneutrons from high-Z targets

- **A pulsed electron accelerator produces high-energy x-rays (10-MeV) to generate photonuclear reactions**
- **Nuclear materials will undergo photofission and generate prompt and delayed neutrons**
- **The delayed neutrons continue to be emitted after each prompt neutron emission**



D.R. Norman, J.L. Jones, K.J. Haskell, P. Vanier and L. Forman,
IEEE NSS-MIC Conference Record, October 23-29, 2005

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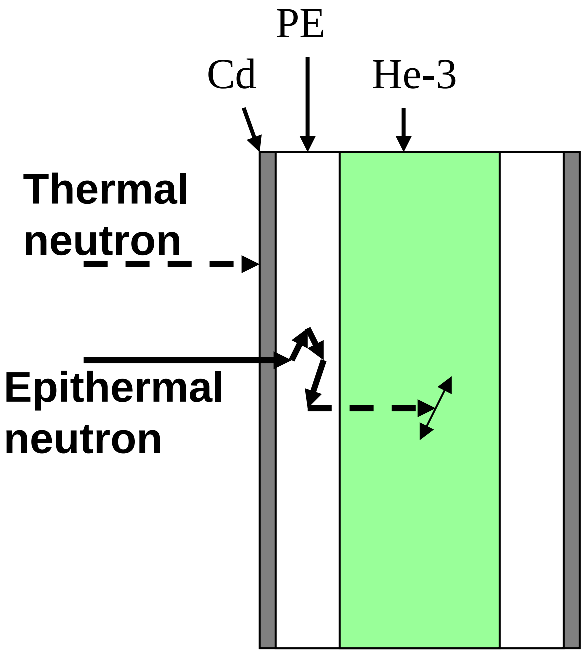
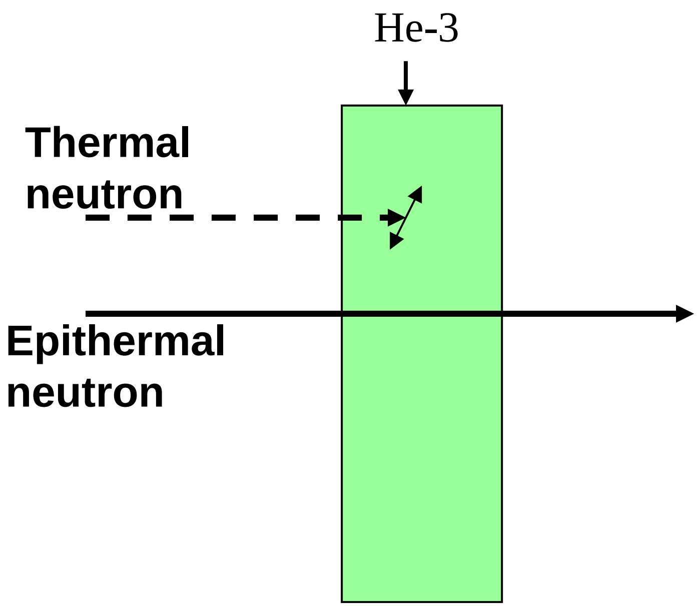
Thermal and epithermal neutron detection

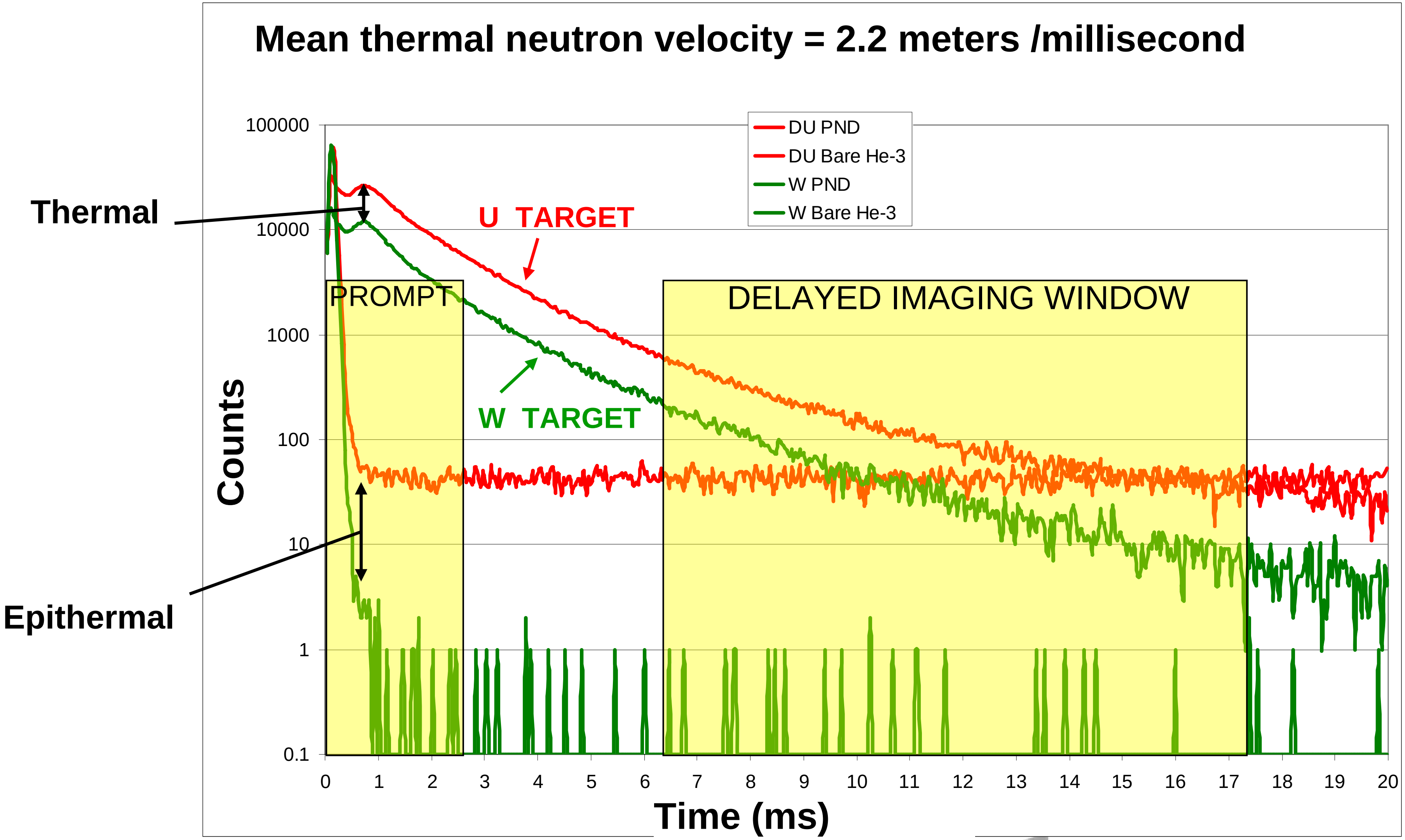




INL PHOTO-NUCLEAR DETECTOR

BARE He-3 DETECTOR

Neutron responses after short pulses of photons



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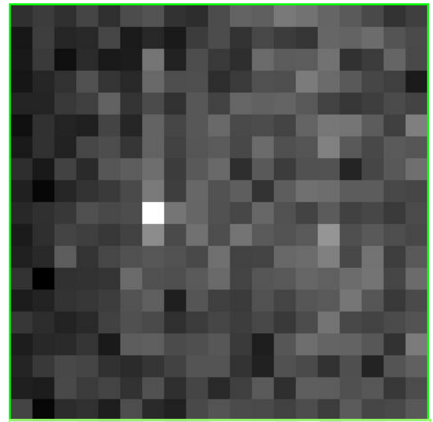
Delayed neutron images

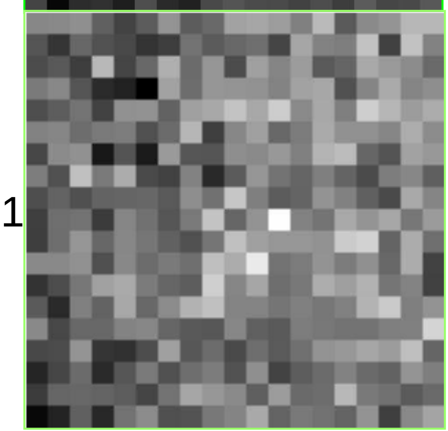
Depleted uranium in polyethylene

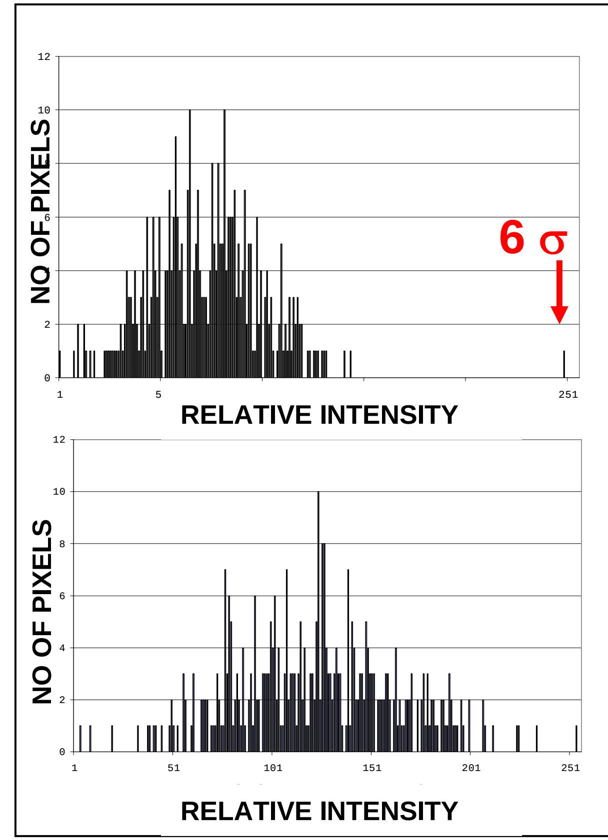
- 6.5-17.5 ms image window
- 69k neutrons, mean = 72, σ = 28



Tungsten in polyethylene

- 6.5-17.5 ms image window
- 17k neutrons, mean = 122, σ = 41





PIXEL INTENSITY HISTOGRAMS

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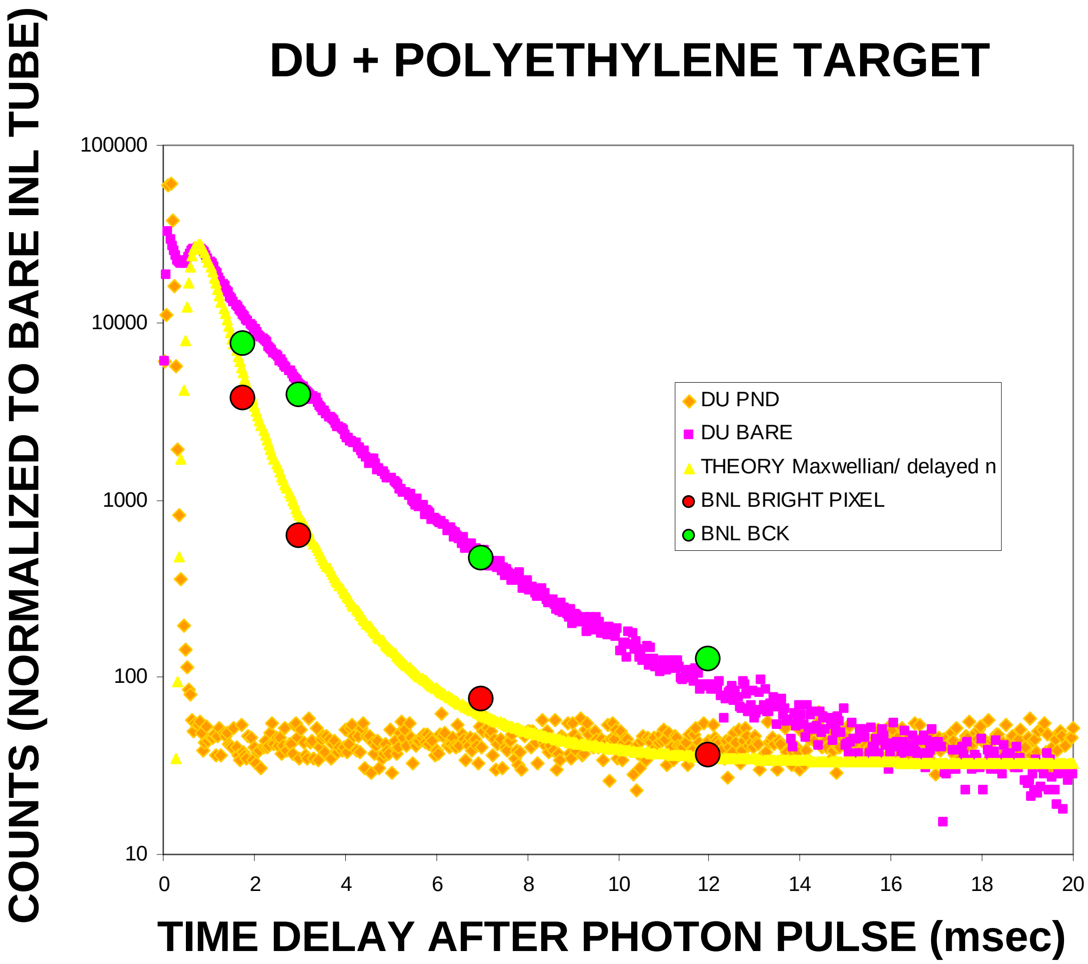
Time progression of image and background

DU + POLYETHYLENE TARGET



- Fast neutrons slowed down to thermal energy in 10's of microseconds
- Time-of-flight distribution for source pixel retains Maxwellian distribution of delayed neutrons from fission in DU+poly target
- Background dies away as a function of distance from thermalization materials in scene

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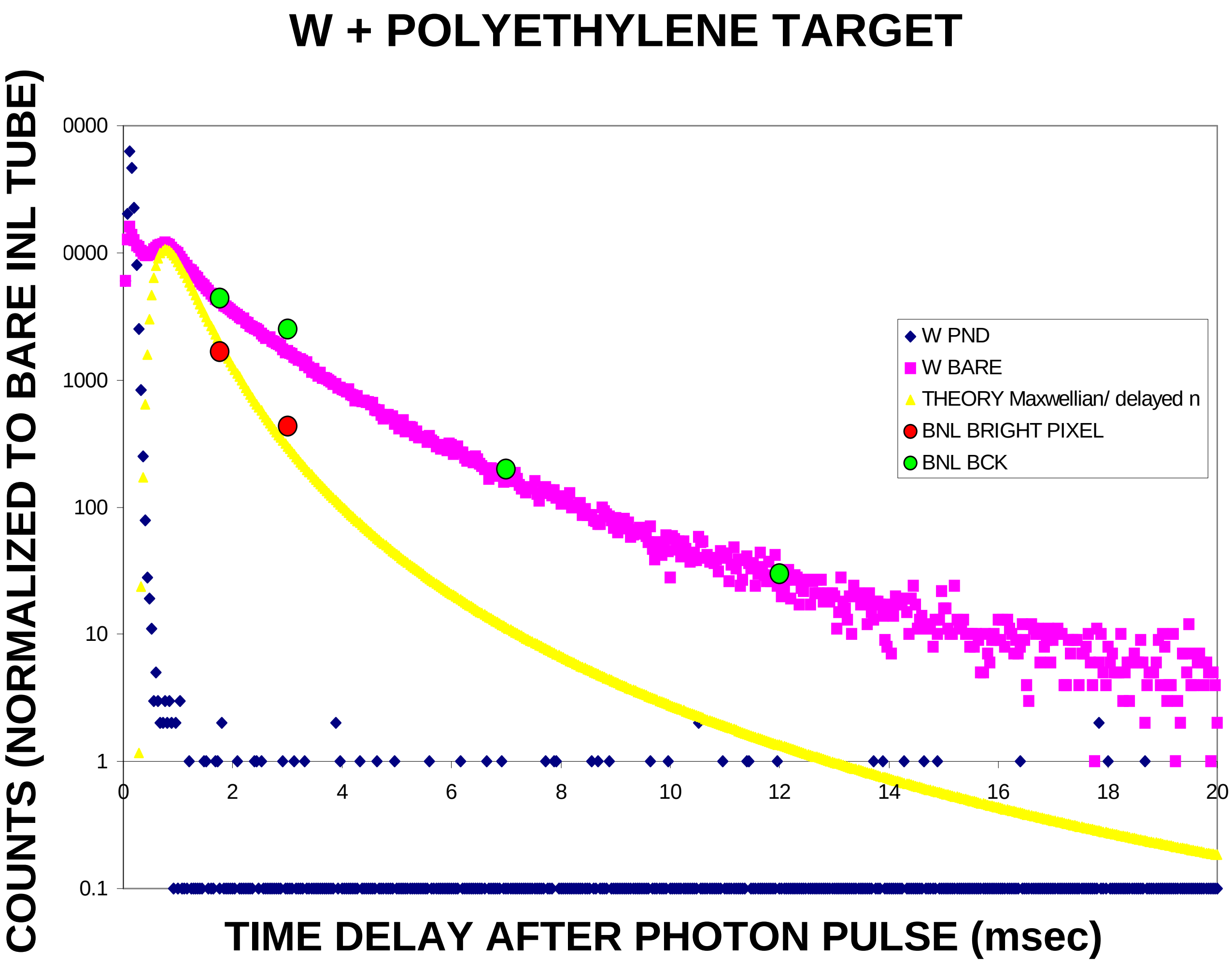
Time progression of image and background



•W+poly target does not produce delayed neutrons

Background overwhelms direct thermals after 4 ms

Note scale starts 2 decades lower than DU+poly

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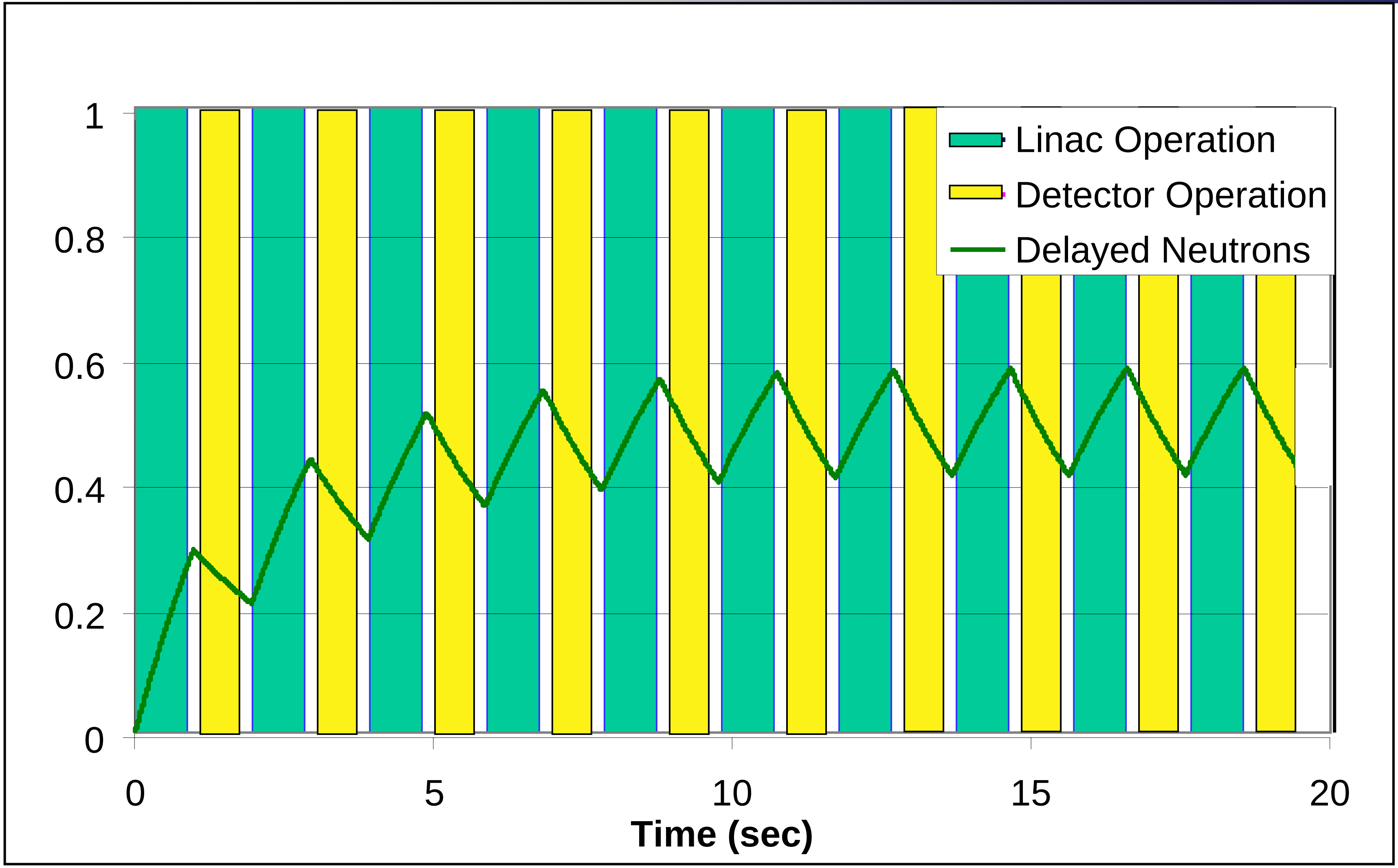
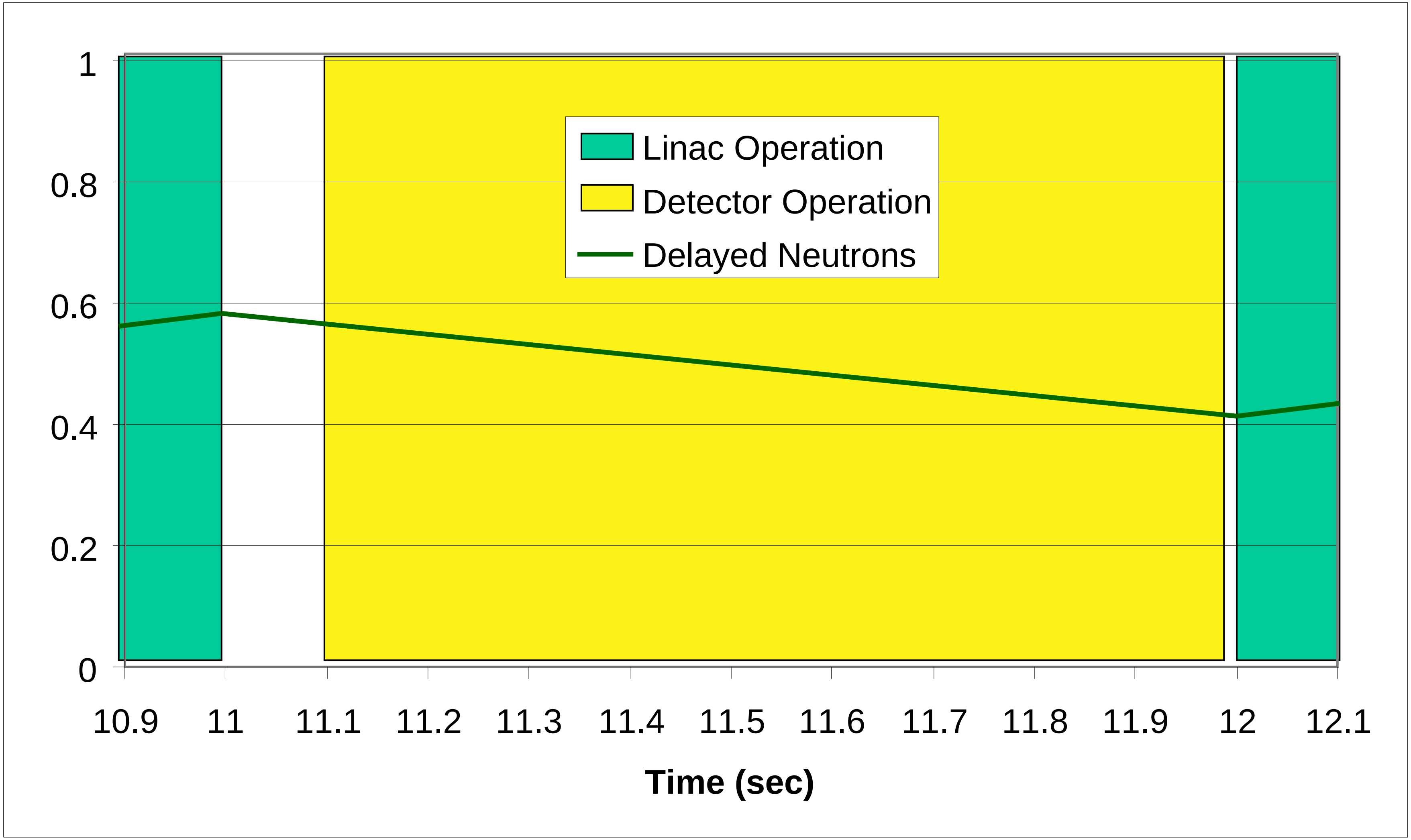
Interlaced Linac and Detector Gating for Delayed Neutrons



Detail of gating schematic

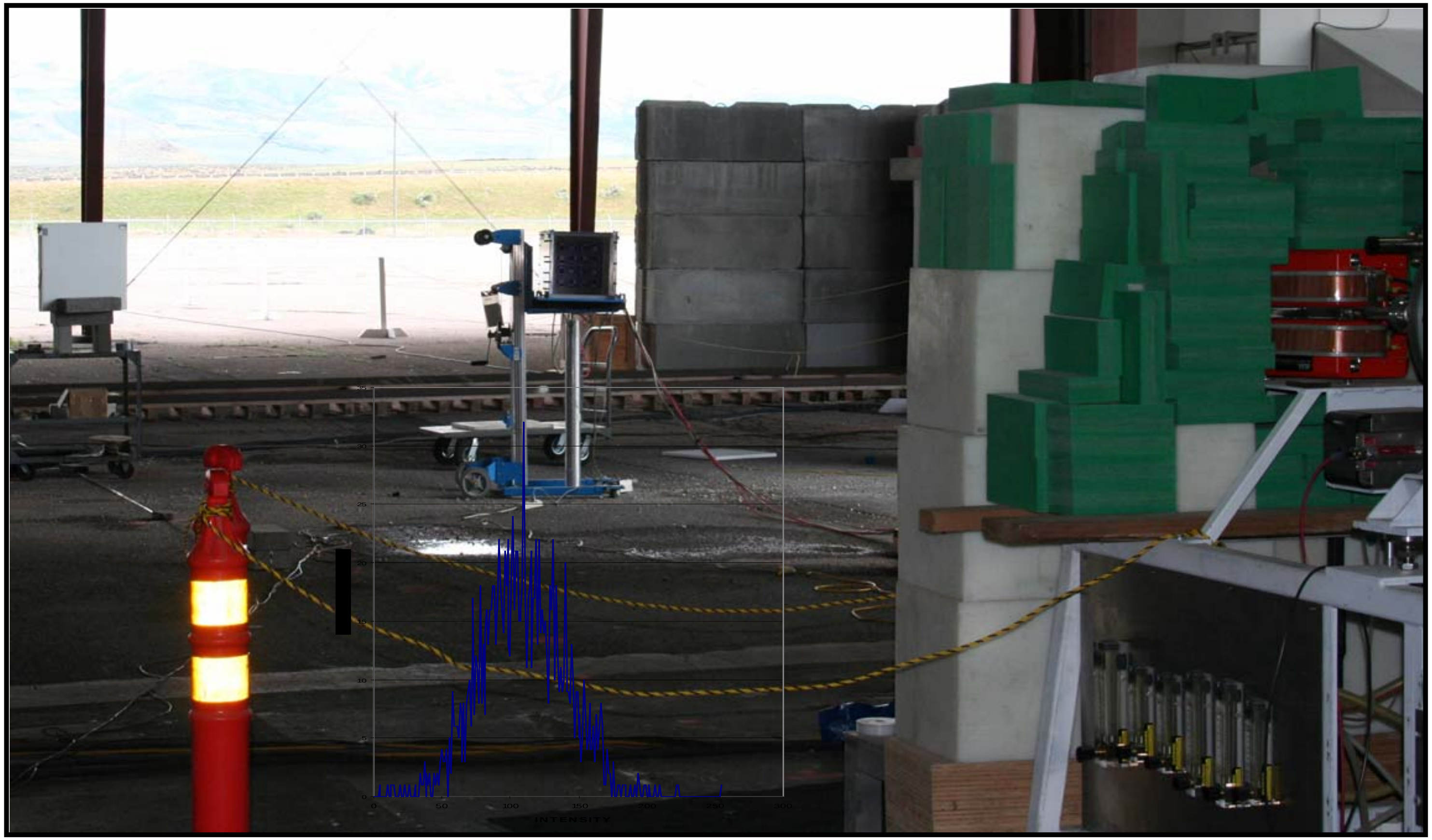


15 Meter Standoff Detection

DU target with poly, 10 min acquisition, gated (delayed) 1080 counts

Accelerator distance = 15 m

Detector distance = 2.4 m (a 1 m^2 detector would have same solid angle at 16 m)

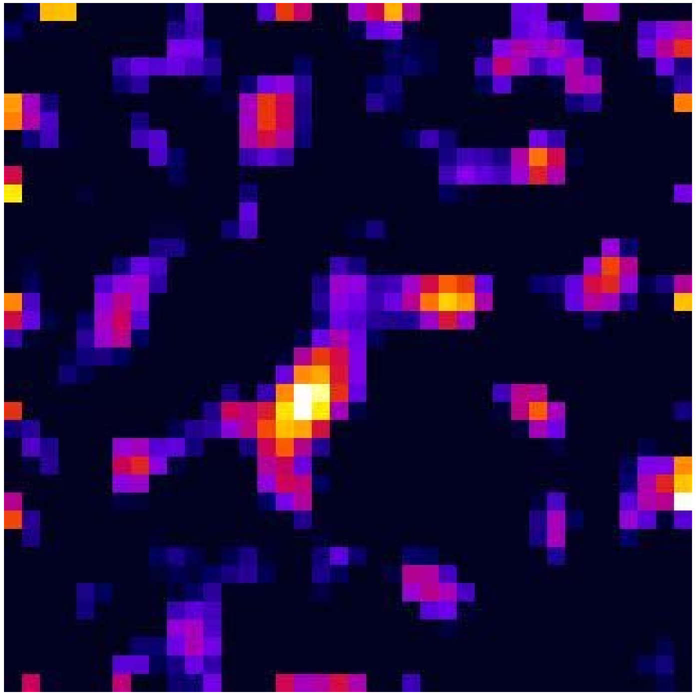


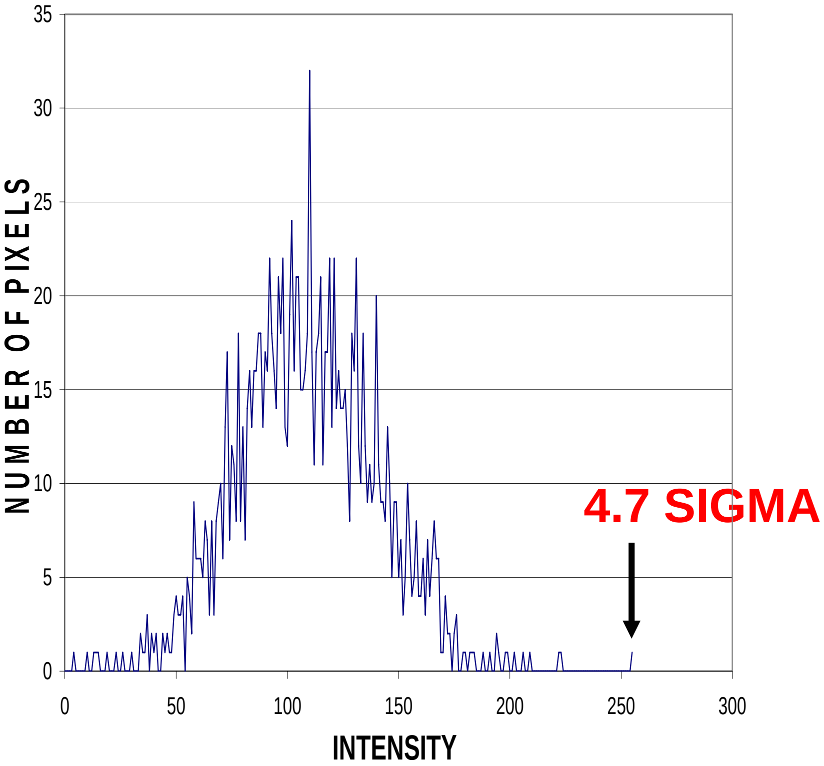
Bright spot in 1-second delayed image implies fissionable material

DU TARGET 15m FROM ACCELERATOR

MEAN =106
SIGMA = 31
MAX =256

1080 DELAYED THERMAL NEUTRONS

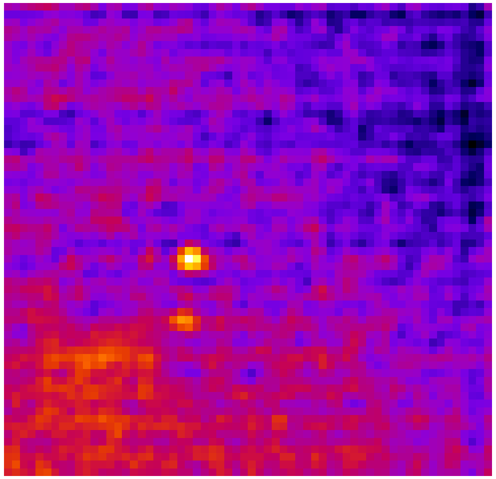




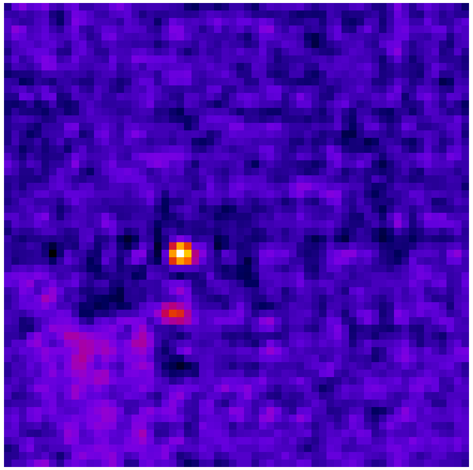
REDUCING BACKGROUND

Recent experiments at Idaho Accelerator Center

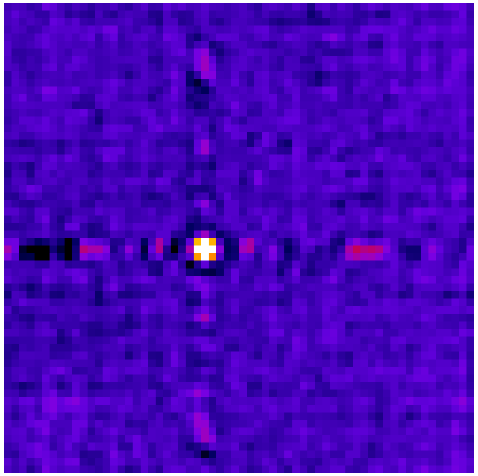
- Reduced high voltage on He-3 chamber to avoid saturation of preamps
- Higher count rates achieved for prompt component
- Explored effects of better shielding of accelerator and converter
- Explored time gates in the range 0.2 ms to 20 ms
- Should be able to reduce background



Long time gate



Shorter gate
More shielding



Extra shielding

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Future work for the remainder of the project

- Continued active interrogation experiments at INL

- More quantitative estimates of fluxes of
  - photons
  - fast neutrons
  - epithermal neutrons
  - thermal neutrons

- Suppression of effects of gamma flash on detector
- Time sliced imaging – separating direct signal from background scatter