Studies with Dense Plasma Focus Fusion Sources

Progress at NSTec
September 2011

E. Chris Hagen
National Security Technologies, LLC (NSTec)

This work was done by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy.

National Security Technologies LLC
Vision • Service • Partnership

Introduction

- Introduction
  - DPF scaling? have we made progress?
  - We have reached the plateau in DD yield at ~ 2.8 MA and ~ 1 x 1012 neutrons per pulse.

- Does it make sense to expend research effort into extension of scaling?
  - The plasma and nuclear physics of DPF fusion are not fully understood.
  - We have applications that would benefit from higher neutron yield.
    - Neutron Imaging
    - Nuclear Physics
    - Materials Science

- One "High Yield" Application is Pulsed Neutron Resonance Spectroscopy [NRS]
  - **Can, for a specific purpose, a DPF replace a multi-million dollar accelerator as a pulsed source of epithermal neutrons?**
  - **Can a DPF be used to perform materials and physics research?**

- We have initiated a feasibility study to answer these questions.

Outline

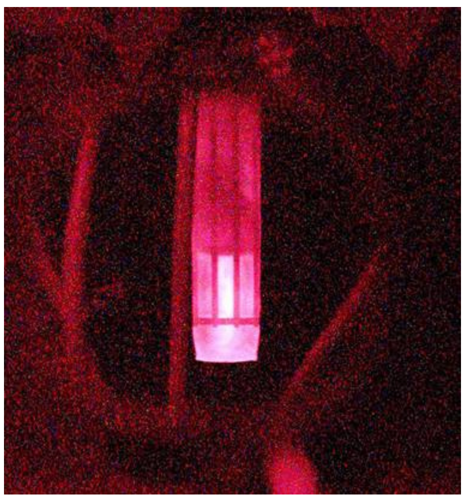
- NSTec Description
- Short History of Sources
- Current Status
- Description of NRS Feasibility Study
- Future

NORTHROP GRUMMAN | AECOM | CH2MHILL | NFS NUCLEAR FUEL SERVICES, INC.

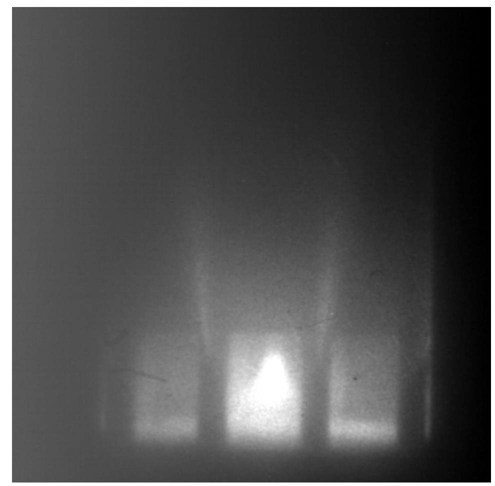
NSTec

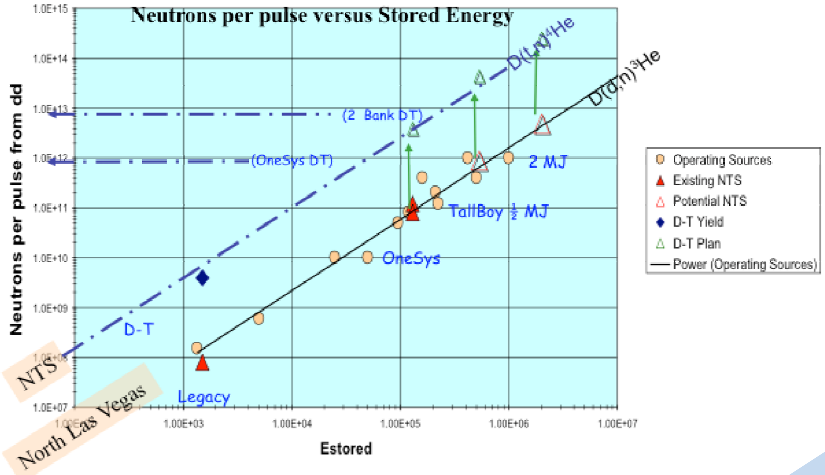
- NSTec teams with:
  - Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), and Sandia National Laboratories (SNL) on many programs.
  - NSTec also works on projects for other federal agencies such as the Defense Threat Reduction Agency, NASA, the Nuclear Regulatory Commission, and the U.S. Air Force, Army, and Navy.
  - Our missions include Defense Experimentation and Stockpile Stewardship, Homeland Security and Defense Applications, and Environmental Management.

Overview of DPF Sources at NSTec



DENSE PLASMA FOCUS
FUSION RESEARCH GROUP



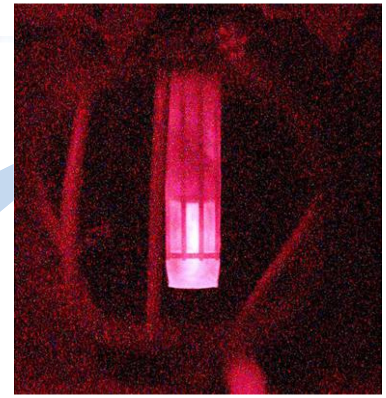


NSTec is steadily executing plan for needed neutron systems and sources.

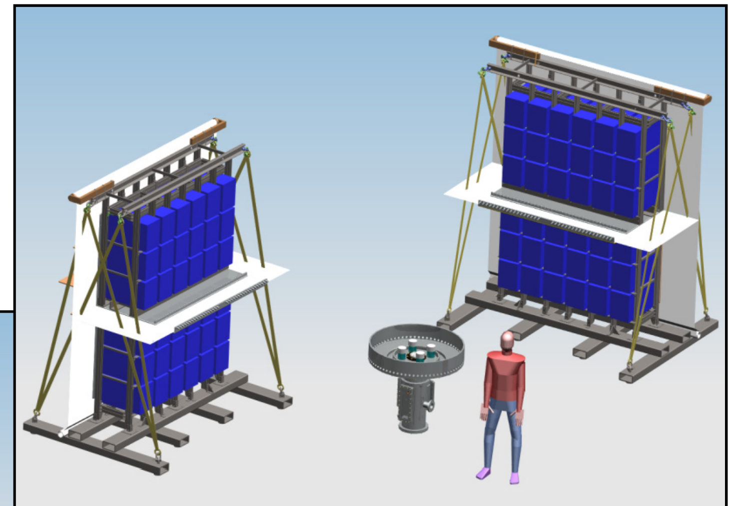
20070110

17

• Future . . . .

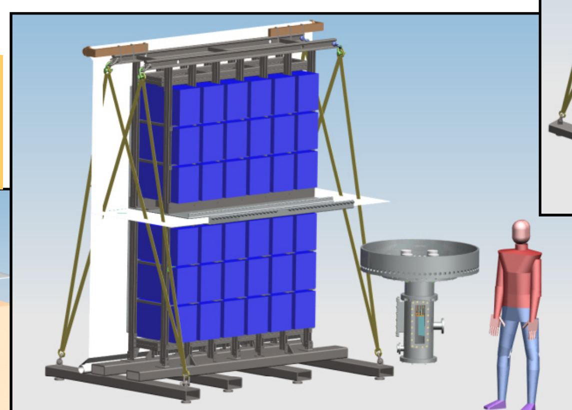


DD_2009
Purpose: > 3 MA
Physics at 1 MJ



Gemini

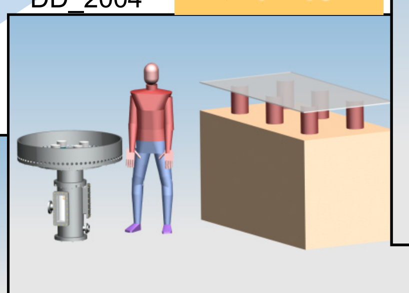
DD_2008
Purpose: approach 10^{12} DD



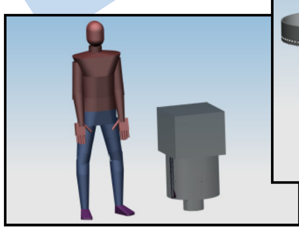
TallBoy

DT_2007
Purpose:
~ > 1 * 10^{12}

DD_2004



OneSys

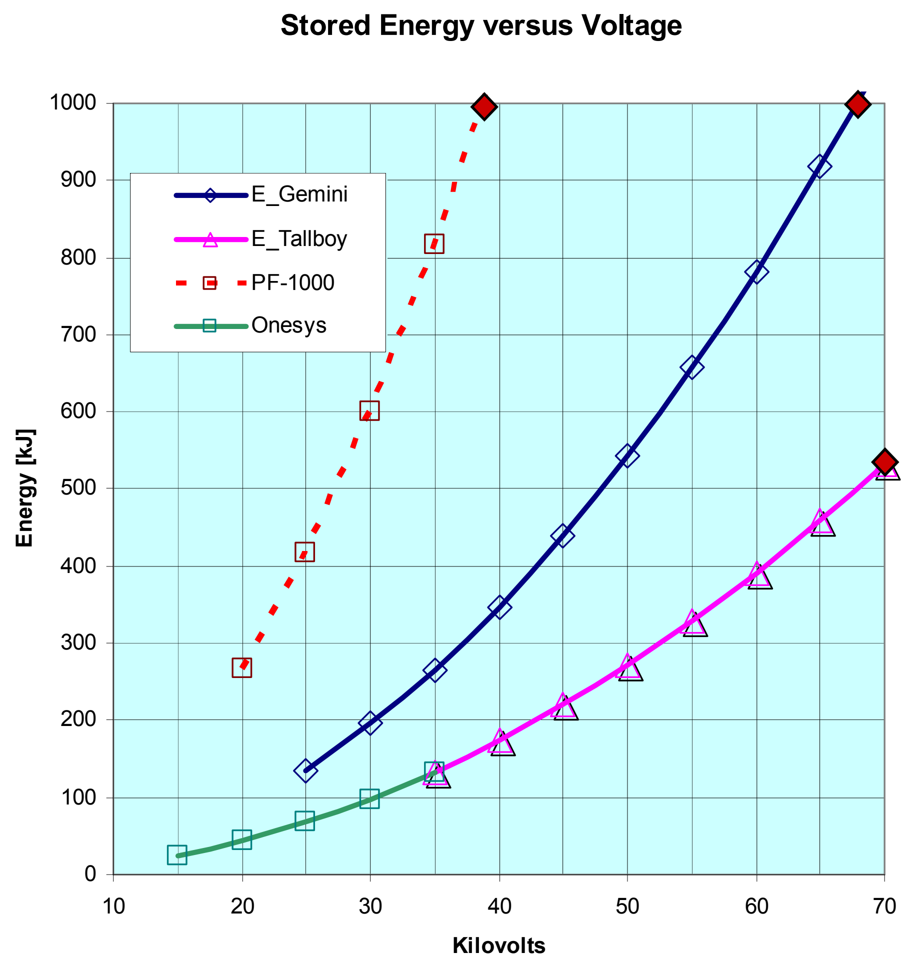


DT2002

National Security Technologies LLC
Vision • Service • Partnership

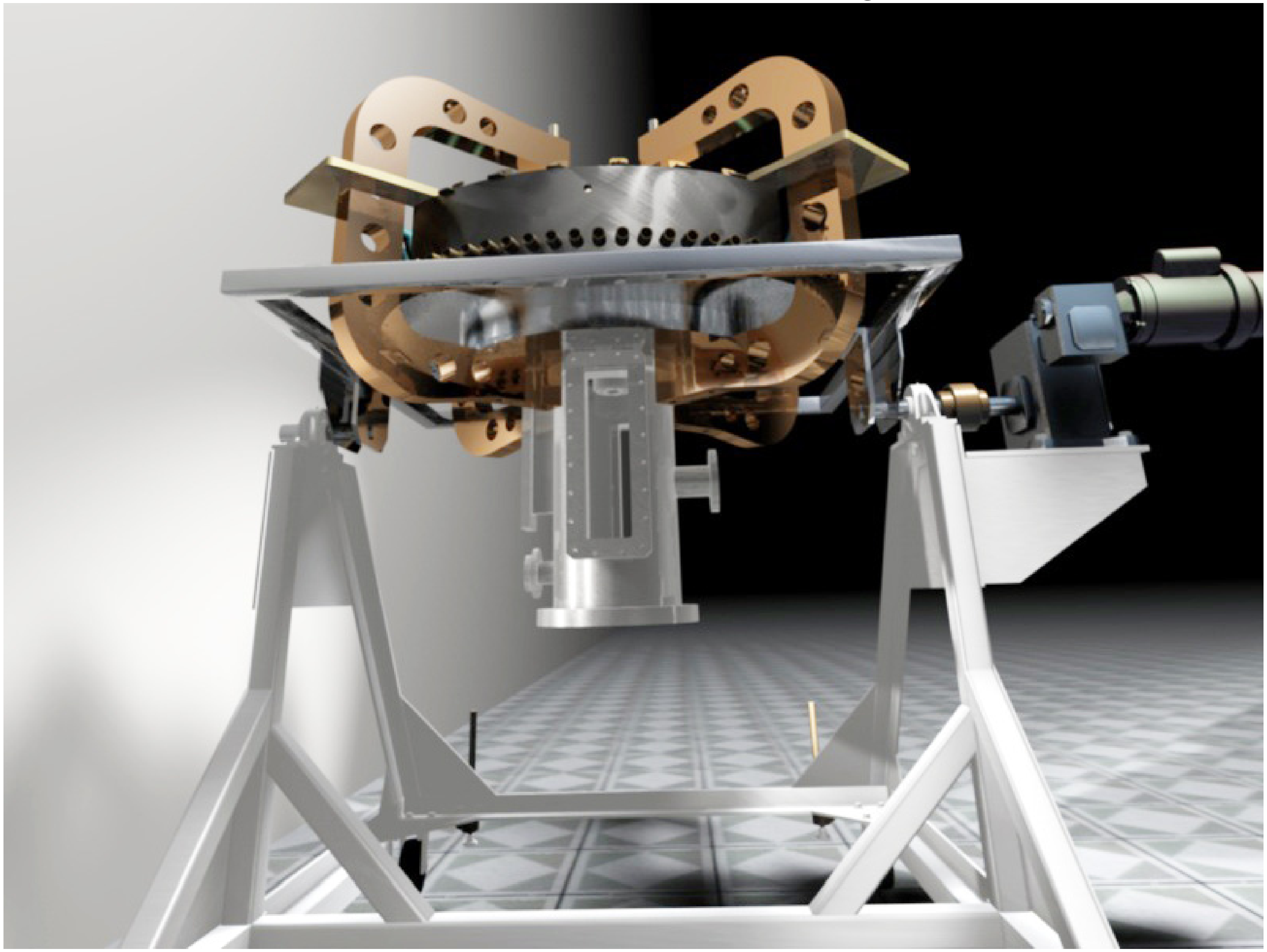
Sources in Operation

- Several small sources
  - 1.5 kJ, 220 kA, ~ 5 X 10^7 DD, ~1x 10^9 DT
- OneSys
  - 1/8 MJ, 1.3 MA, 1.2 x 10^{11} DD (Max)
  - Modified, now at Nevada Test Site:
    - 4 x 10^{12} *D-T* (Max)
- TallBoy
  - ¼ MJ @ 50 kV, 3 MA,
  - 3.5 10^{11} (Max)
  - ½ MJ @ full voltage (70 kV)
- Gemini ½ MJ @ 50 kV
  - 1 MJ @ 70 kV full voltage
  - 1.2 10^{12} (Max)



National Security Technologies LLC
Vision • Service • Partnership

Activities this year



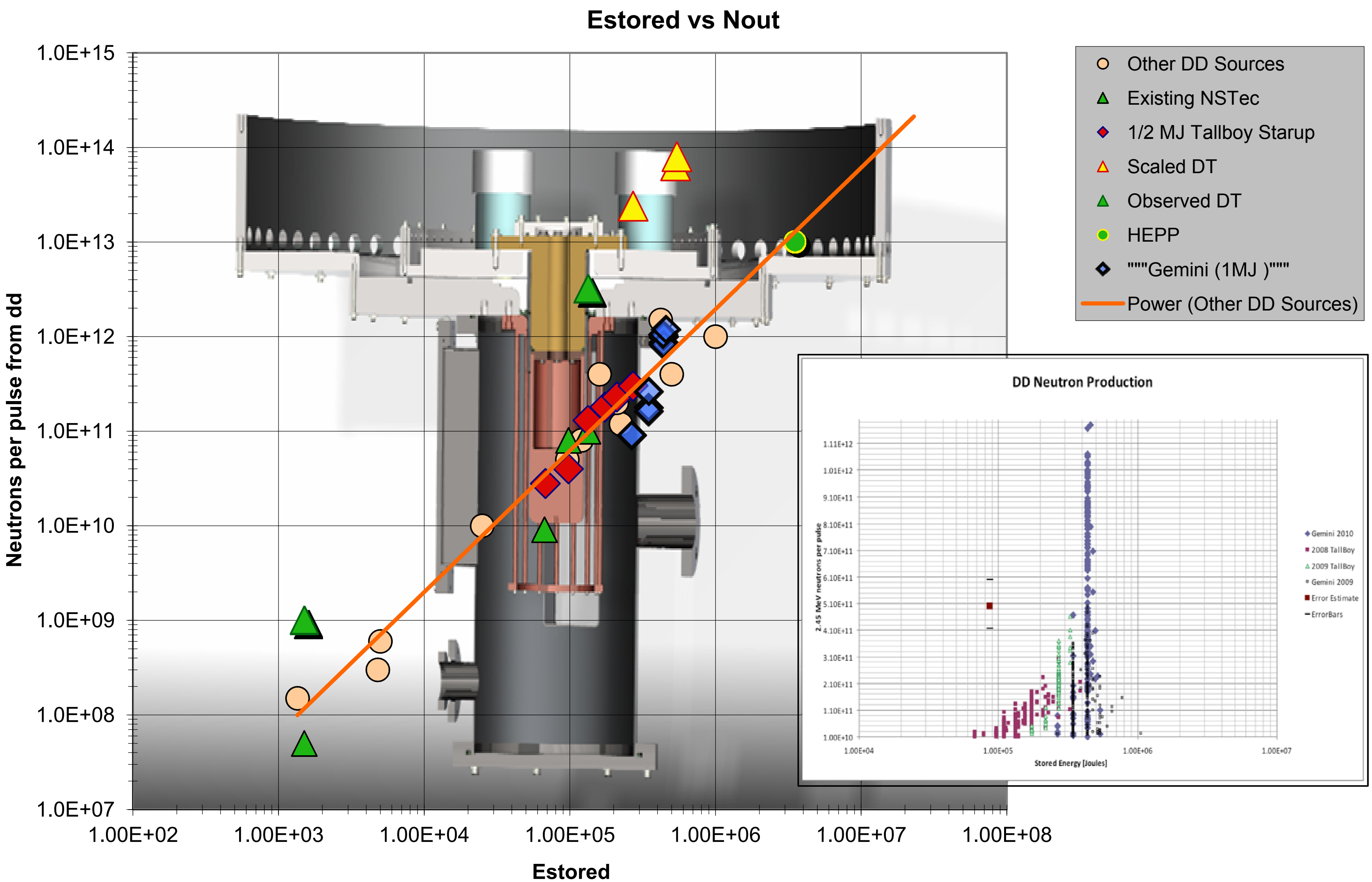
Status

- 1 MJ Gemini bank in routine operations
  - > 500 shots supporting a wide variety of experiments
  - Investigating cessation of yield scaling with increased current
  - Search for evidence of Turner Relaxed States initiated
  - Modifications to source tube for more reliable high current operations
  - Improved diagnostics
  - Attempting to get 3D MHD code running (2D in place)
- Beginning work to increase yield of D-T source.
  - Capacity of 133 kJ bank to be increased

Gemini

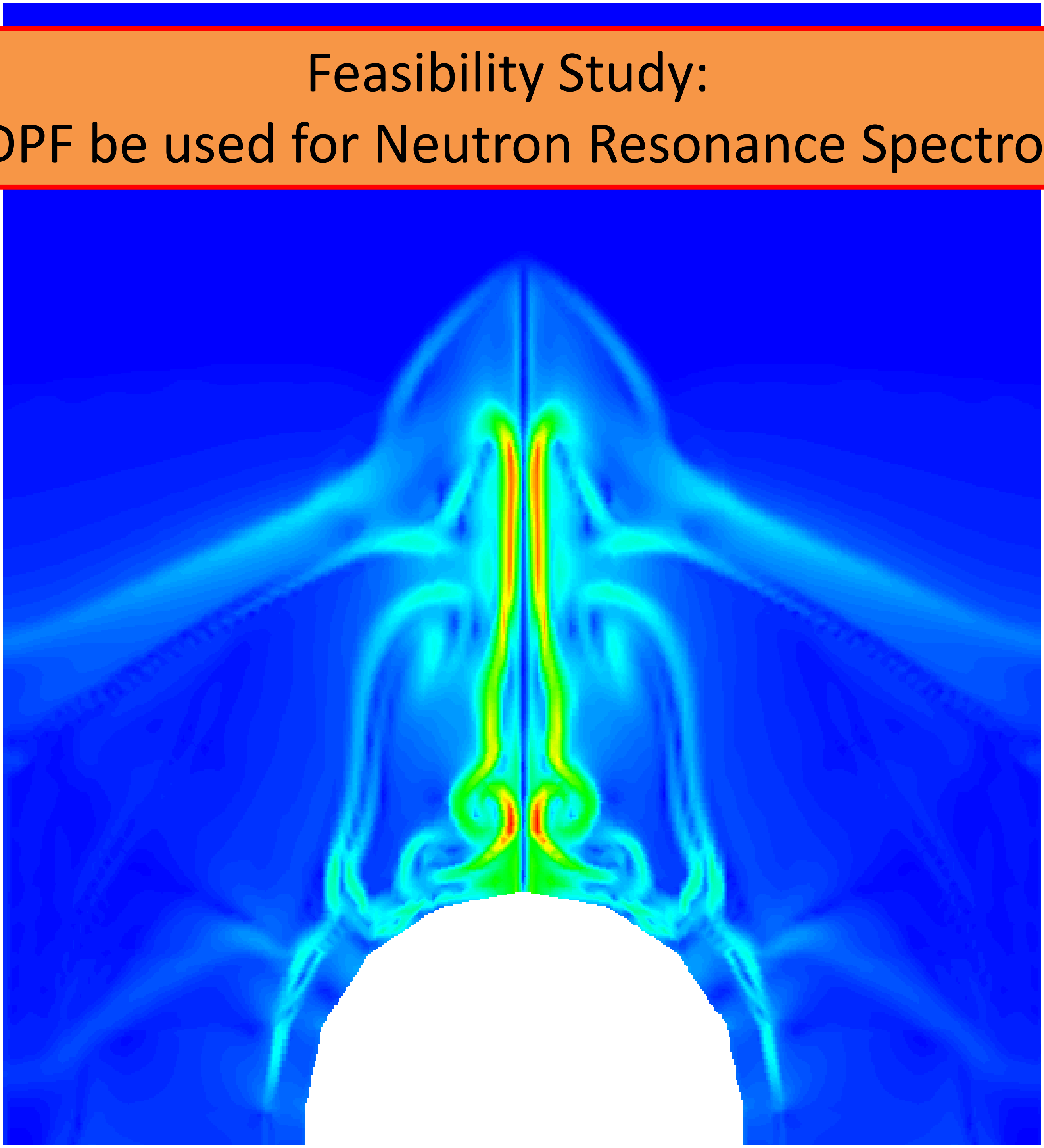
- Current Y(max)
  - 1.2×10^{12} @ 45 kV
- 1 MJ at 70 kV
- 3.25 MA @ 50 kV
- Normal operation
  - ~ 2.5 MA
  - ~ $2\text{-}6 \times 10^{11}$ neutrons per pulse
  - Yield scalable over 5 decades

NSTec is extending Yield Scaling of Dense Plasma Focus Devices



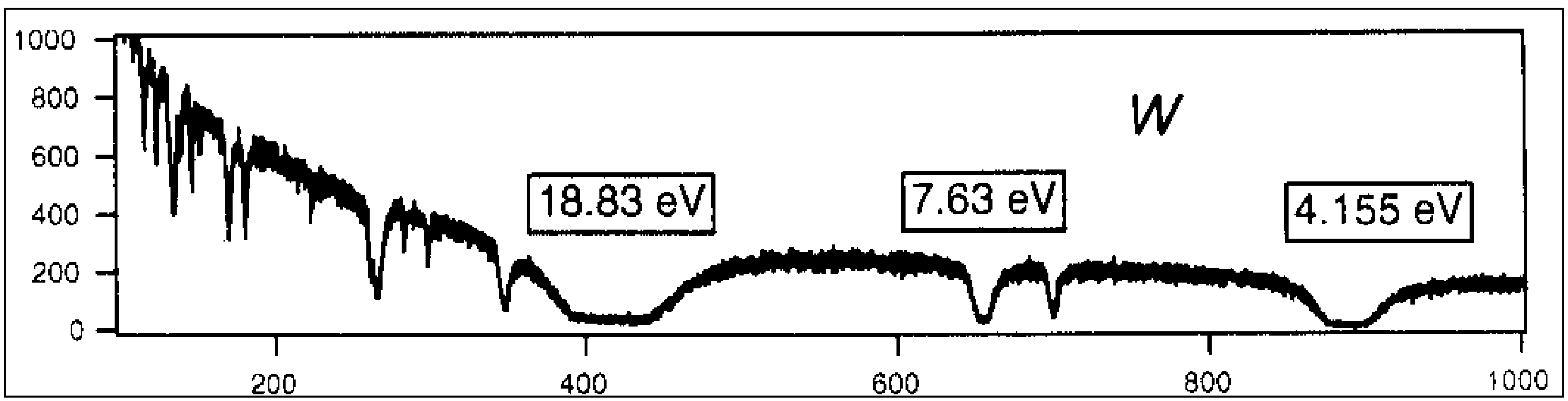

DANGER
HIGH VOLTAGE
UNAUTHORIZED PERSONNEL
KEEP OUT

Feasibility Study:
Can a DPF be used for Neutron Resonance Spectroscopy?



Neutron Resonance Spectroscopy

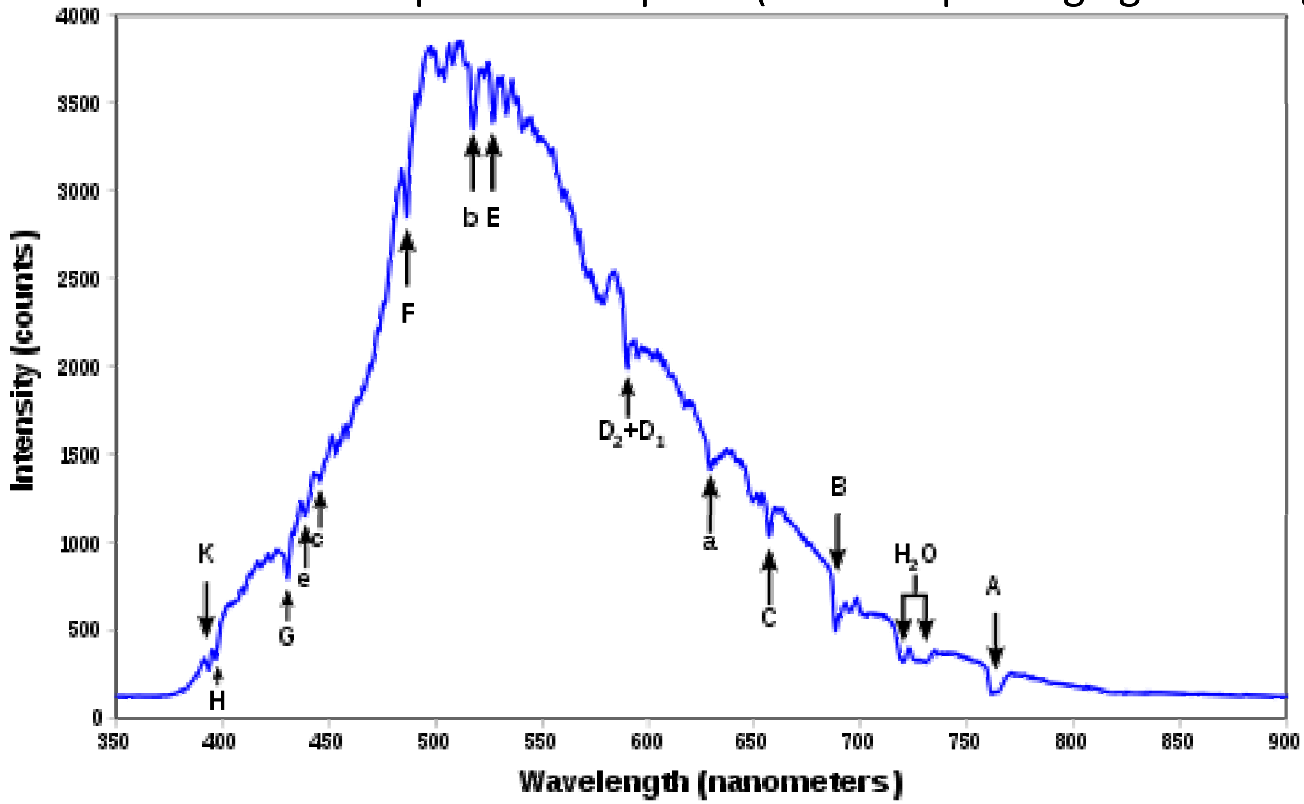
- A Non-intrusive Method for instantaneously sample temperatures
- Transmission measurement: Some energies are strongly absorbed

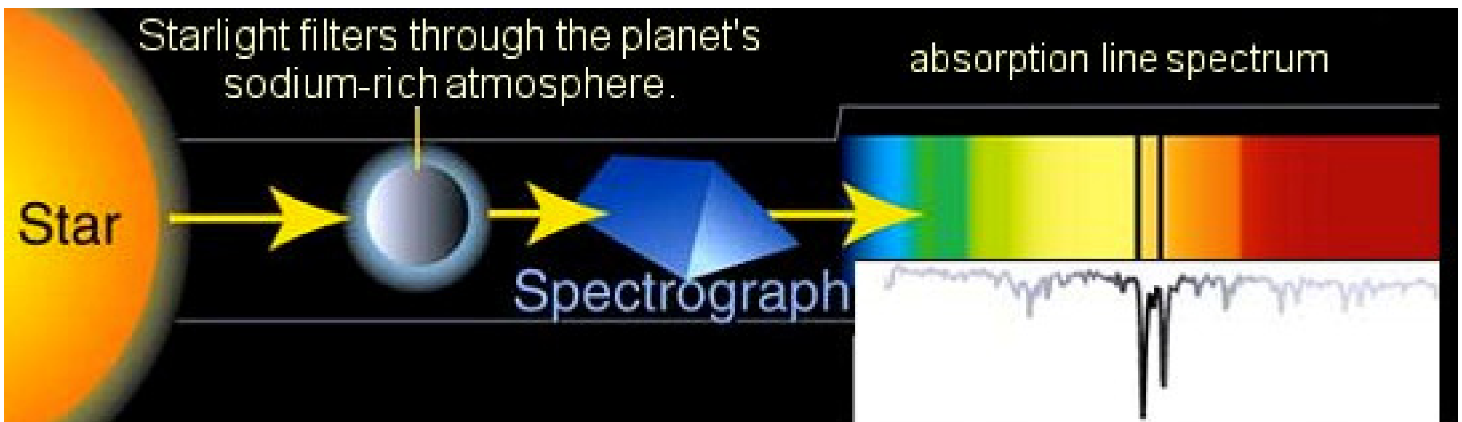


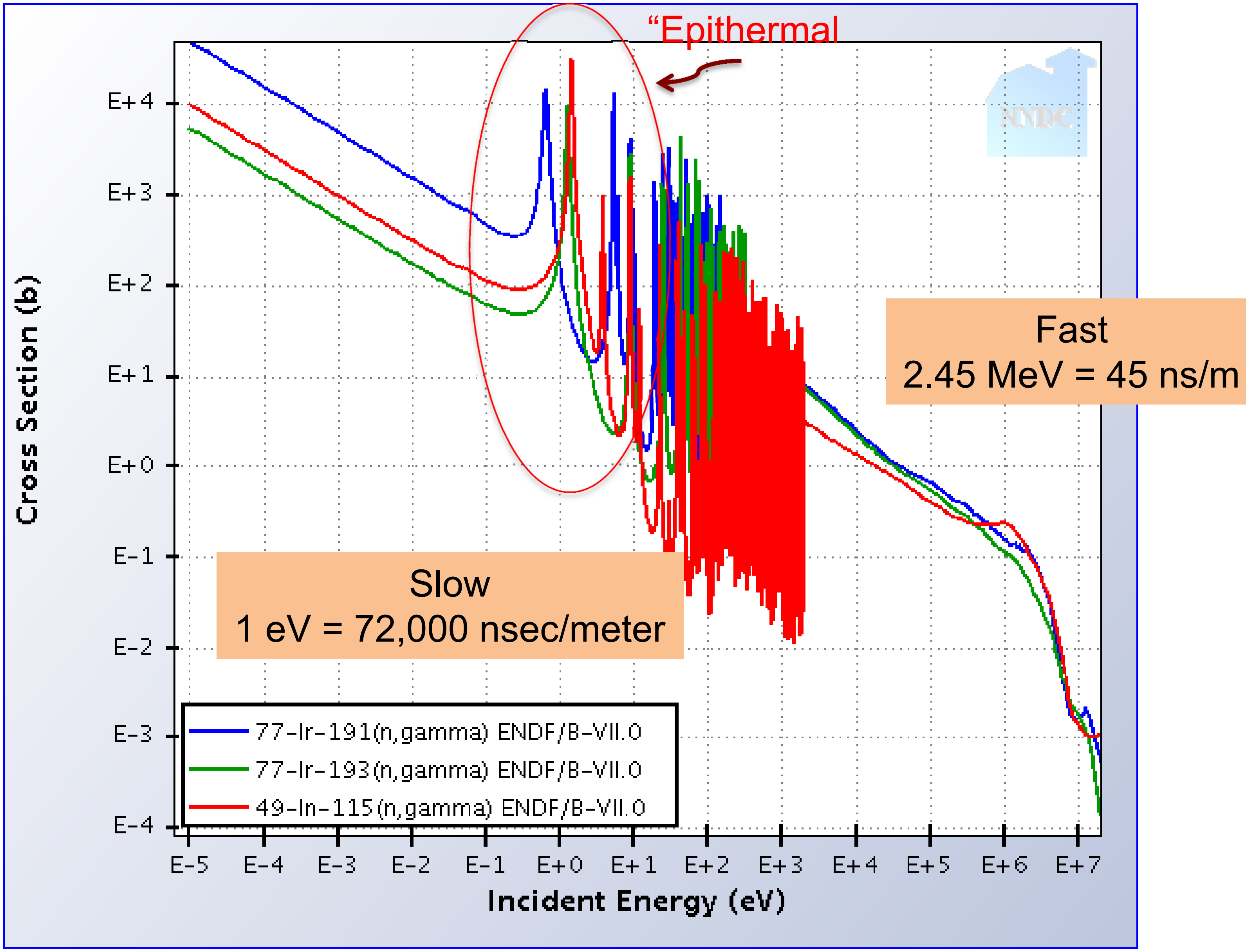
Result of passing epithermal neutrons through matter.

National Security Technologies LLC
Vision • Service • Partnership

Optical absorption (result of passing light through air)







National Security Technologies LLC
Vision • Service • Partnership

NRS with intense pulsed source:
Non-intrusive Method for measuring temperature - at an instant

- Width of absorption resonance is function of temperature..
- Measure width of absorption resonance, infer temperature.
- Required: Generate epithermal neutron beam, pass through sample, eliminate background through shielding, detect, measure width of known absorption resonance

Neutron Resonance Spectroscopy

- Neutrons are resonantly absorbed in nuclei at specific energies, removing them from the beam.
- Width of absorbed line is doppler broadened due to thermal motion of absorbing atoms, allowing temperature to be determined.
- Spectrum is determined by time-of-flight temporal spreading.

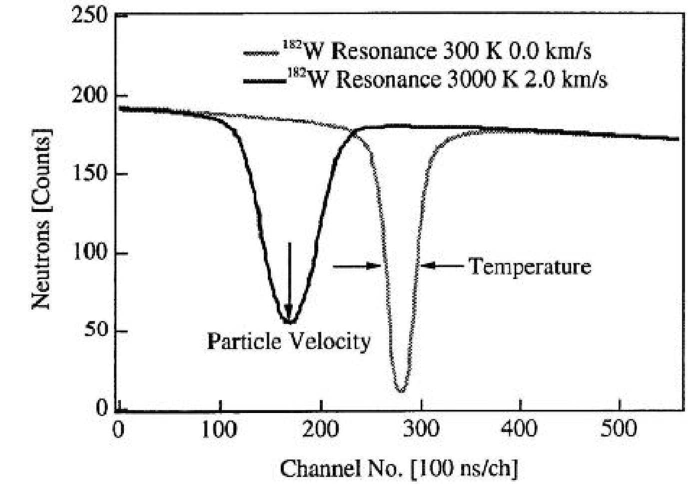
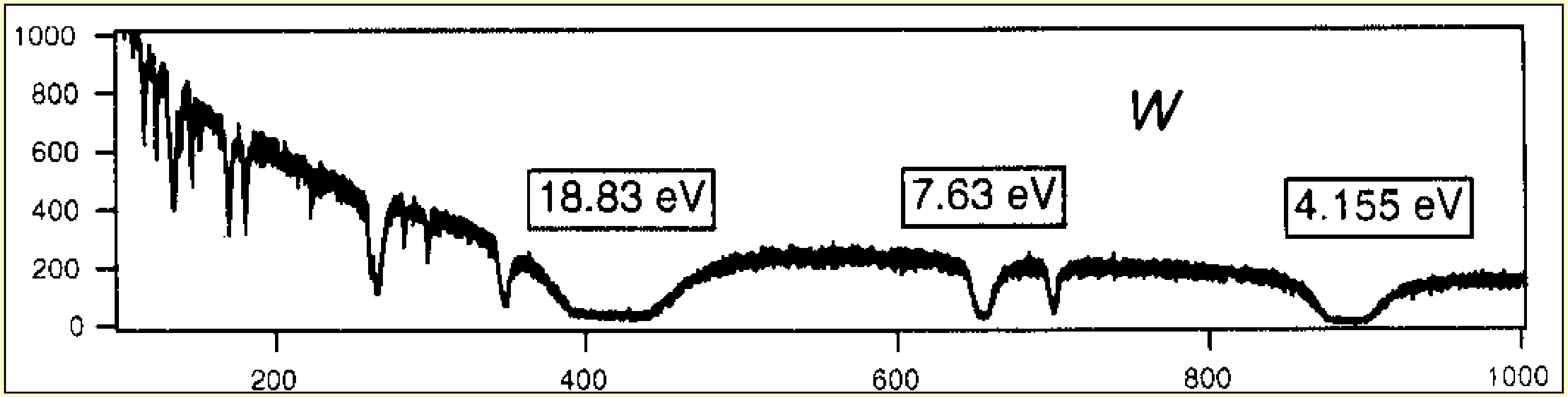
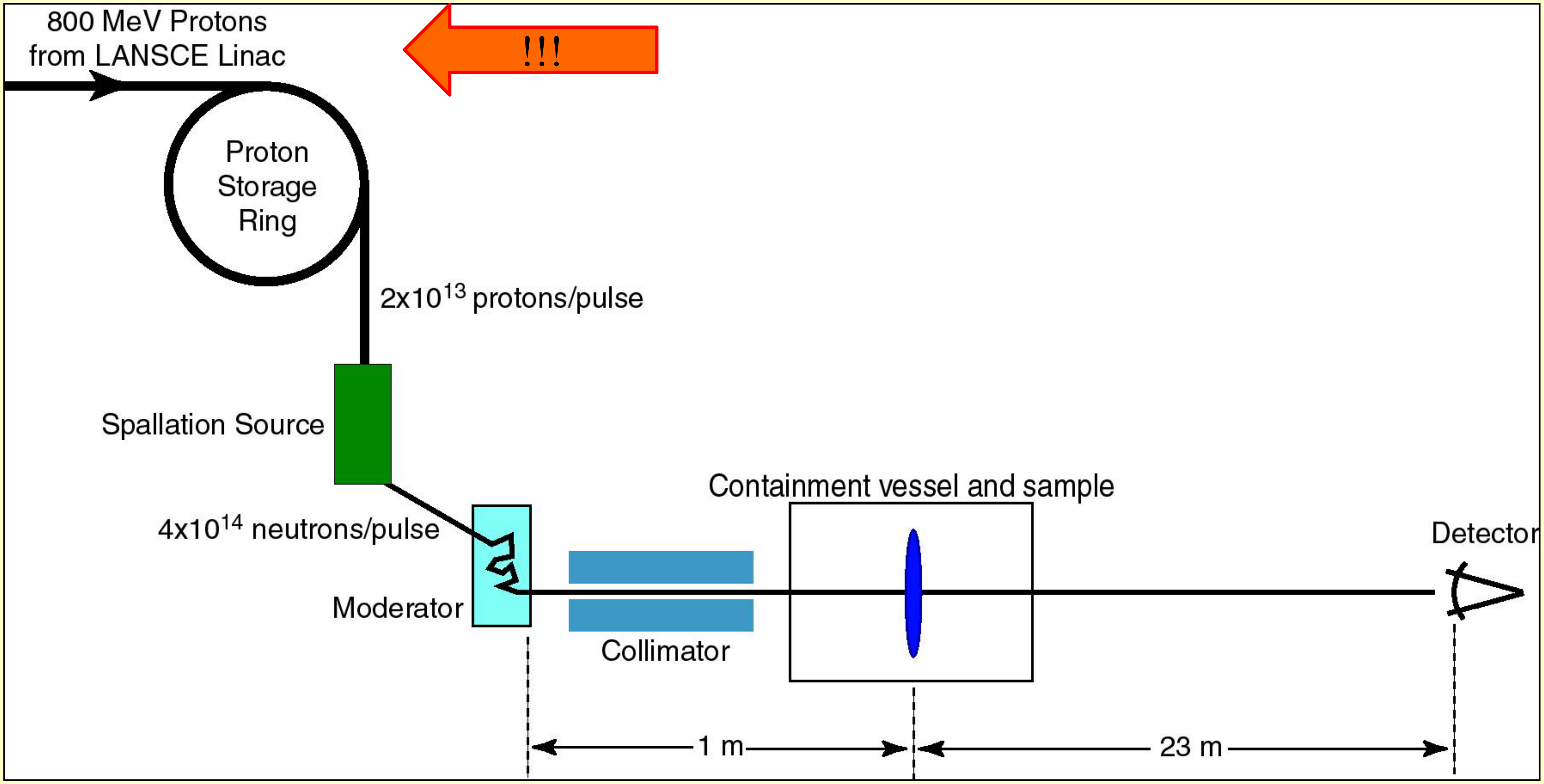


FIGURE 1. Simulated Time-of-Flight (TOF) neutron spectrum of the ^{182}W resonance at 21.10 eV. Note the shift in the centroid, the increased width, and decreased peak cross section at high temperature and particle velocity.



Los Alamos

Existing NRS Configuration at LANSCE



Source strength = 1.5× 10^{-5} n/p/eV/steradian/cm^2 for 25 eV at the detector

Possible Solution

- A high-yield DPF could provide copious neutrons in short pulse
- Moderator lowers energy;
  - from MeV to eV region
- Shielding lowers background
- Fast thermal neutron detection allows NTOF energy measurements

Challenges

- How to make up Yield deficit? *(Factor of 200)*
  - Current NRS uses 4 x 10^{14} neutrons per pulse….

    but

  - DPF state of the art is ≈ 2 x 10^{12} with deuterium

Tactics

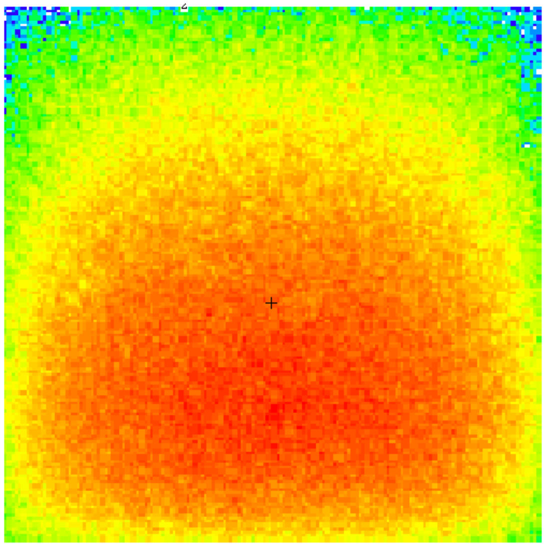
- Replace Deuterium fuel with Deuterium –Tritium
  - *Gain = (Factor of > 50)*
- Modify experimental arrangement
  - Improved solid angle
    - Shorter flight path
    - More detectors
  - Better signal-noise ratio
    - Quieter source
    - Improved detectors

epithermal neutrons

- typical 1 to 20 ev
- velocity
  - ~ 10 to 100 usec/meter
- Detection
  - Li6 glass on PMT
  - Count rates ~ 1e6/sec

Moderation

- Efficiency
  - Must convert MeV neutrons to eV energies efficiently
- Pulse Width
  - Short enough to measure resonance width



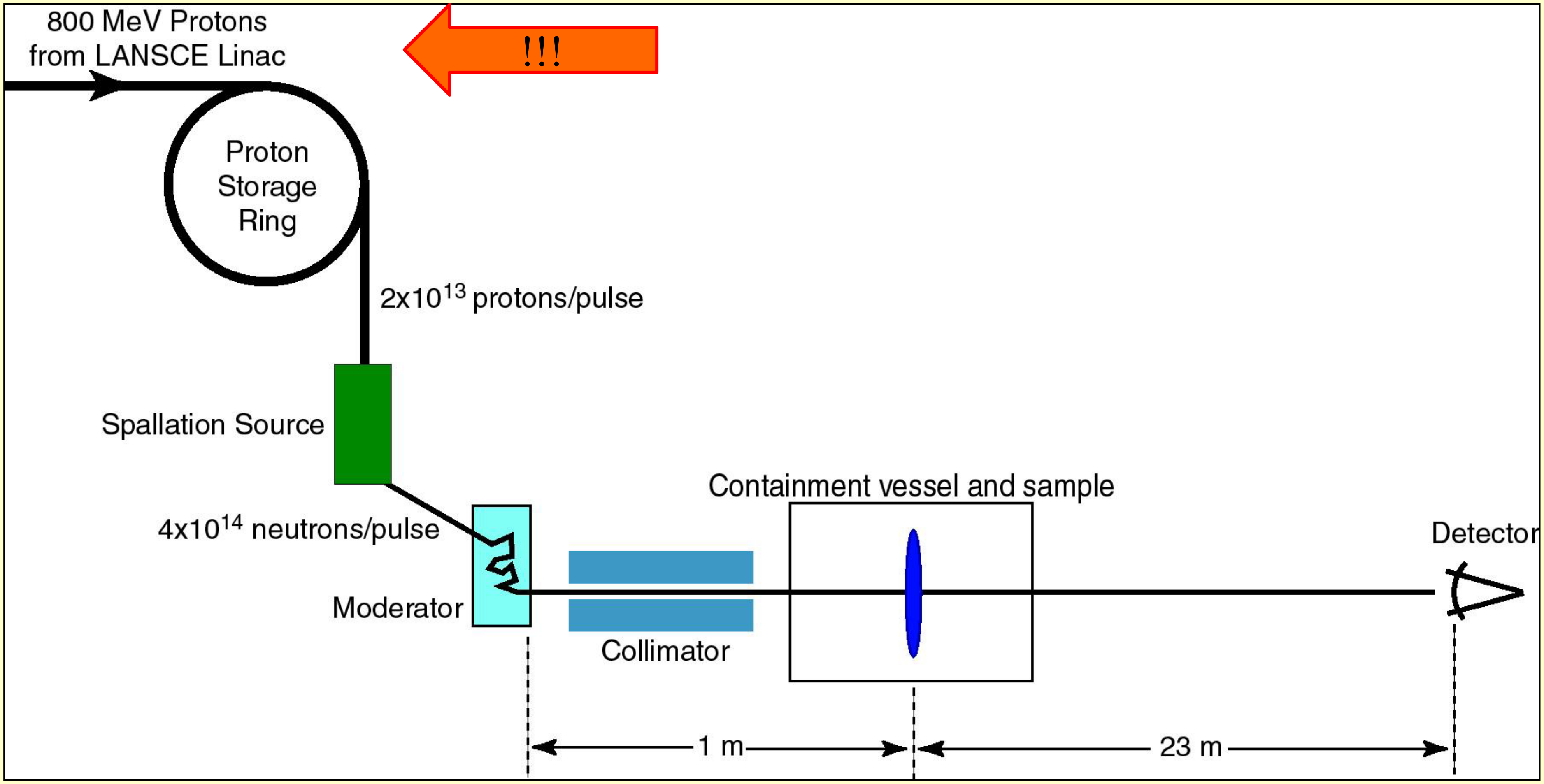
Shielding

- Shield Sensitive Detectors from Scattered Neutrons

AND.....

- Shield Detectors from gammas generated by shielding! (neutron capture in the shield.)

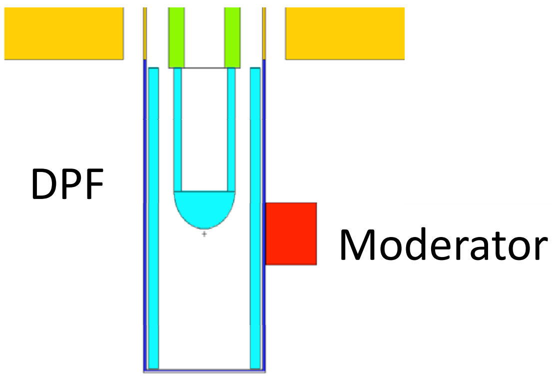
Existing NRS Configuration at LANSCE



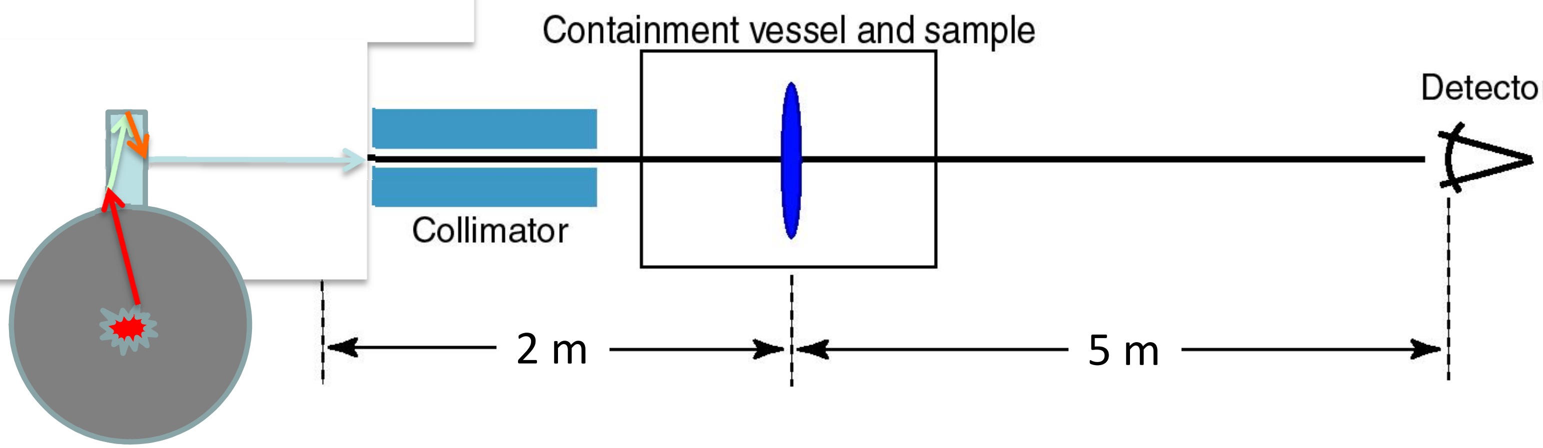
Source strength = 1.5× 10^{-5} n/p/eV/steradian/cm^2 for 25 eV at the detector

Los Alamos

DPF NRS Configuration



D-T DPF replaces
800 MeV Proton Accelerator as
intense *pulsed* source
of epi-thermal neutrons



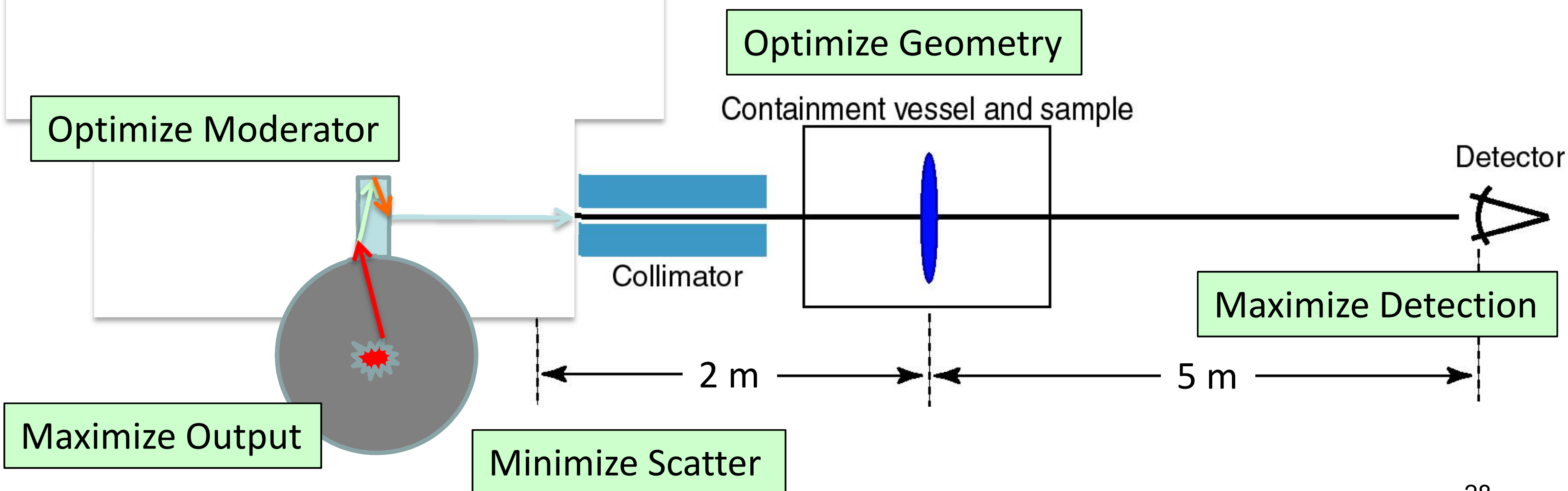
DPF NRS Configuration:

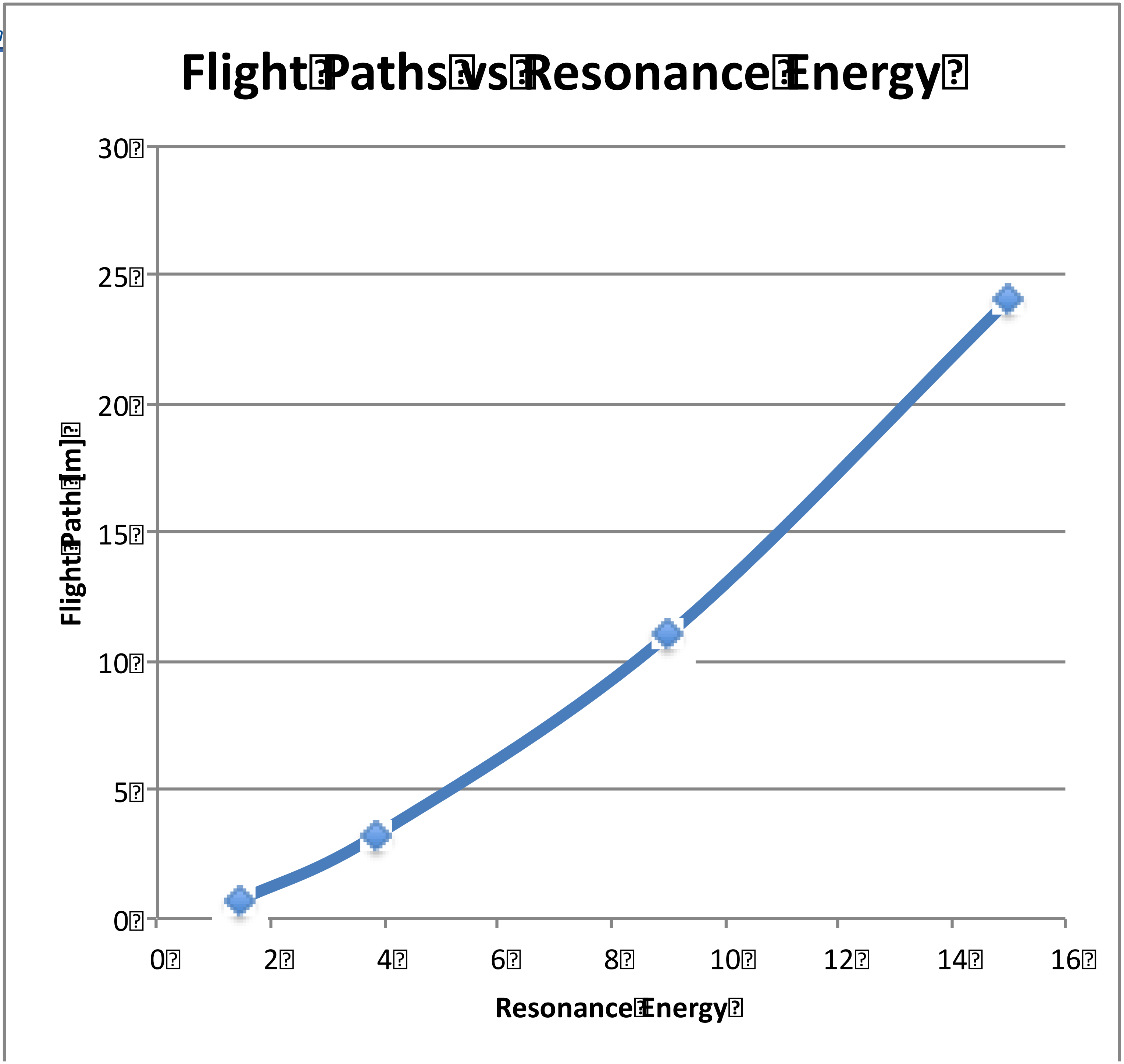
(Challenges)

Optimization Process:
Weak signal in presence of strong noise

GOAL = maximize $\frac{\text{Signal}}{\text{Noise}}$ ratio

Almost all variables interact

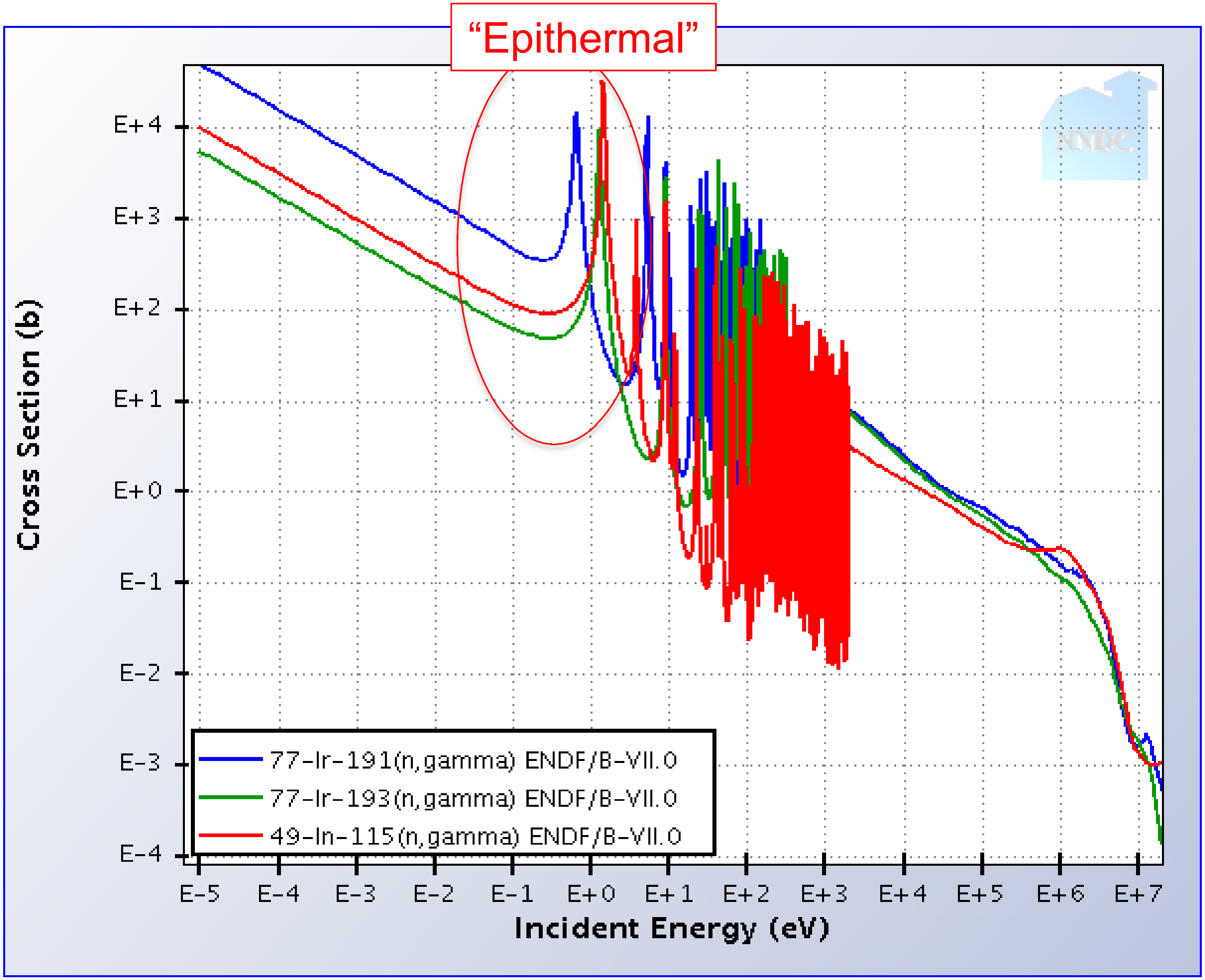



Flight Paths vs Resonance Energy
Flight Path [m]
30
25
20
15
10
5
0
0
2
4
6
8
10
12
14
16
Resonance Energy

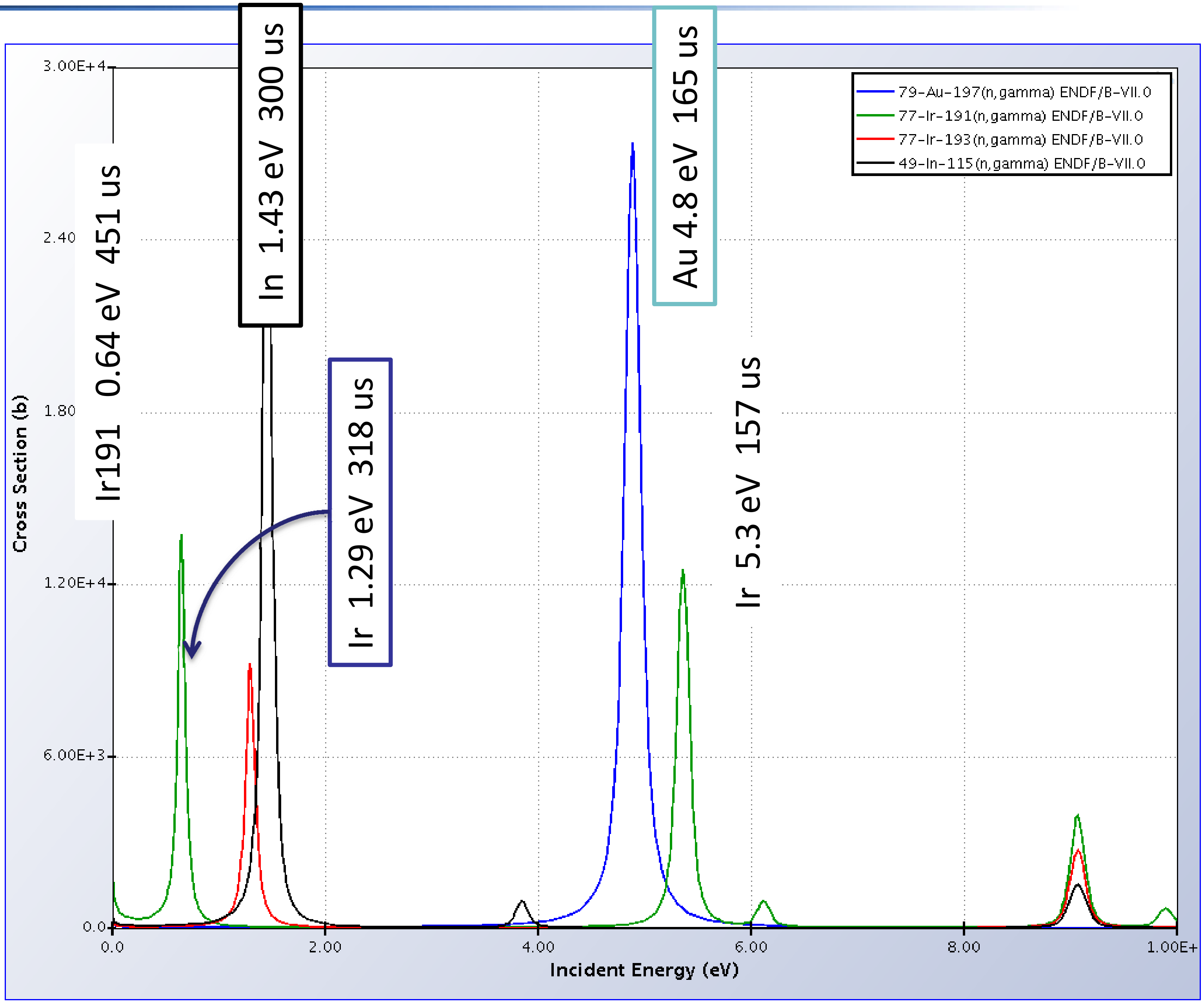
Target and Detectors for static test

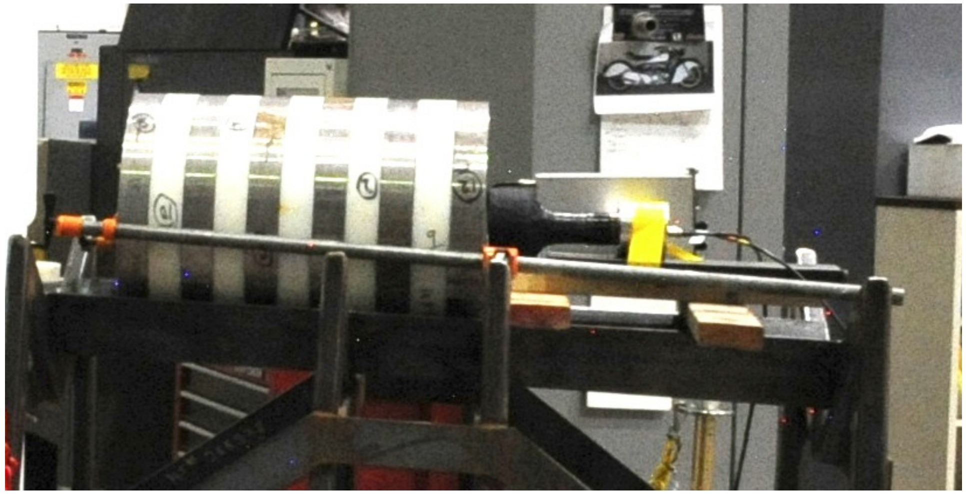
Tradeoff

Cross-section, Flight time, Efficiency.



"Epithermal"
E+4
E+3
E+2
E+1
E+0
E-1
E-2
E-3
E-4
Cross Section (b)
E-5
E-4
E-3
E-2
E-1
E+0
E+1
E+2
E+3
E+4
E+5
E+6
E+7
Incident Energy (eV)
77-Ir-191(n,gamma) ENDF/B-VII.0
77-Ir-193(n,gamma) ENDF/B-VII.0
49-In-115(n,gamma) ENDF/B-VII.0
NNDC


In 1.43 eV 300 us
Au 4.8 eV 165 us
Ir191 0.64 eV 451 us
Ir 1.29 eV 318 us
Ir 5.3 eV 157 us
79-Au-197(n,gamma) ENDF/B-VII.0
77-Ir-191(n,gamma) ENDF/B-VII.0
77-Ir-193(n,gamma) ENDF/B-VII.0
49-In-115(n,gamma) ENDF/B-VII.0
3.00E+4
2.40
1.80
1.20E+4
6.00E+3
0.0
Cross Section (b)
0.0
2.00
4.00
6.00
8.00
1.00E+
Incident Energy (eV)



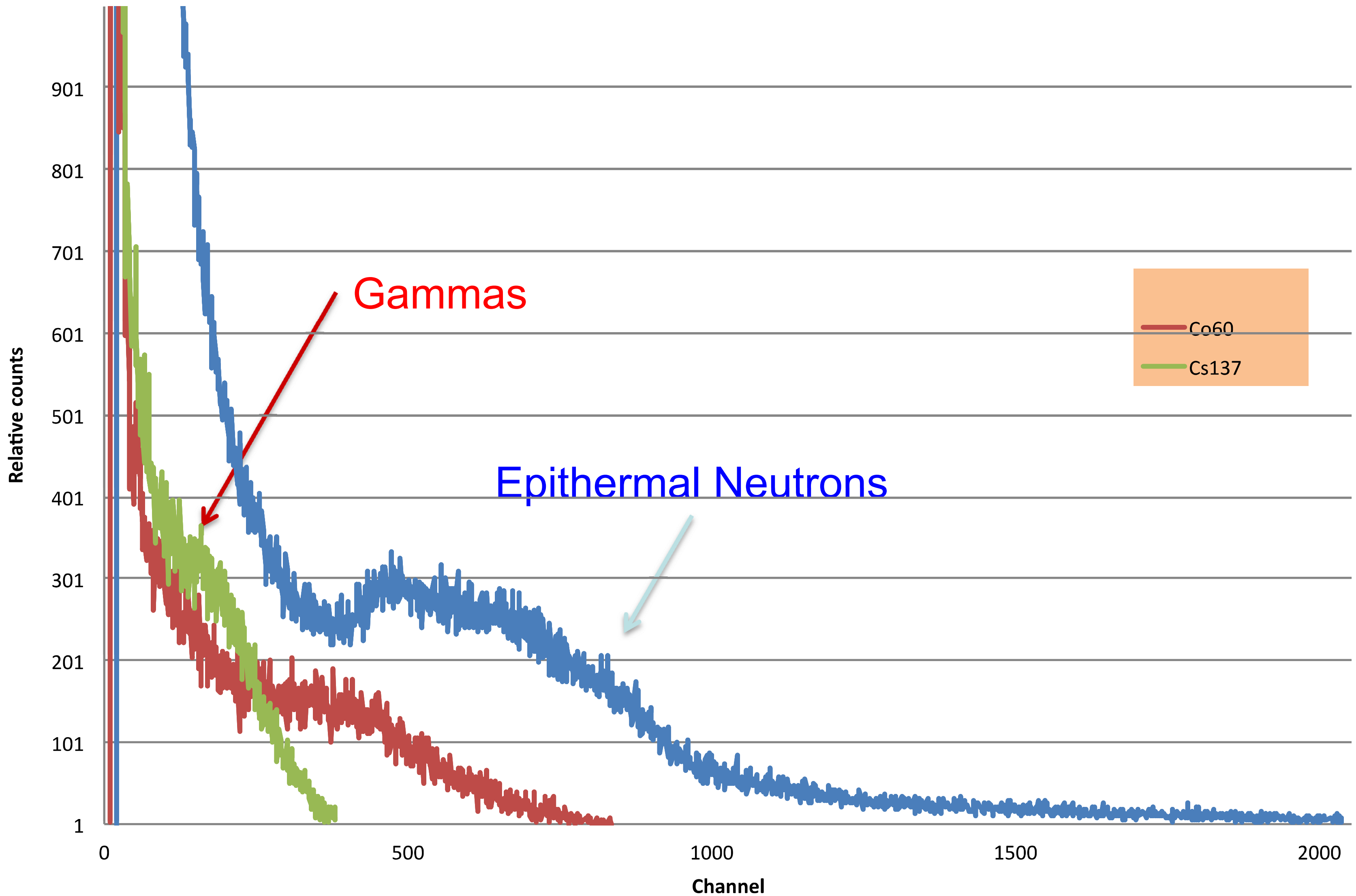
Detector Types for static test

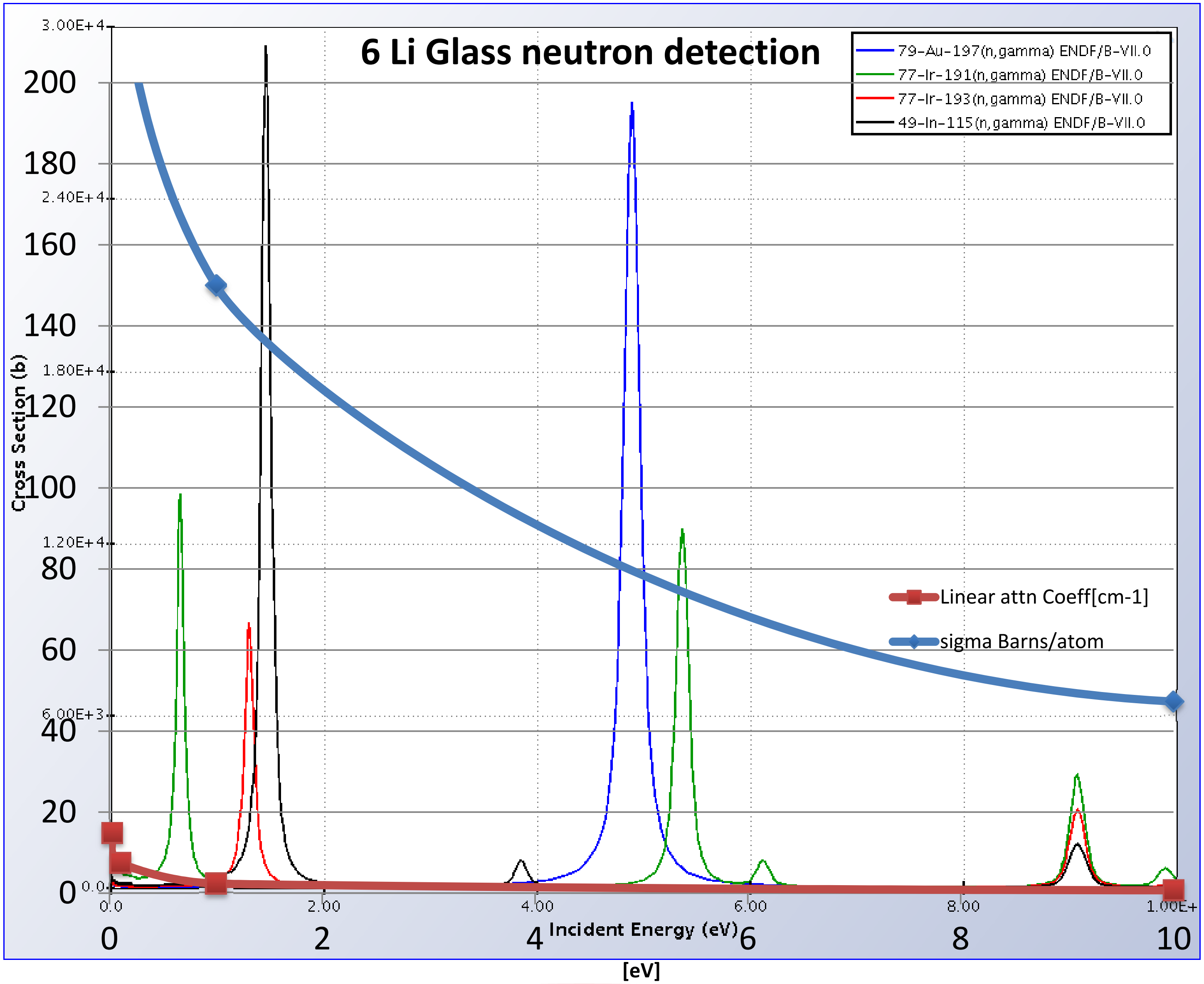
Sensitive to epithermals

Fast

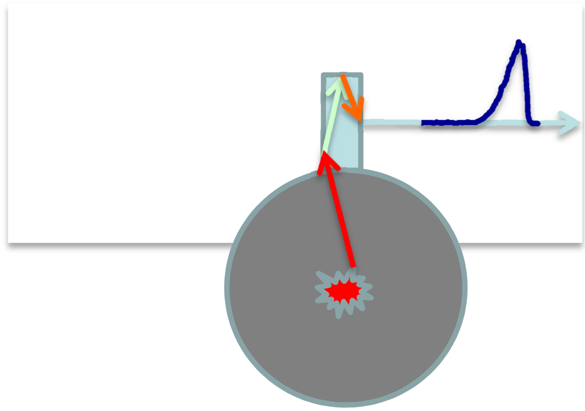
Low/no gamma response desirable

LiF Glass Responses
Gammas and Neutron Sources (background subtracted)





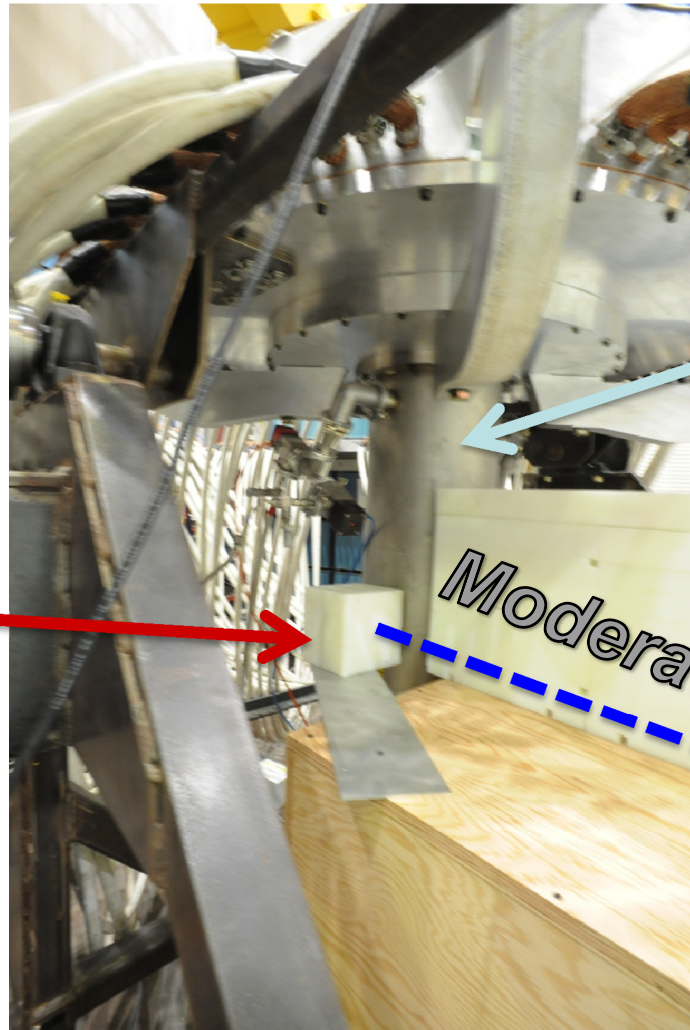
National Security Technologies LLC
Vision • Service • Partnership

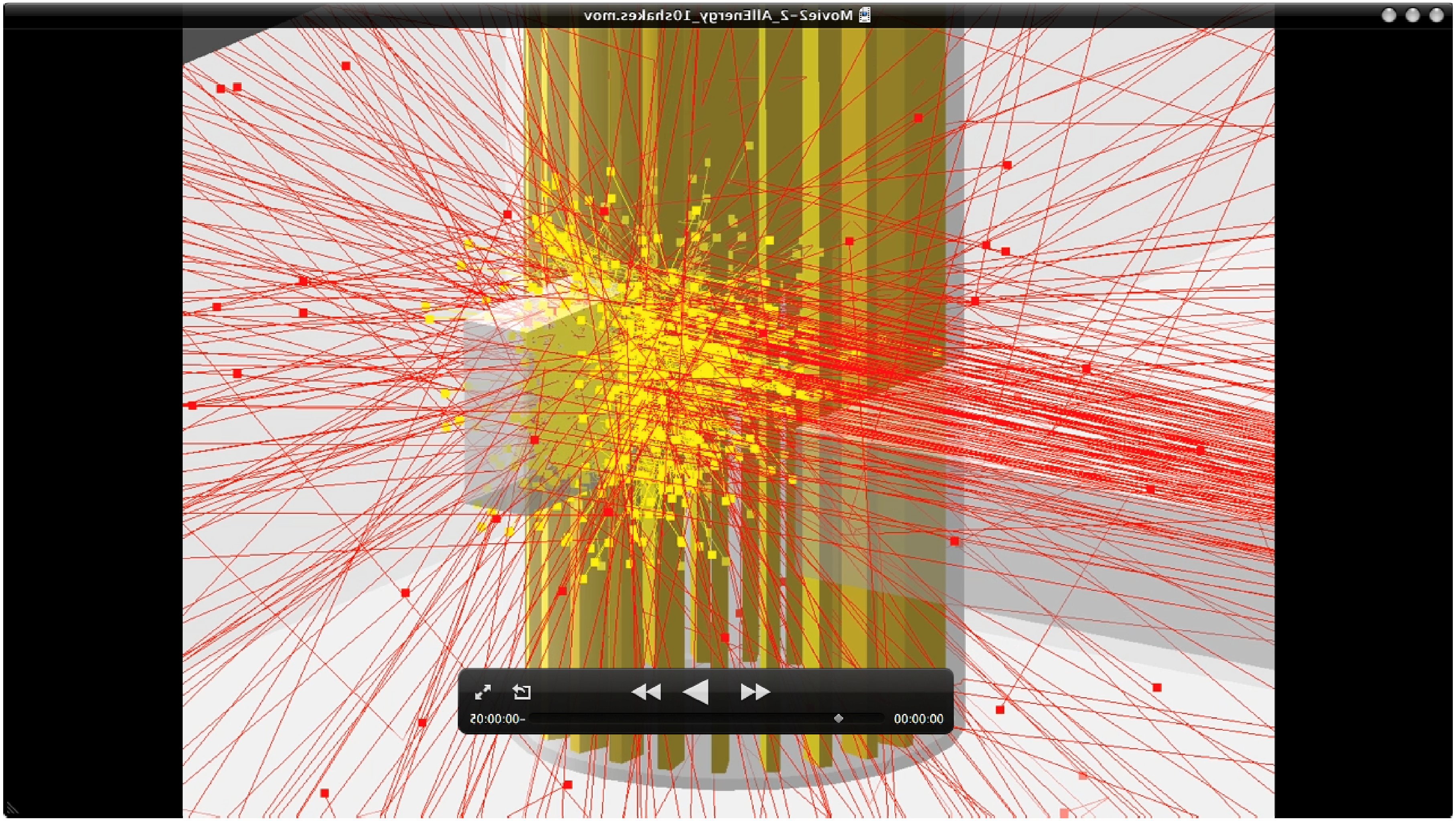


Moderator pulse-width

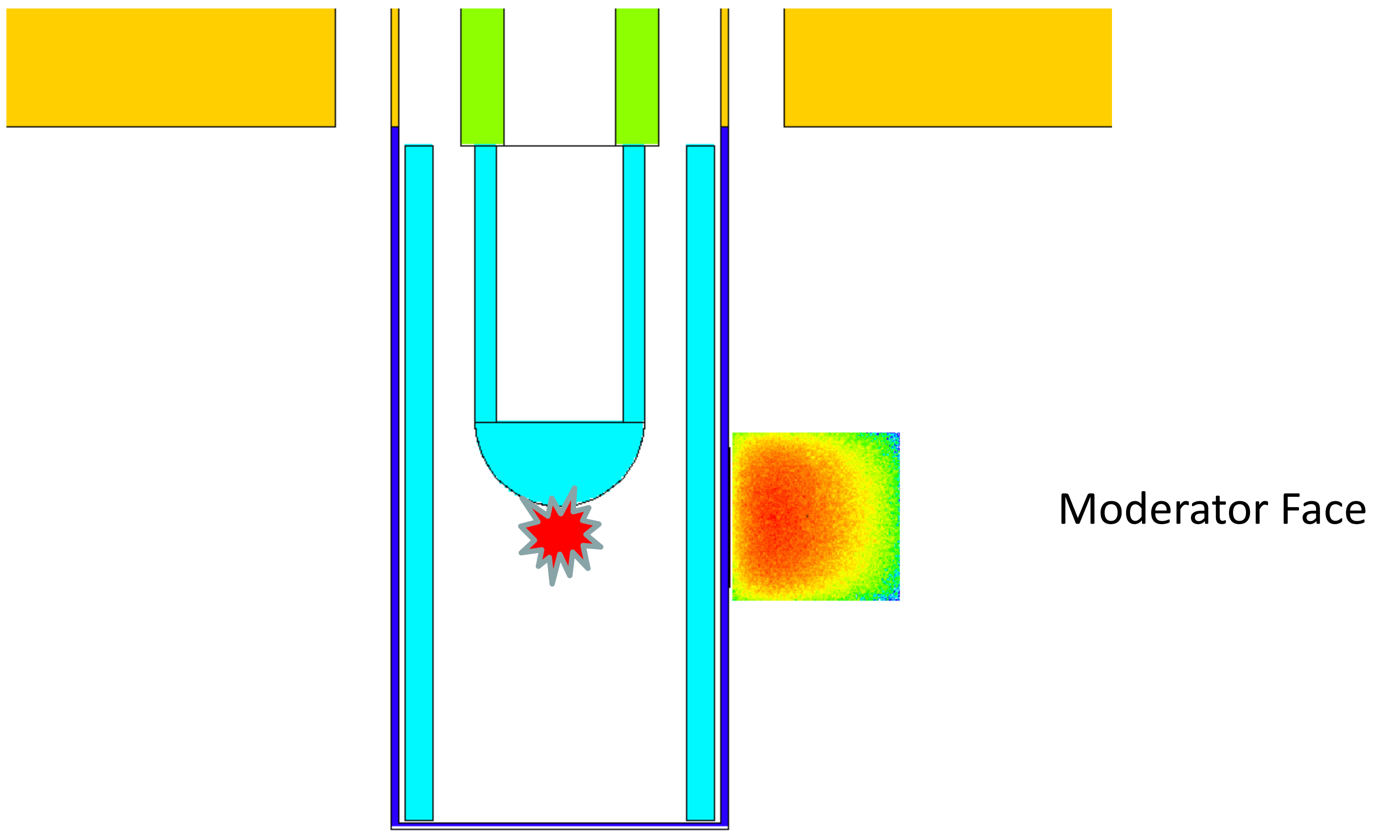
Pulse Width and Efficiency

Movie of Moderator

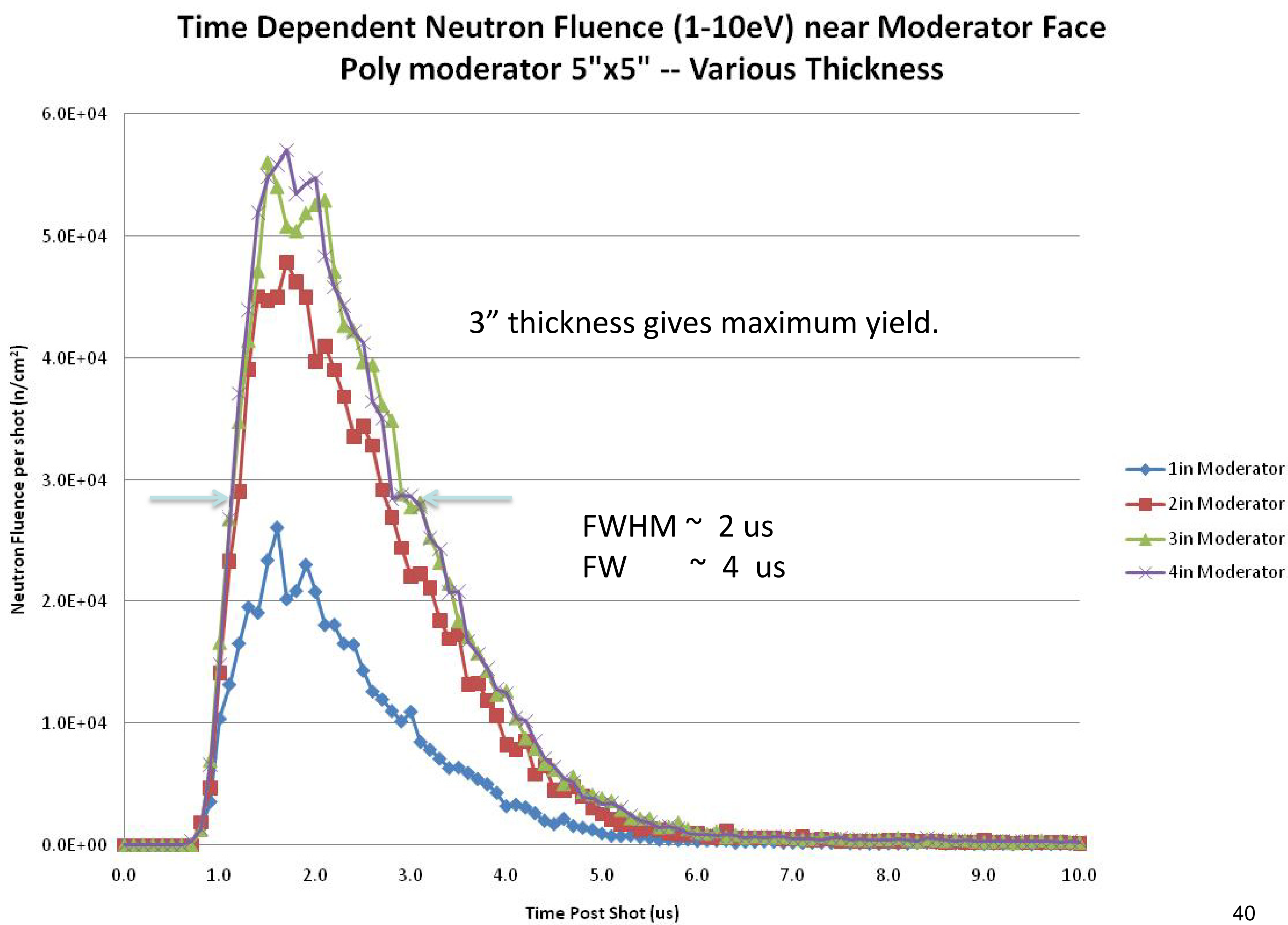



00:00:00

Model Geometry (Vertical Slice)



National Security Technologies LLC
Vision • Service • Partnership


Time Dependent Neutron Fluence (1-10eV) near Moderator Face
Poly moderator 5"x5" -- Various Thickness
3” thickness gives maximum yield.
FWHM ~ 2 us
FW ~ 4 us
Neutron Fluence per shot (n/cm²)
6.0E+04
5.0E+04
4.0E+04
3.0E+04
2.0E+04
1.0E+04
0.0E+00
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Time Post Shot (us)
1in Moderator
2in Moderator
3in Moderator
4in Moderator

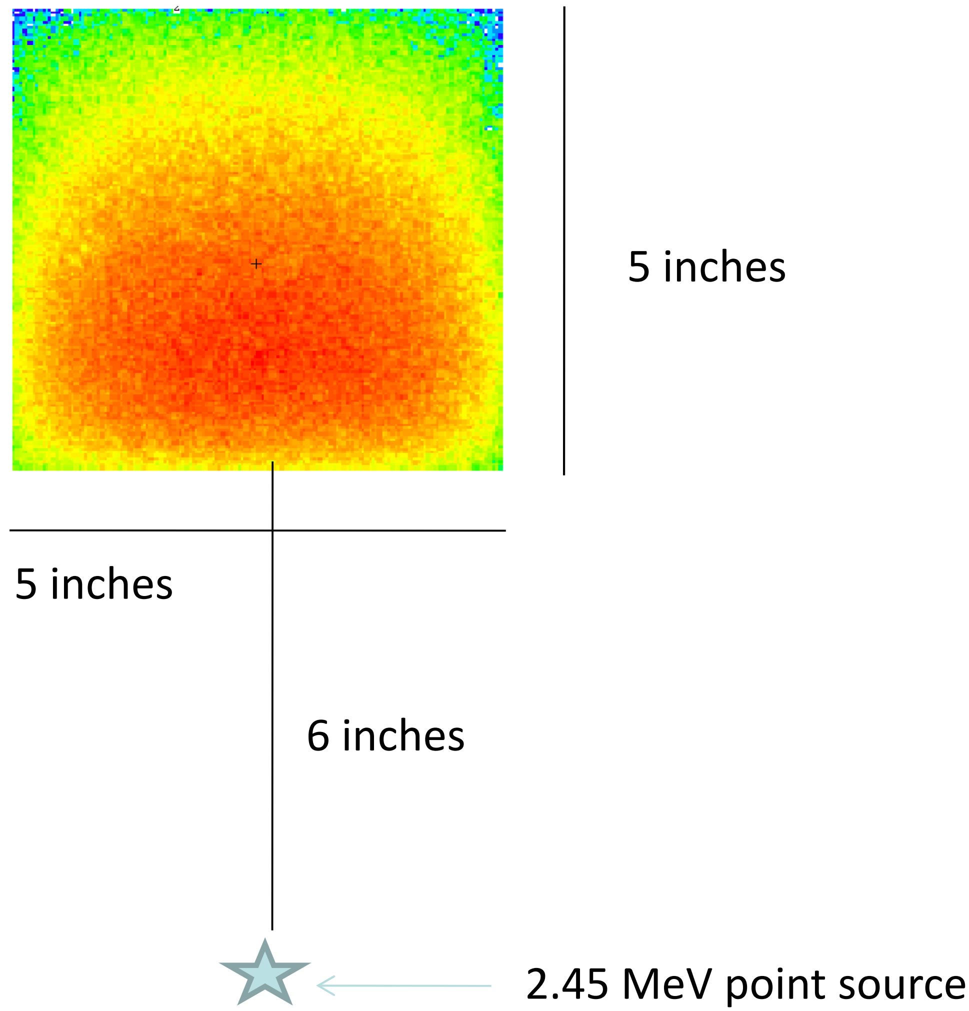
Moderator Size

Moderator tradeoffs:

pulse width vs output

(2 inch thick poly)

Plot shows neutrons (0.1 to 20 eV) crossing surface of moderator



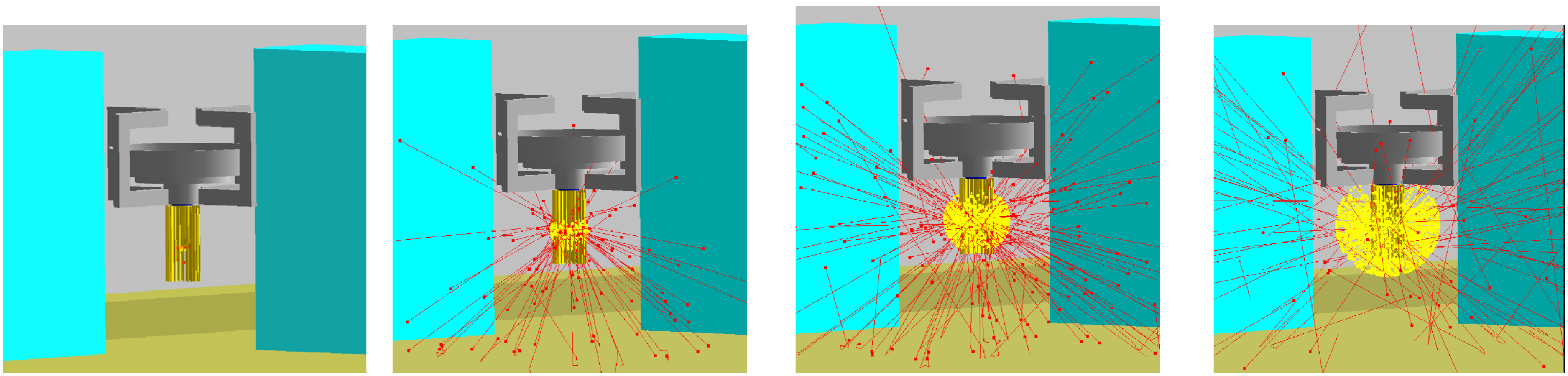
Shielding

Allow moderated neutrons

Shield:

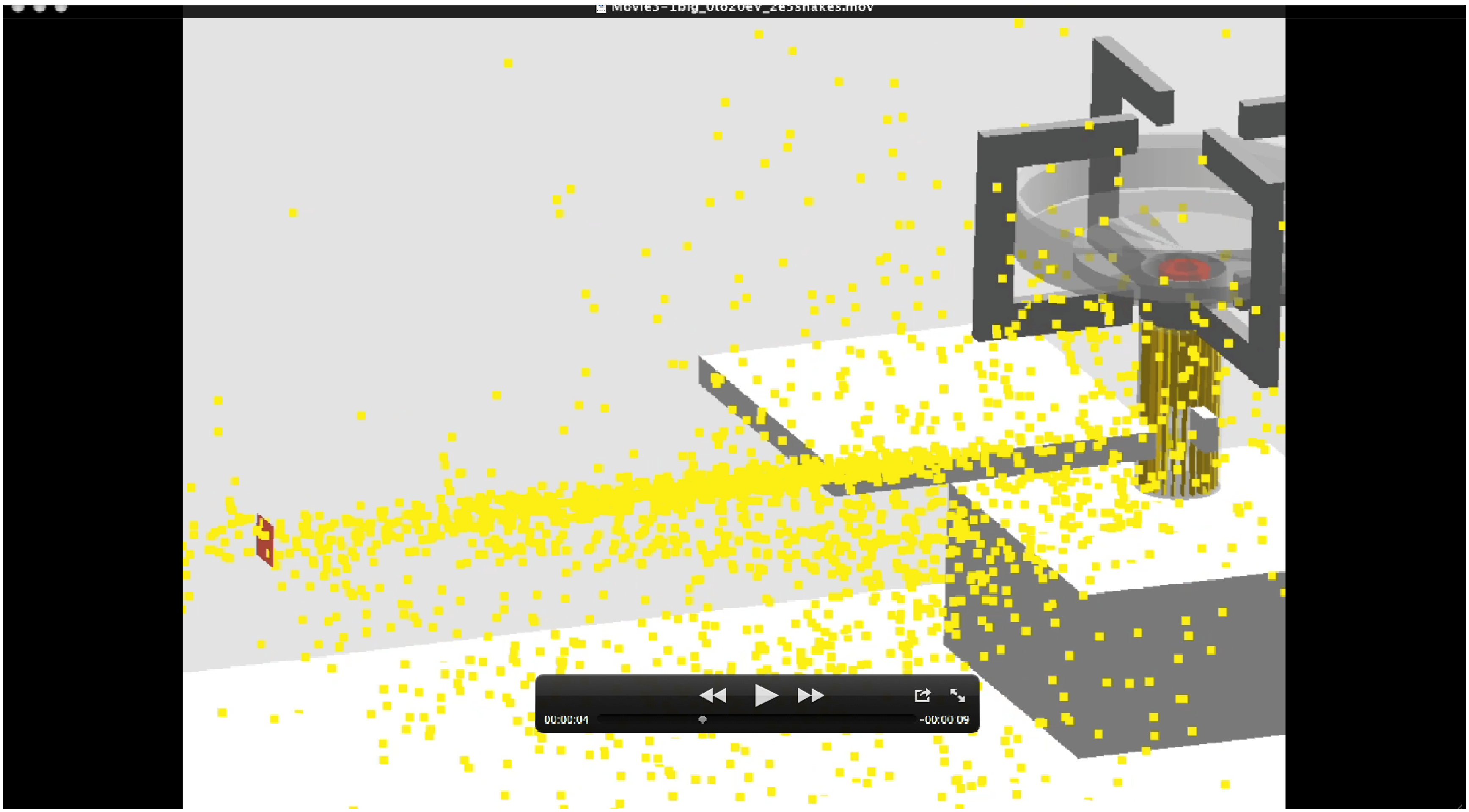
- DPF Source from Detector
- Scattered neutrons from Detector
- Capture gammas from Detector

Movie of Shielding Problem



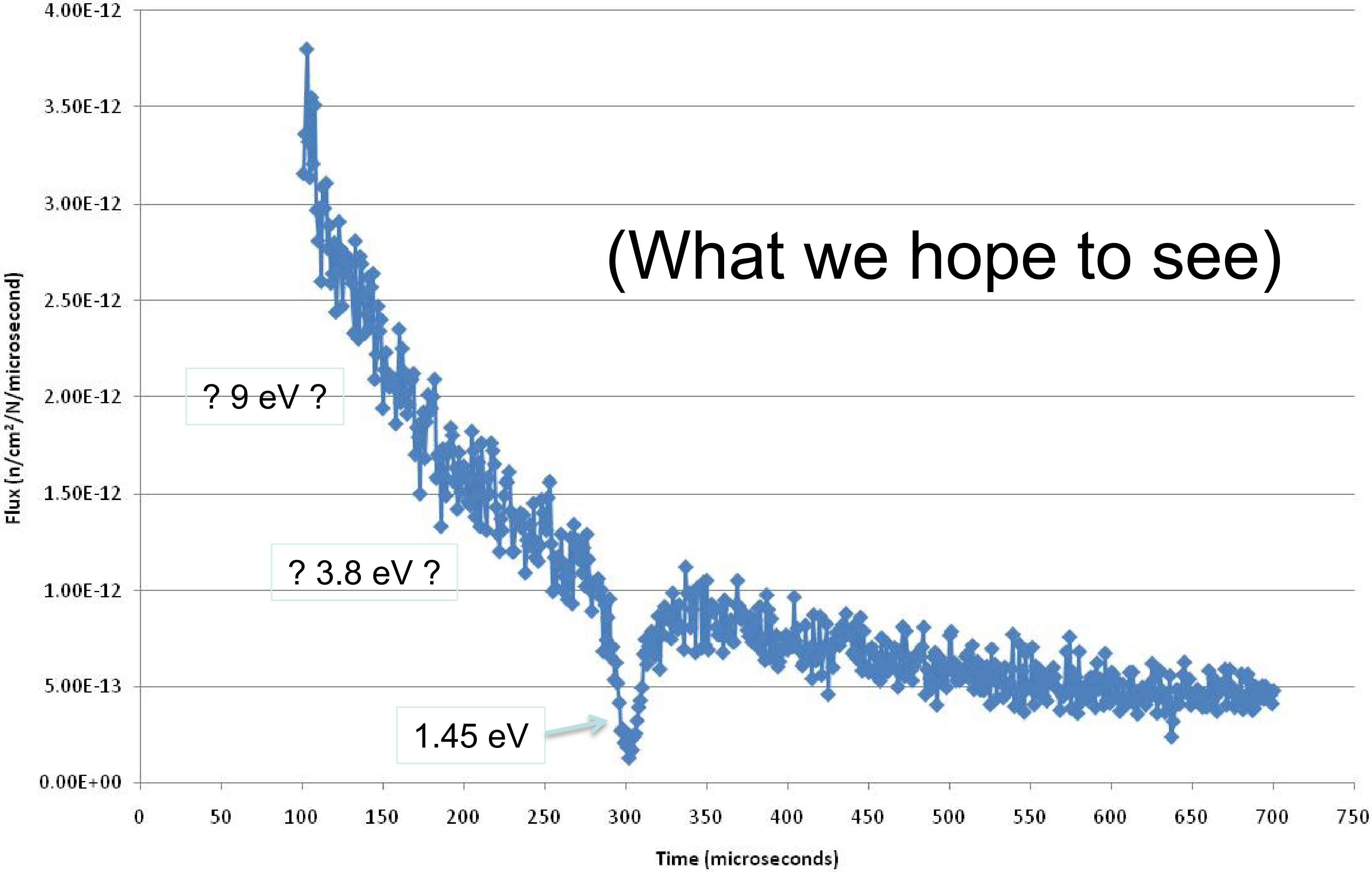
National Security Technologies LLC
Vision • Service • Partnership

NRS System Model



MCNPx calculation of NRS spectrum

0.025 mm Indium Foil @ 5 Meters



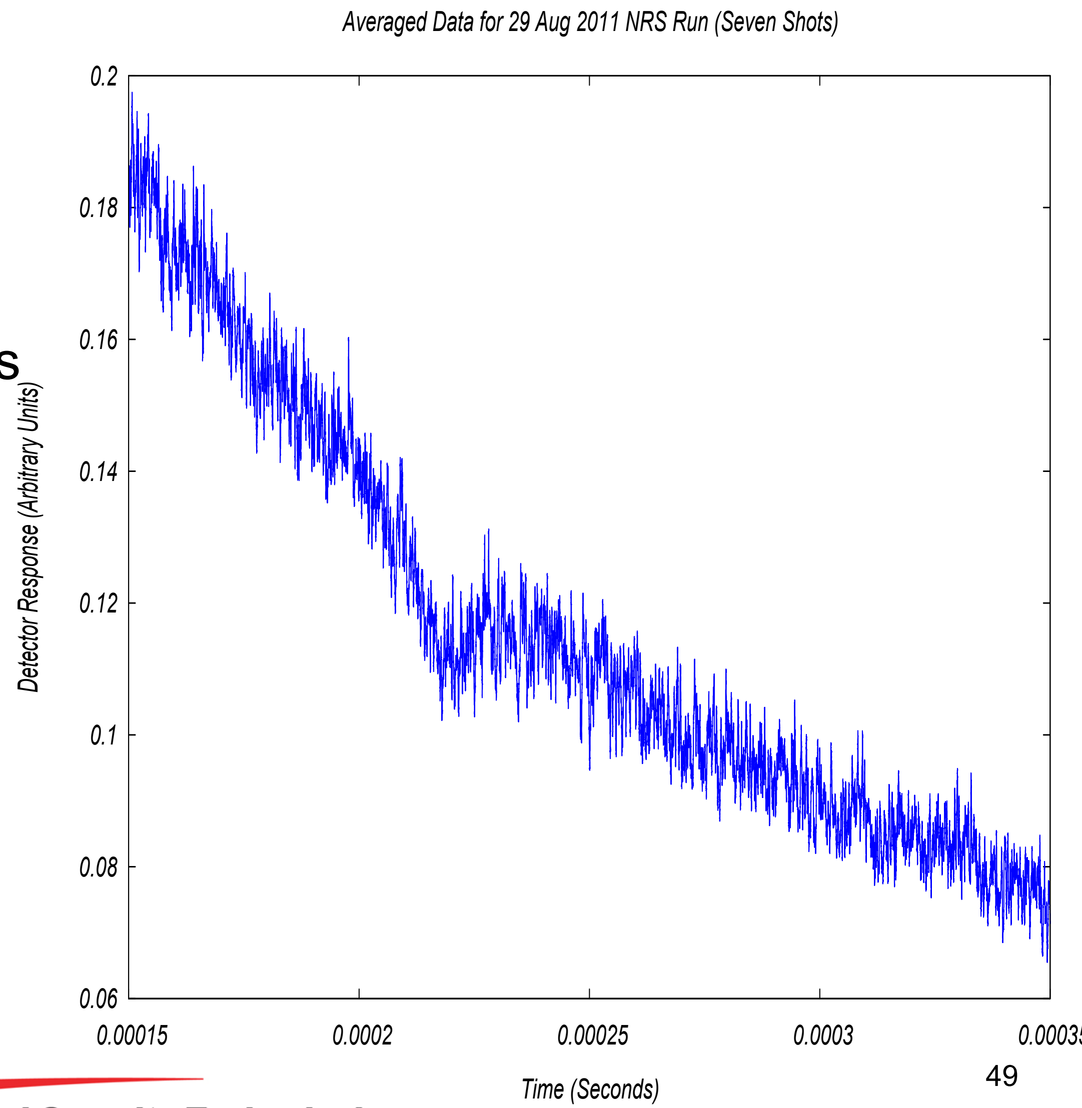
Test Design with:

DPF, moderator, Water shield, Indium foil, FePoly collimator, single detector

Data from first runs

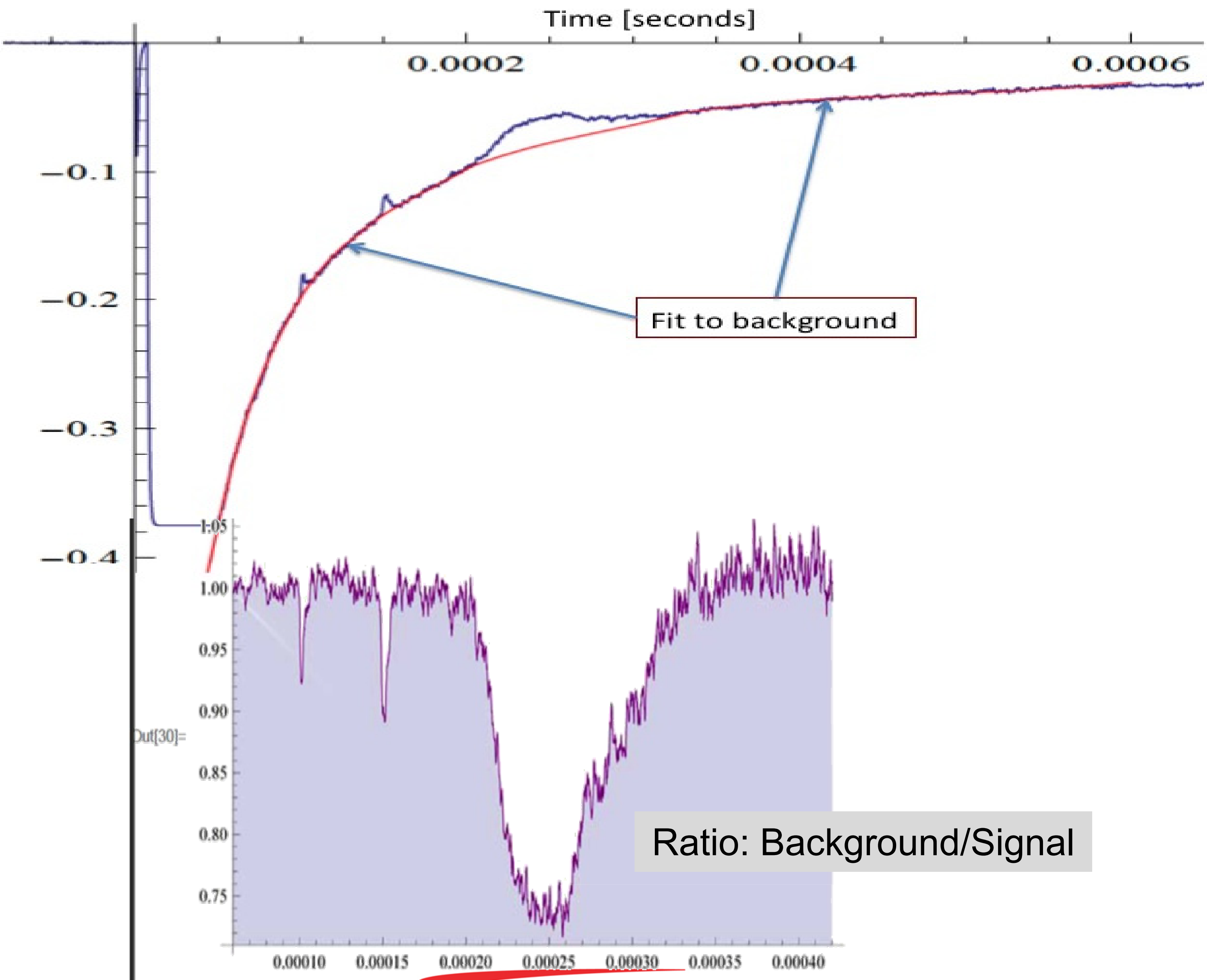
Data from NRS-DPF configuration test

- Data shown is sum of 6 shots
- Single Detector
- 3.5 m flight path
- 2.5 x 10^{12} equivalent yield
- 0.025 mm Indium target



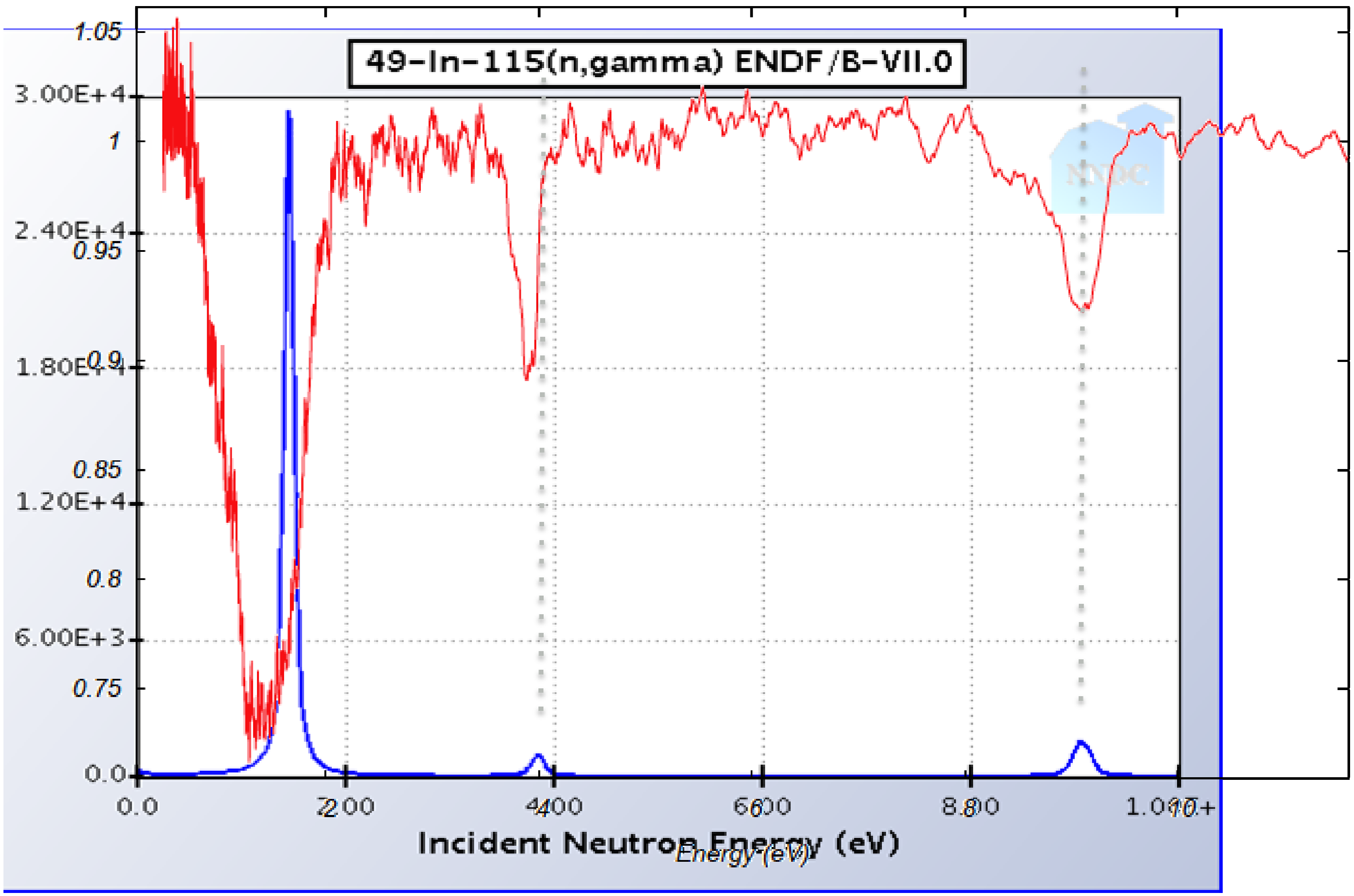
National Security Technologies LLC
Vision • Service • Partnership

30 Aug 2011, 0.5 mm Indium Target



National Security Technologies LLC
Vision • Service • Partnership

Averaged NRS Data for 30 Aug 2011



NRS Conclusion

- *PRELIMINARY DATA* suggests that:
  - With an adequate source (> 5 x 10^{13} neutrons per pulse), material science experiments are possible using moderated neutrons from Dense Plasma Focus Devices! Higher yield allows resonances of higher energies to be measured.
- *Conclusion:* Extending neutron yield scaling beyond 10^{12} DD is an important research area.
  - Fundamental Plasma Science
  - Enabling technology for a variety of DPF applications

Credits

- Mather, and Filippov for DPFs
- NSTec and US-DOE for support
- **Our NSTec DPF Team!**