SAND2013-4765C

Active Detection Experiments on the 16 MV Hermes-III Facility using Pulsed Bremsstrahlung Excitation*

T. J. Renk, B.V. Oliver, V. Harper-Slaboszewicz, M. S. Derzon, D. K. Derzon, P. W. Lake, E. Brubaker, M.D. Gerling, J. Steele

Sandia National Laboratories, Albuquerque, NM 87185 USA

40th IEEE International Conference on Plasma Science (ICOPS) and 19th IEEE Pulsed Power Conference (PPPS 2013)

San Francisco, CA June 16-21, 2013

*This work conducted under auspices of the NNSA-DTRA MOU on Counterterrorism, Survivability and Weapon Effects

Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin company, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

Outline

- Intense Pulsed Active Detection (IPAD) concept – use of single short (~40ns) interrogation pulse on target material – more prompt and near-prompt output compared to delayed, less competing background counts.

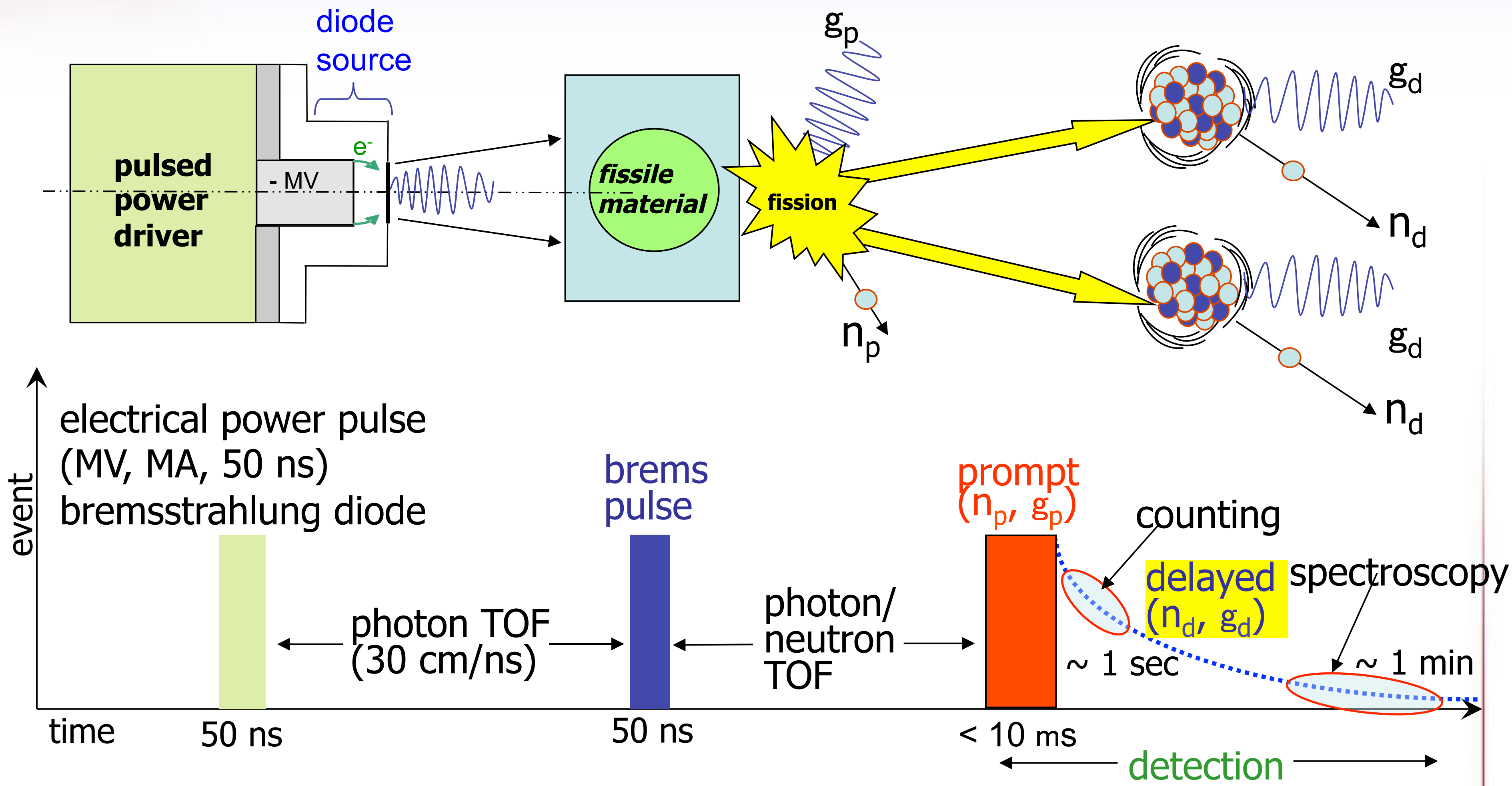
- Hermes III and Experiment description: detector setups and teams

- Code Modeling tools
  - Integrated Tiger Series (ITS) Monte Carlo: generates photon spectrum from electron impact to converter
  - MCNPX Monte Carlo: predicts gamma-neutron population generated by ITS photons

- Detector systems emphasized for this talk: Neutron Scatter Camera (Brubaker) and high-pressure He-3/He-4 (Derzon)

- Summary and Path Forward.

With IPAD approach, detection occurs in a short time following an intense burst of interrogating radiation

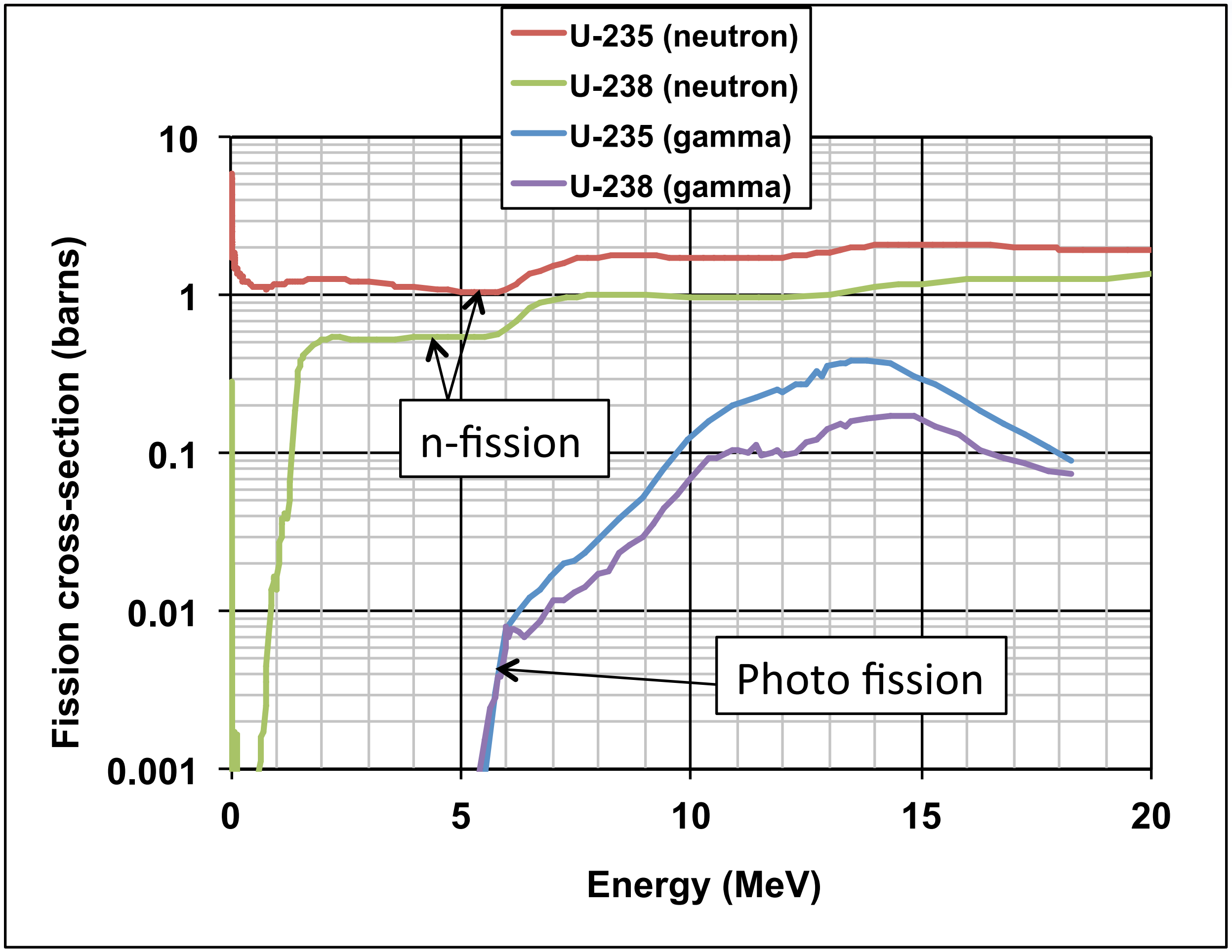


- **Single intense <100-ns irradiation pulse**
  - up to seconds for entire inspection
  - high signal/natural background allows trade off for lower dose
  - "single-pulse" allows access to prompt fission signatures

Many groups are involved in the Hermes-III IPAD experiments

- **Sandia Albuquerque (M. Derzon and Team)**
  - **Neutrons: ^{4}He Fast Neutron Sensors & ^{3}He detectors**
  - **Gammas: High-Pressure Xe, LaBr, BC418Q (both gamma and neutrons)**
- **Sandia Livermore (E. Brubaker and Team)** **Talk 7E-5**
  - **Neutrons/Gammas: liquid scintillator (neutron scatter camera)**
- **NRL Code 6770 (pulsed power physics branch)** **Talk 7E-4**
  - **Neutrons: ^{3}He tubes, plastic scintillators, rhodium foil activation**
  - **Gammas: BGO array**
- **NRL Code 7650 (high altitude space environments branch)** **Talk 7E-6**
  - **Gammas: NaI array (coded aperture imaging), LaBr**
  - **Neutrons: ^{3}He tubes, liquid scintillators**
- **U. Missouri Kansas City**
  - **Solid state neutron spectrometer**

Fission cross sections: photofission threshold > 5 MeV



Sandia National Laboratories

Photofission detection options

- Prompt g-rays
  - Probably impossible compared with scattered X-rays
- Prompt neutrons
  - Can be detected by time of flight (TOF) detection or energy discrimination
  - must be distinguished from (g,n) background
- Delayed g-rays must be distinguished from
  - Cosmic background
  - Induced (n, g) and activation
- Delayed neutrons
  - Cosmic background
  - But 100x fewer delayed than prompt neutrons

Sandia National Laboratories

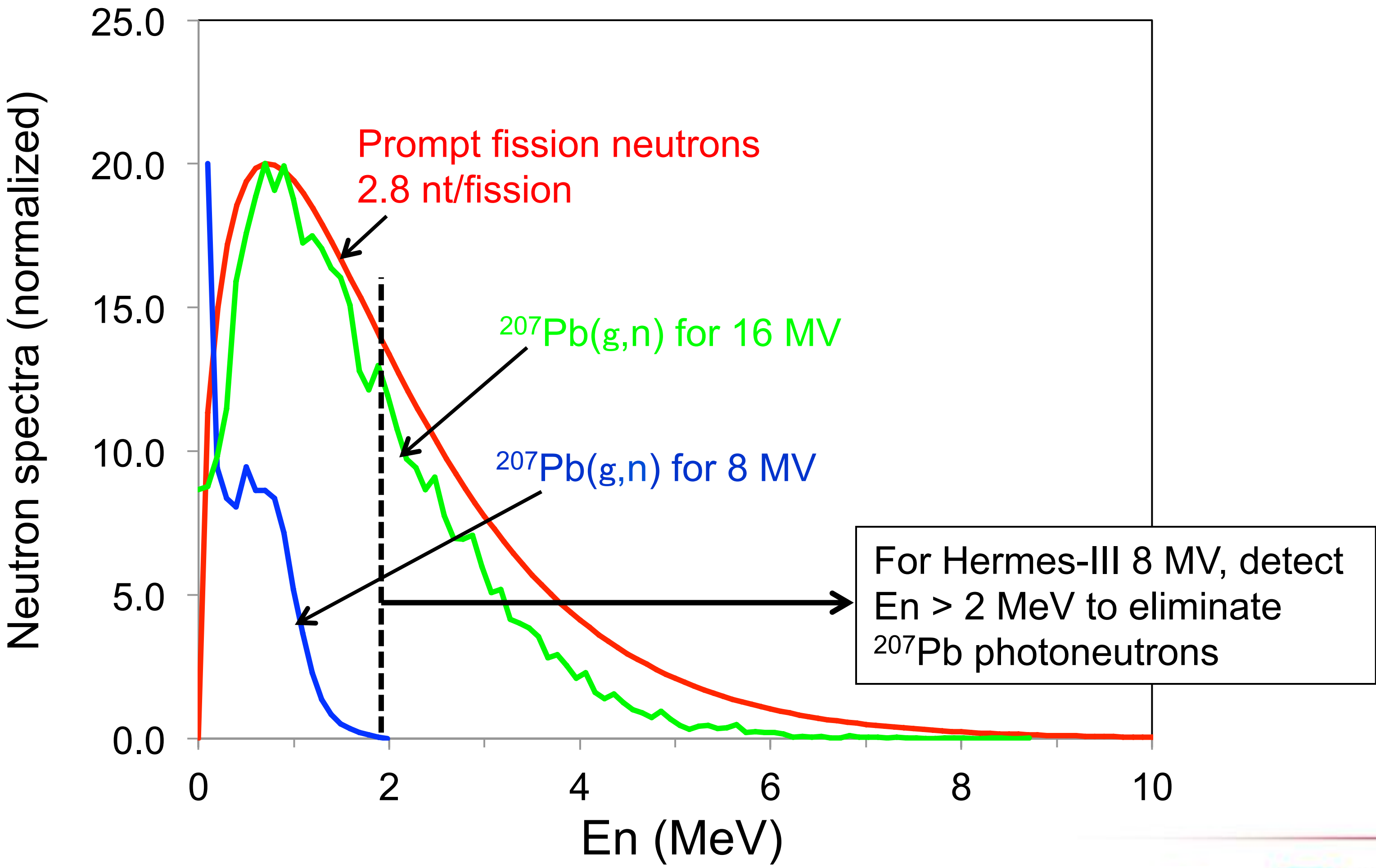
IPAD development requires both driver and detector optimization

- **Optimum interrogating voltage:**
  - **As g-energy rises above 6 MeV, more fissions produced, but also more induced background occurs. This talk: 6, 12, and 16 MV end-point voltage**
- **Photon flux:**
  - **More flux, more fissions, but bigger source (driver) needed**
  - **Longer interrogation/detector distances, more flux needed. Here, source distance ~ 19 m, detector distance up to 45 m**
- **Time-scale for detection:**
  - **Prompt competes with induced photofissions (Pb, etc)**
  - **Photo-neutrons: TOF spreads detection time, Pulse-shape Discrimination (PSD) possible**

Sandia National Laboratories

8 MV end-point: ^{207}Pb photoneutrons limited to < 2MeV. If S/N is adequate, discrimination easier than 16MV, where ^{207}Pb photofission spectrum comparable to fission

NRL

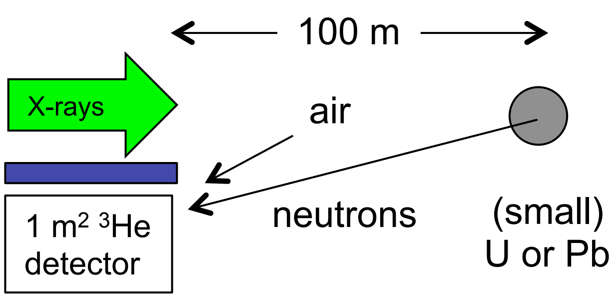


Sandia National Laboratories

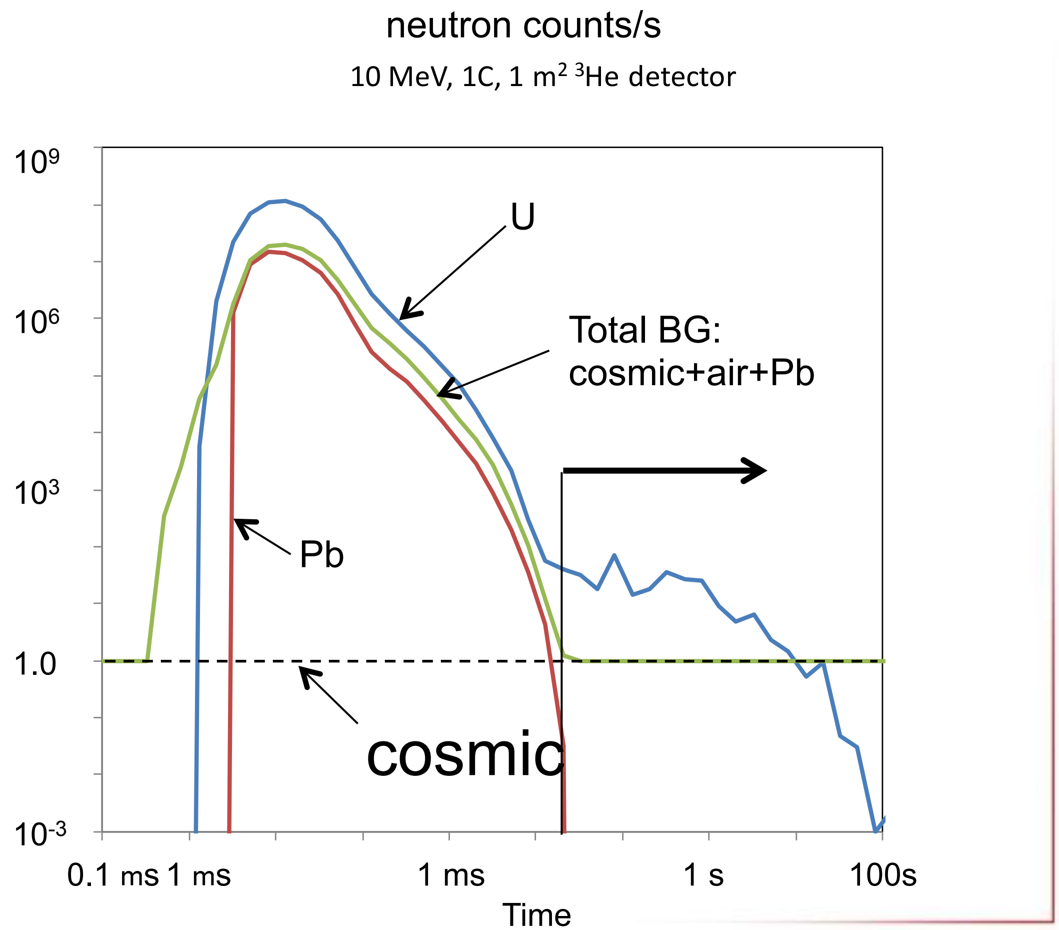
Delayed fission neutrons can be detected after induced background becomes small

NRL

Example MCNPX calculation



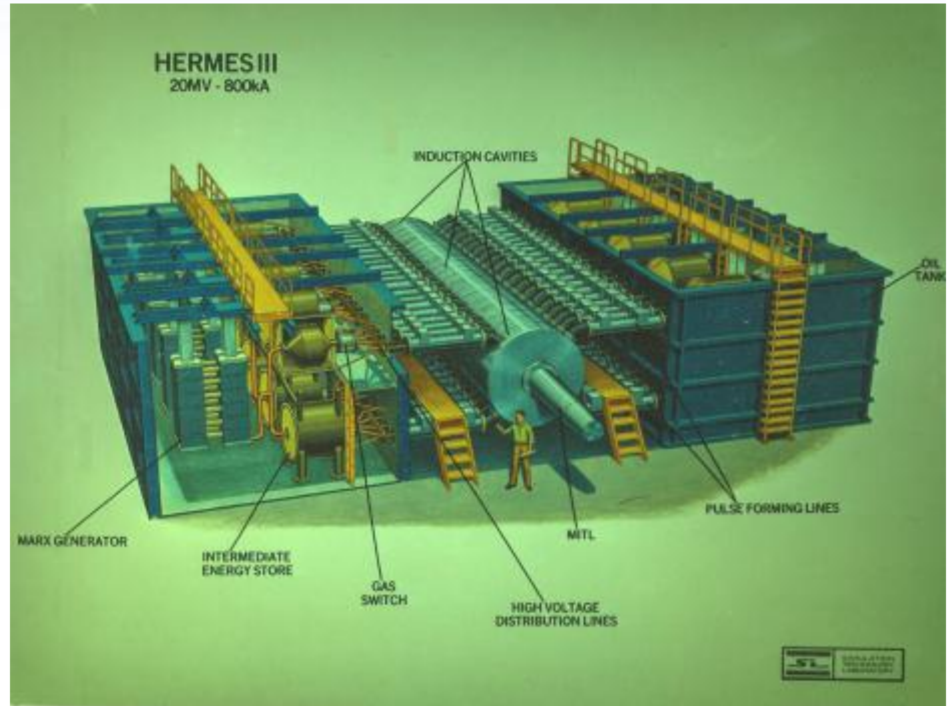
X-rays produced by 100 ns, 1C pulse of 10-MeV electrons at normal incidence on 0.1 CSDA tantalum + 0.9 CSDA aluminum bremsstrahlung converter

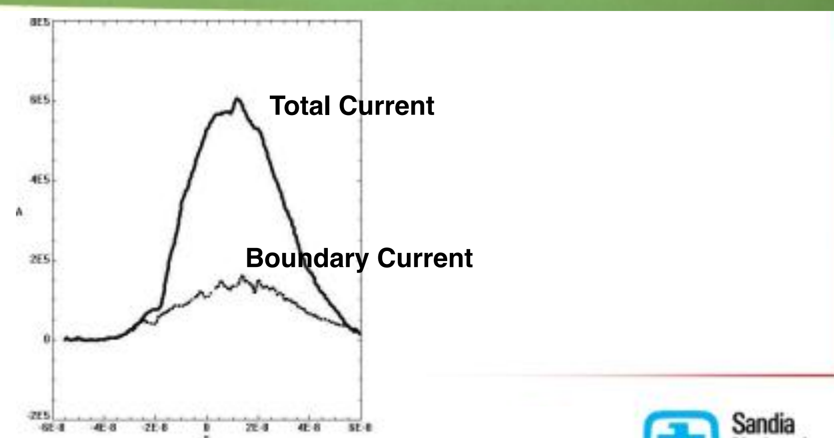


Sandia National Laboratories

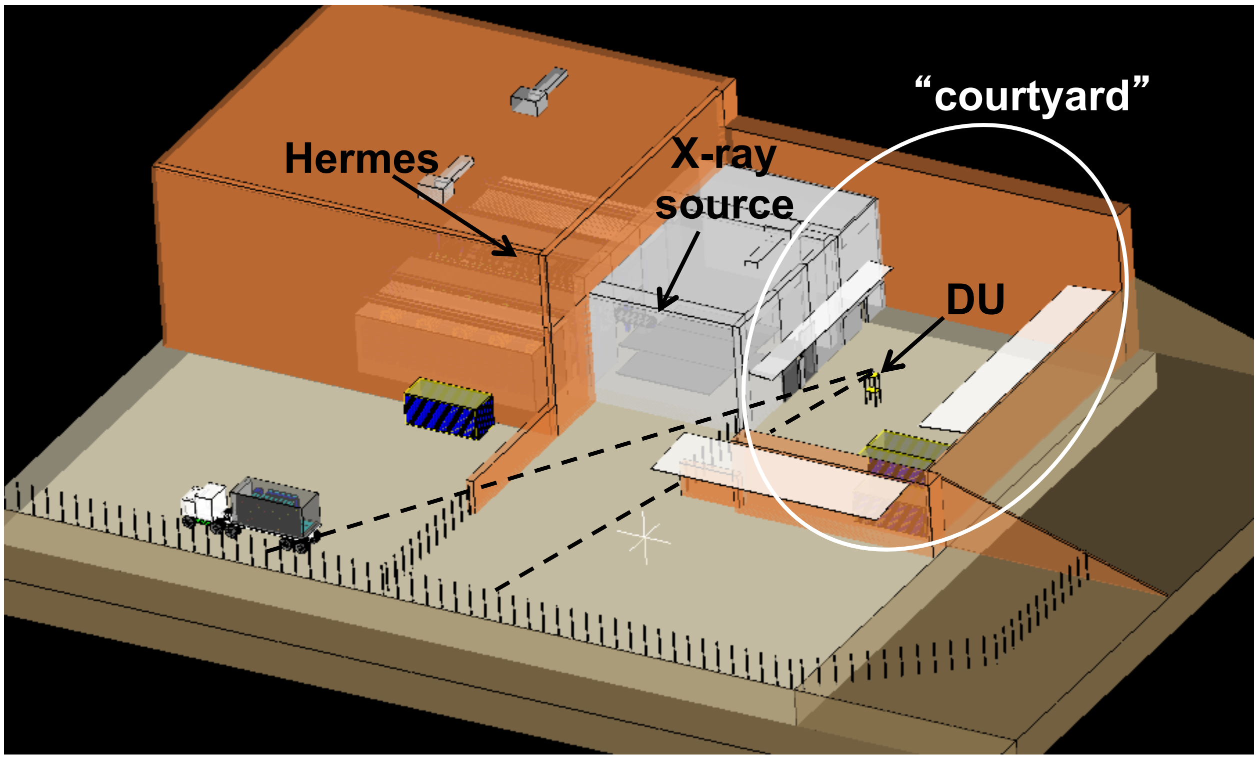
Hermes III is the Test Bed for these experiments

- **Hermes III - Inductive Voltage Adder (IVA) architecture, 18 MV 600 kA 40 ns when operated in negative polarity normal pulse**
- **20-stage IVA: significant vacuum current (Right below) (Total minus Boundary)**
- **Desired: electron flow across 67-cm A-K gap at 'relatively' normal incidence to Ta converter**
- **Desired: forward-directed x-ray output towards target(s) at 19-m distance, minimizing scatter within building and in 'courtyard'**
- **Modeling tools: LSP for electron trajectories, ITS/MCNPX for x-ray and (g,n) characterization**



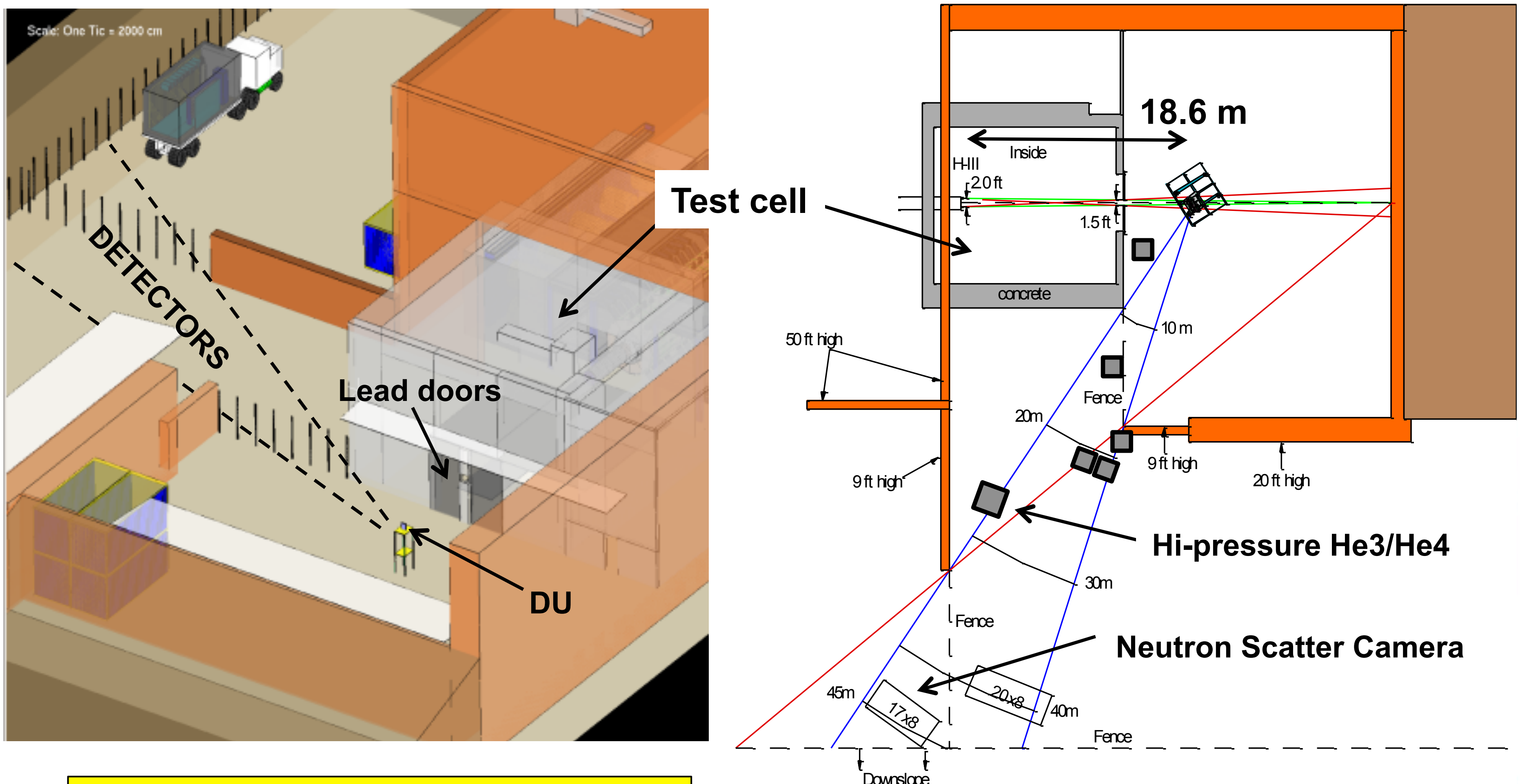


HERMES schematic layout: from 8 MV to 16 MV and to distances of 10s of meters



- 3 modes of operation
  - 'Half machine' 8 MV, 300 kA
  - 'Full machine' non-core reset 12 MV
  - 'Full machine' 16 MV, 600 kA
- Setup for IPAD expts
  - 18.6 m source-DU
  - 5 to 45 m DU-detector
  - Evaluate potential of IPAD at 100 m distances
  - Target shown: depleted uranium (DU)

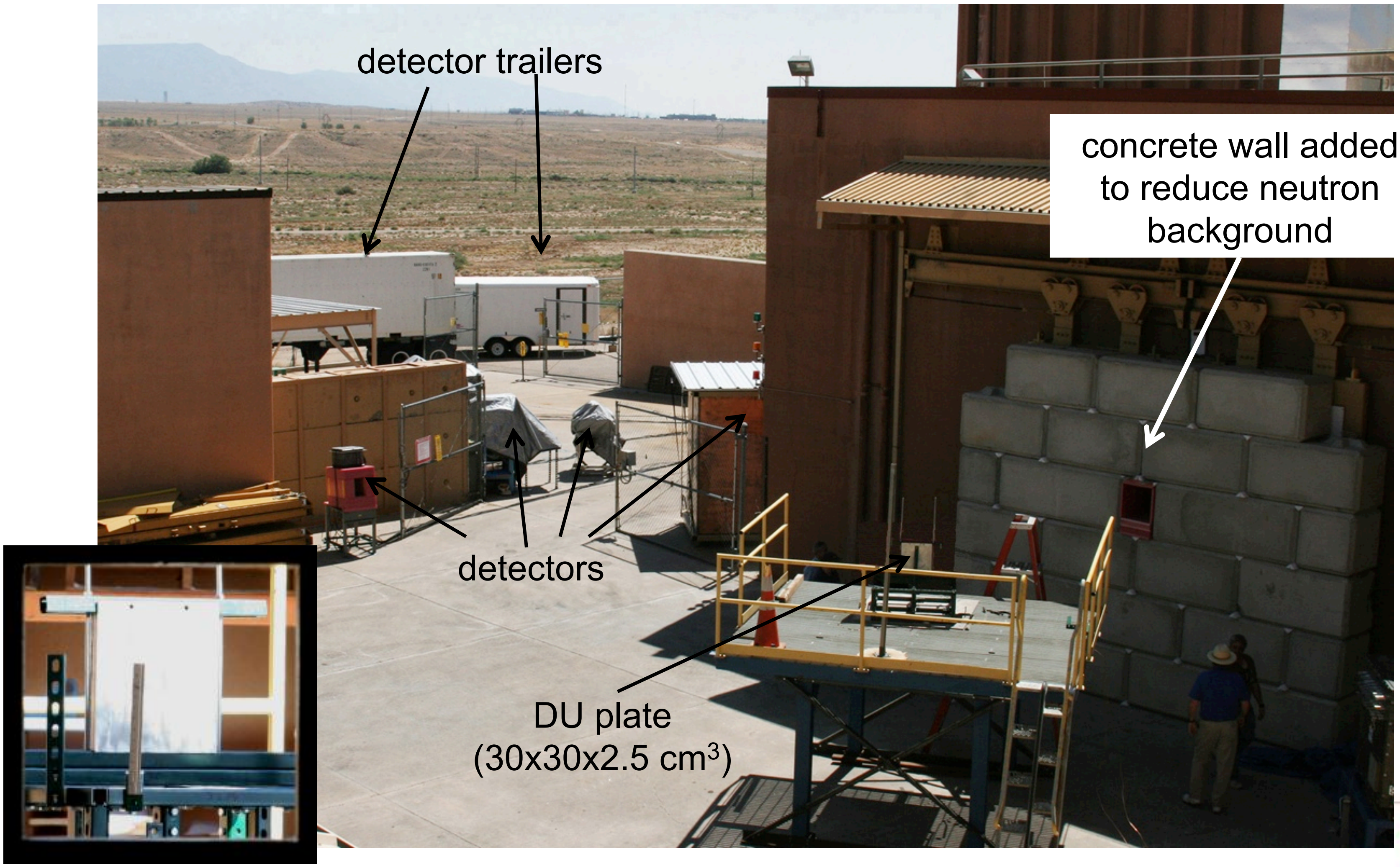
DU location chosen so detectors could be where induced background is low



Lead doors covered by concrete blocks to reduce Pb photofission from doors

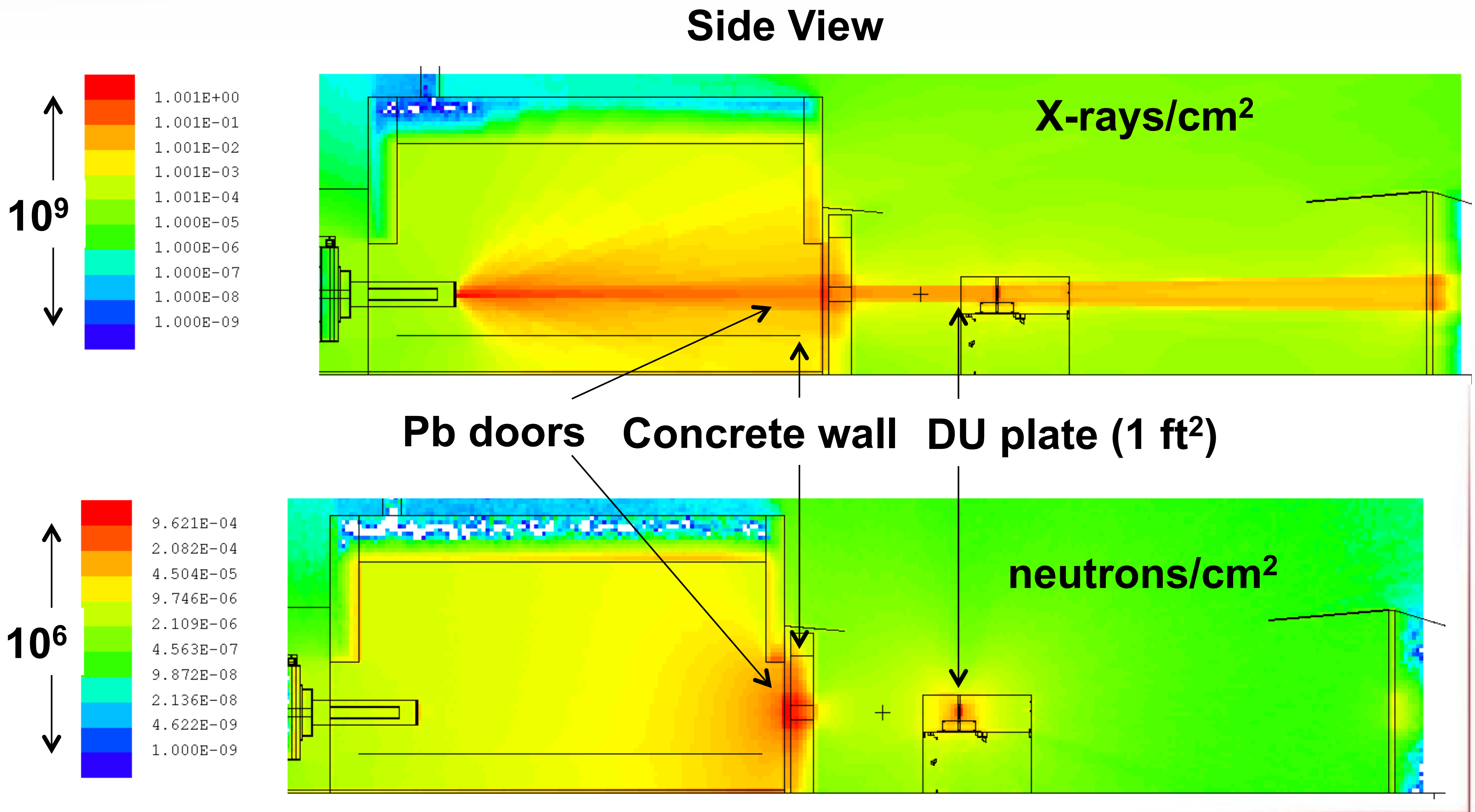
Sandia National Laboratories

Overall view of (outdoor) Hermes-III IPAD experiment layout



Target view thru aperture

Hermes-III IPAD environments modeled using MCNPX



Sandia National Laboratories

Measurements of the fast neutron spectrum (~>7 MeV) and Backgrounds are needed to discern the difference between materials (e.g. fissile vs fissionable)

Mark Derzon and Team

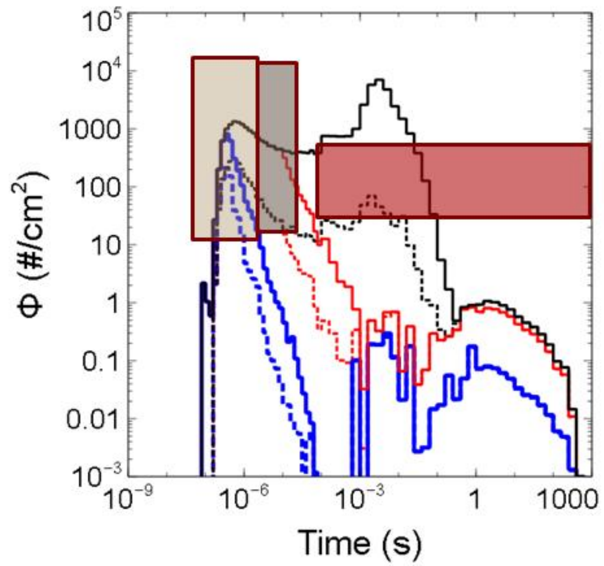
- **To get that data in these environments high quality fast neutron TOF, or spectral measurements, are required**
- **We demonstrated key aspects of measuring these signals and backgrounds with lightly shielded (1 cm Pb) sensors**
- **Needed for the Background Measurements:**

Gamma time histories,

thermal neutron TOF and

fast neutron TOF

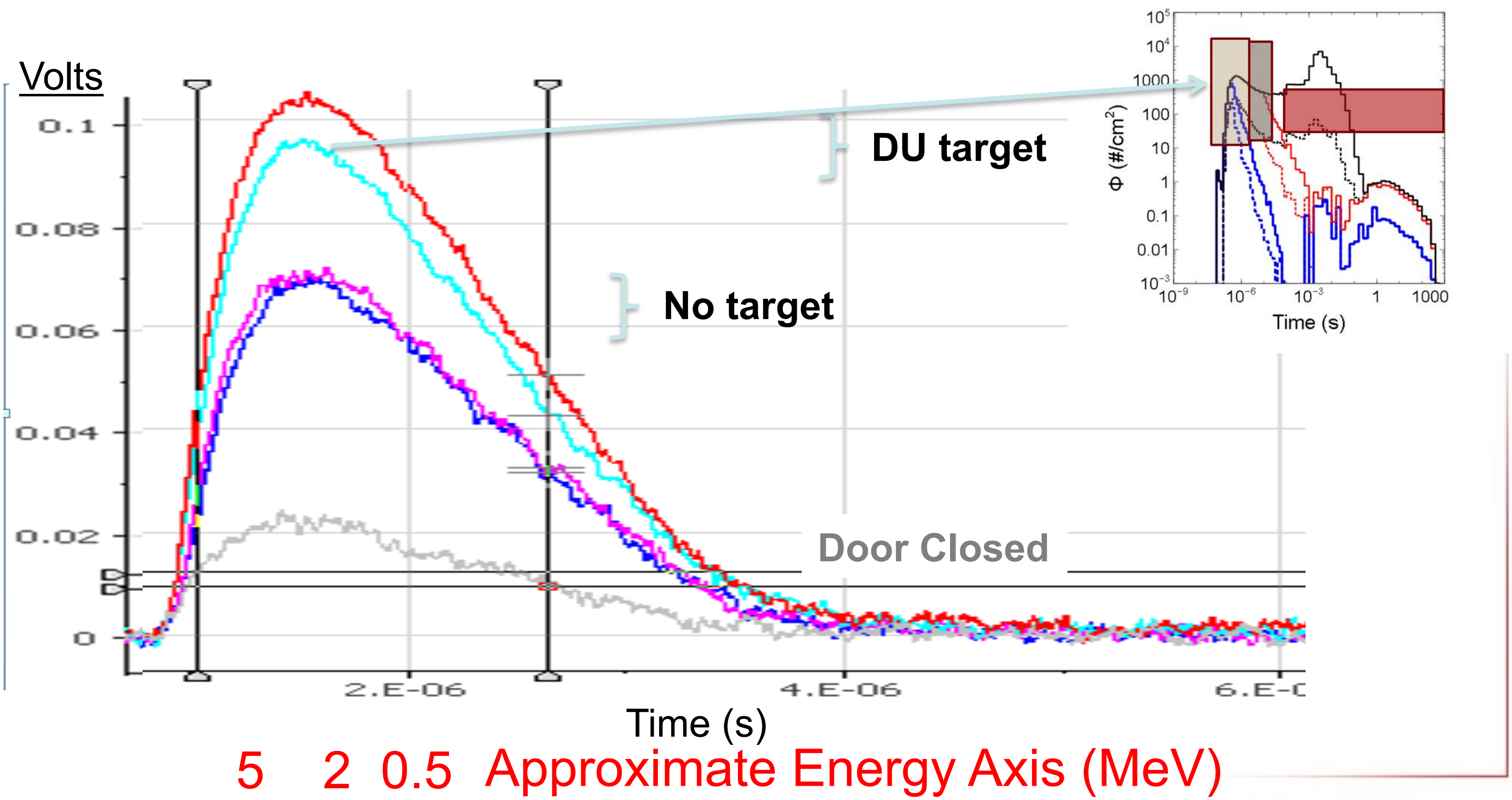
Boxes reflect approximate utility range for the sensors (He-4 recoil, gamma insensitive He-3, and recoil cameras)



We have demonstrated key features required For those measurements

Prompt Fast Neutron Signal Reflects the Presence of Material at the Target at 12 MV using He-4 recoil.

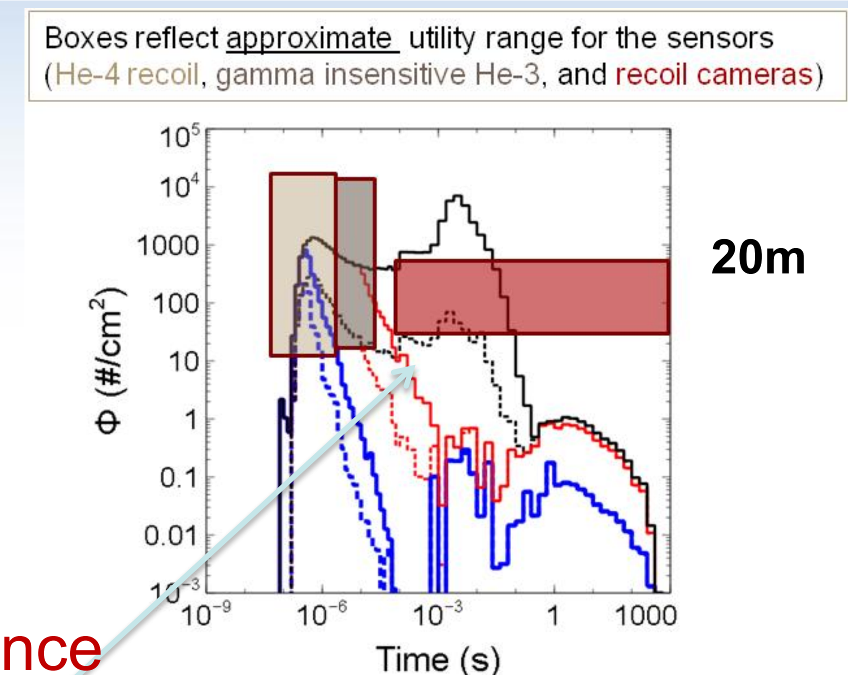
Boxes reflect approximate utility range for the sensors (He-4 recoil, gamma insensitive He-3, and recoil cameras)



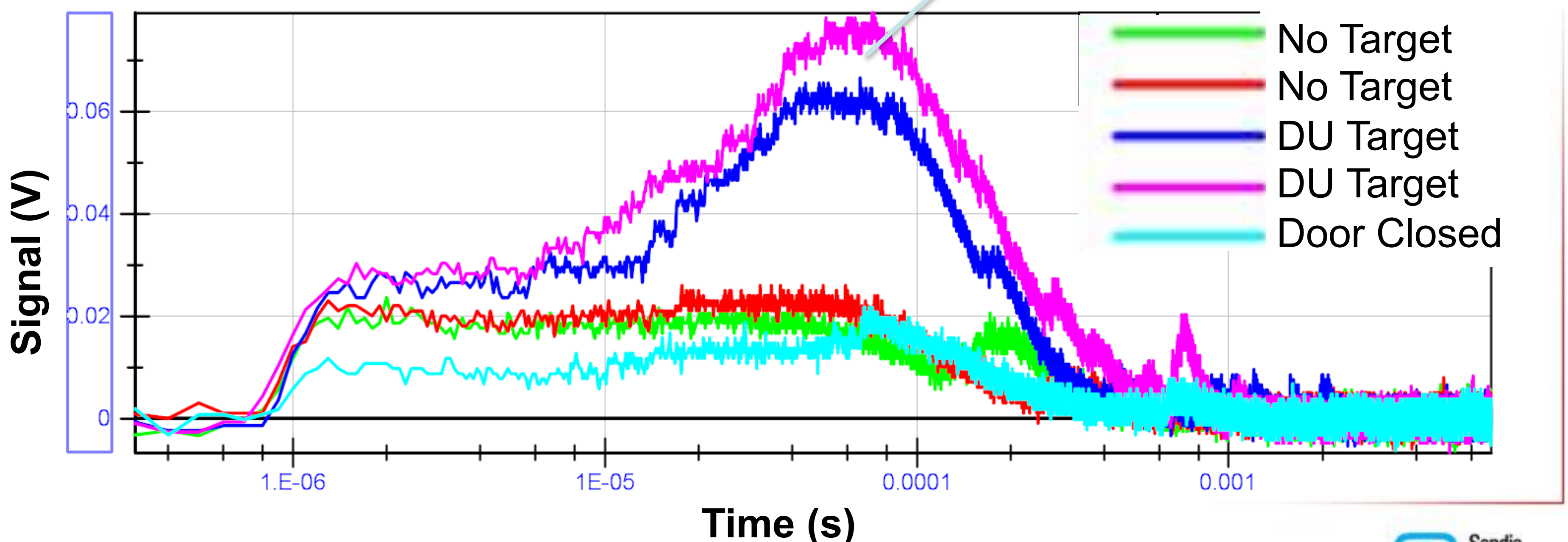
Sandia National Laboratories

Thermal Neutron Time History Clearly Shows DU

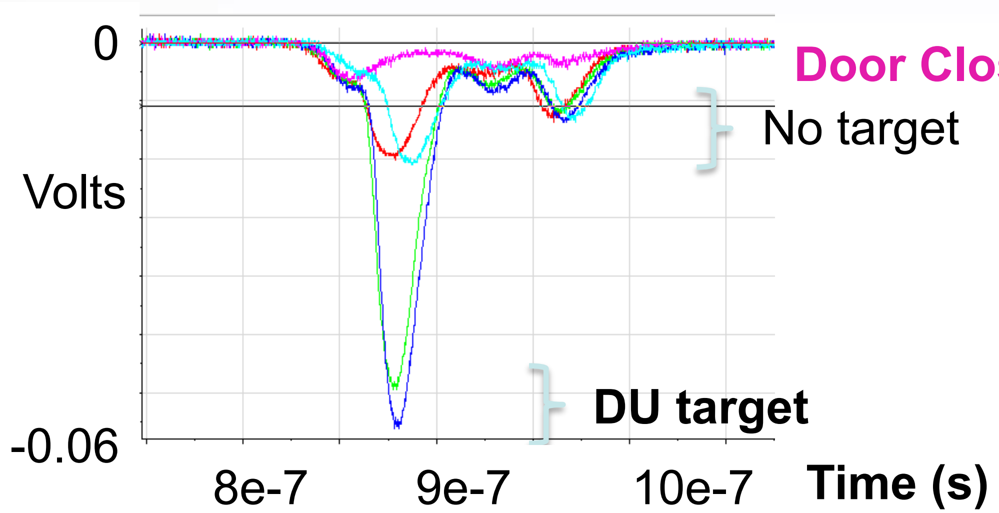
- Gamma Insensitive
- Located at 12.8 m
- 100 cm^2 Flat Plate He-3 Ionization Chamber



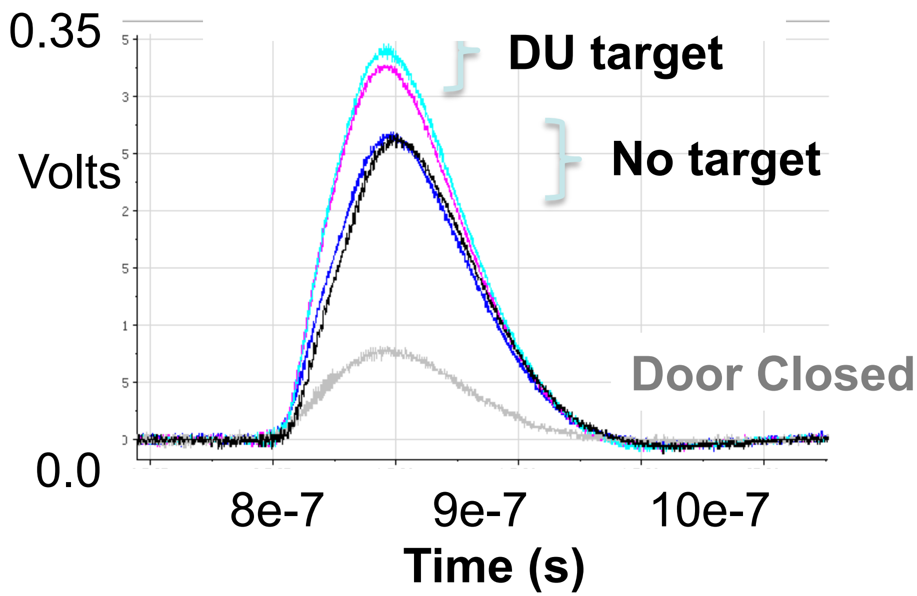
TOF Difference



The Prompt Gamma Spectrum is Very Energy Dependent and Very Sensitive to the Target



Fast plastic (~1 ns risetime)
(Lo-Z Detector)

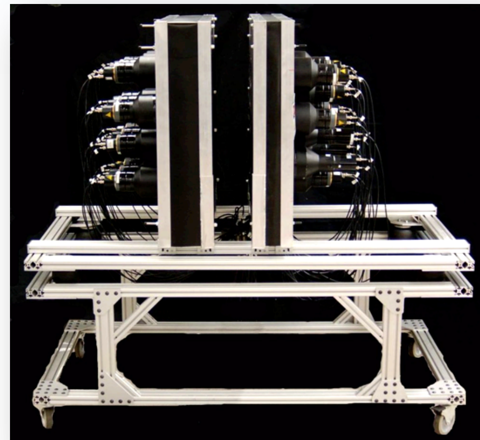


Hi Pressure Xe (Hi-Z detector)
(~250 ns risetime)

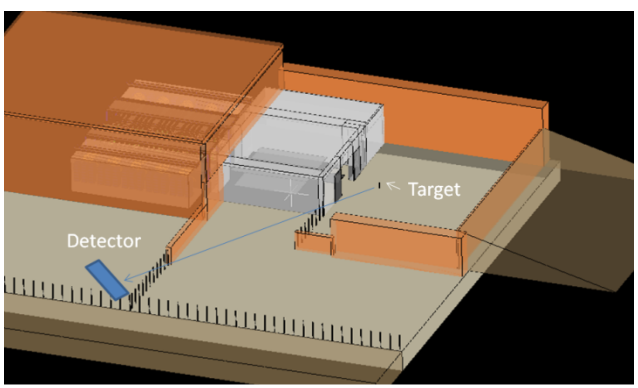
Sandia National Laboratories

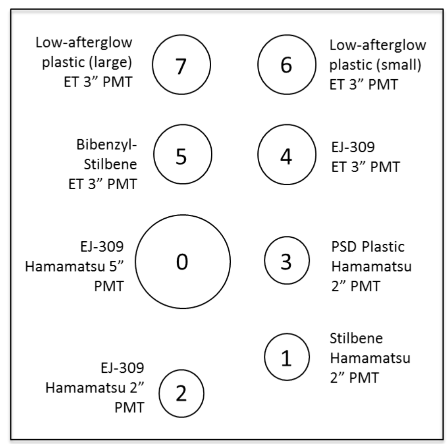
Organic Scintillator Detectors

- **Goal: Investigate the accessibility of three timescales using organic scintillator detectors.**
  - Large detector mass for relatively low cost.
  - Simultaneously sensitive to gamma, neutron, but isolated pulses distinguishable via pulse shape discrimination.
  - PSD not possible when multiple event pileup occurs.
- **Equipment: Neutron scatter camera and Experimental detector array (right top, bottom).**
  - Detector location: in trailer 45 m from target, with clear line of sight (below).
  - Lots of shielding from direct HERMES III radiation.

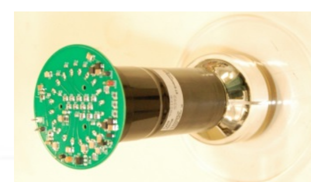


Neutron Scatter Camera:
- 24-channel liquid scintillator array
- 5"D x 5" cells, 5" Hamamatsu PMTs
- 250 MS/s digitizer readout





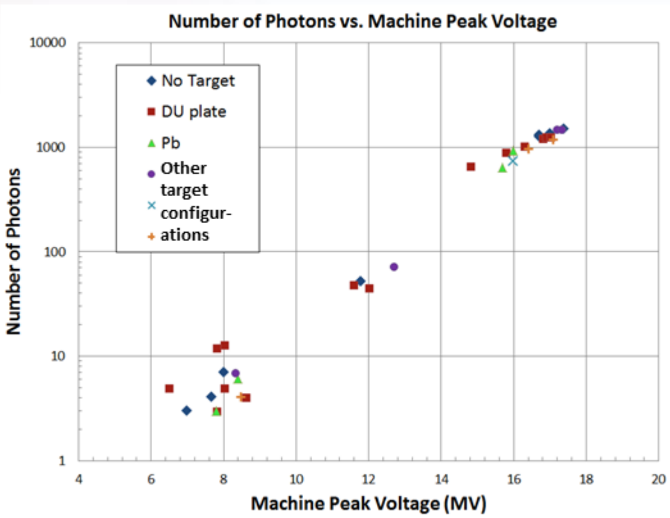
Experimental Detector Array:
- Various liquid & solid organics
- 2", 3", 5" PMTs, some gated
- Struck SIS3350 500 MS/s digitizers



Erik Brubaker and Team

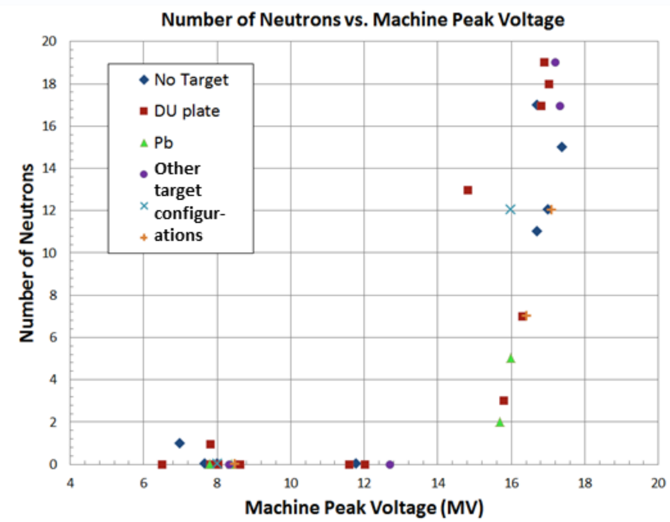
Sandia National Laboratories

Organic Scintillator Results



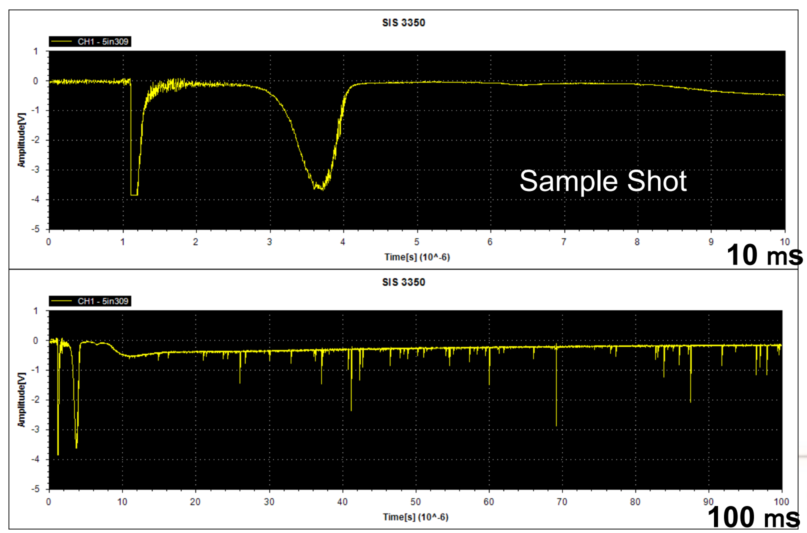
On 250 ms timescale, g and n rates primarily correlated with machine output, not target.
Need good source diagnostics!

With 24-cell LS array, statistically significant difference seen between DU & null targets, at 12 MV machine setting.
See Erik's talk!



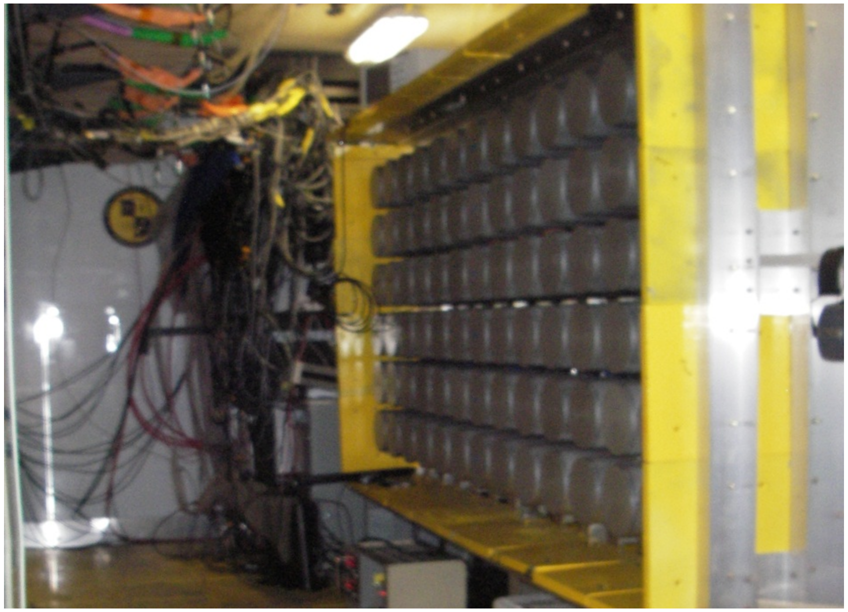
At prompt timescales (<10 ms), transient effects of scattered gammas dominate the potential prompt neutron signal, overwhelming electronics. More work is needed to understand and negate these effects.

Spikes shown on 100ms timescale: gs and ns, resolvable with PSD.



Sandia National Laboratories

SuperMISTI at Hermes



78 NaI detectors (gammas)

- 6 x 13 array
- Dimensions: ø6" x 6"
- Associated 12 x 27 lead mask → coded imaging
- Energies of interest: 3-7 MeV

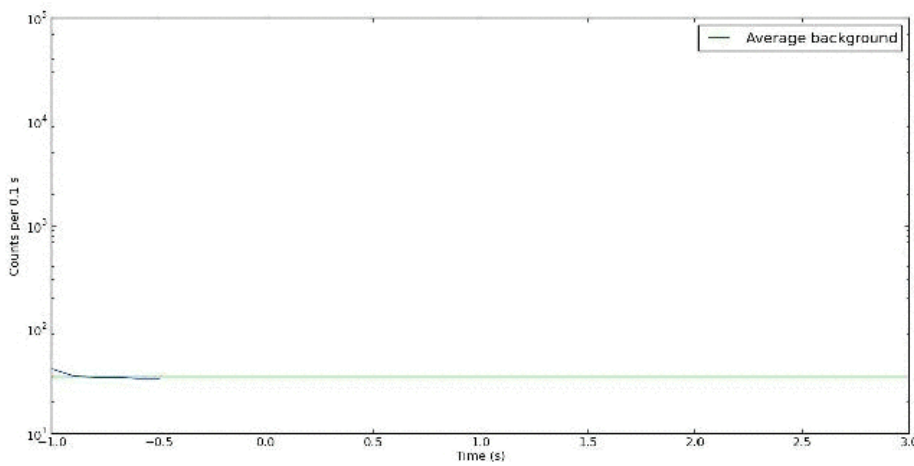
Six ^{3}He detectors (neutrons)

- Dimensions: ø5.8" x 25.2"
- Pressure: 2.66 atm
- 1" each HDPE and BPE → increased sensitivity to high-energy neutrons

SuperMISTI: Coded Image

- Pseudo-random lead mask creates pattern of shadows on NaI detectors that allow for image reconstruction
- "Hot" pixel indicates direction of source of gamma rays

SuperMISTI: DU Imaging



Detector Summary

- **Depending upon detector and upon interrogating, definite differences can be measured between Background and type of target**
  - Different relative signal sizes depending upon half- or full-power
- **Depending upon detector type, prompt (NRL), delayed prompt, and delayed signals can be used to detect DU or surrogate materials (e.g. Pb)**
  - Detectors in continuous improvement
  - Fast neutron detection affected by gamma interference
- **Concrete blocks in front of Lead Doors very successful at reducing competing photofissions**
  - MCNPX calculations validated
- **12 MV operating point (new) may yield optimum results (depending upon detector type)**

Questions?