Neutron Energy Spectrum Characterization on TMR-1 at the IU Neutron Source

Mr. Matthew Halstead

Graduate Student, Nuclear Engineering
Air Force Institute of Technology
Wright-Patterson AFB, OH
Email: Matthew.Halstead@afit.edu

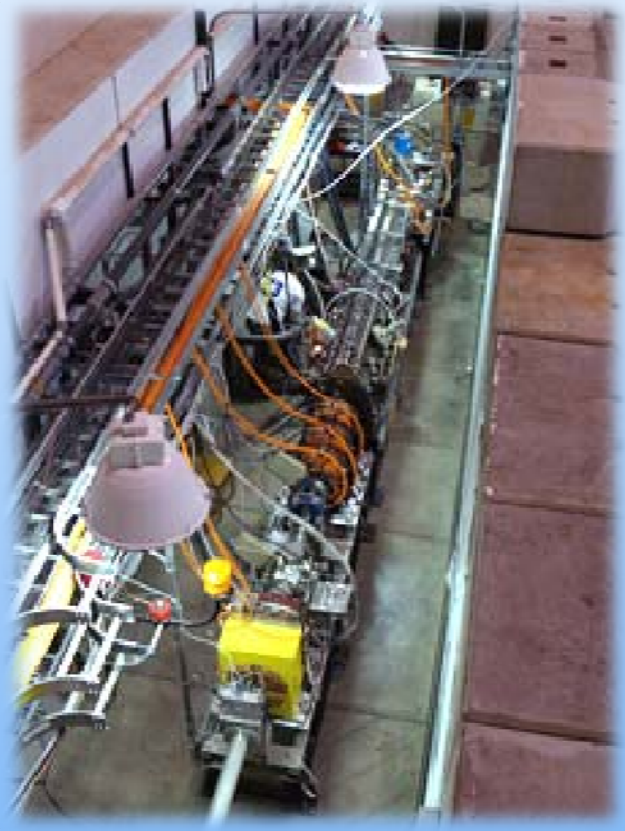
8 July 2011

Acknowledgements

1. *Dr. Sangjin Lee, Dr. Paul Sokol – IU Physics Dept.*
2. *Dr. James Petrosky, Dr. Abigail Bickley – AFIT Engr. Phys. Dept.*
3. *Steve Clark, Lydell Evans, Dr. Mark Savage – NSWC, Crane*
4. *IU Support Personnel*
5. *SMART Fellowship Program*

Overview

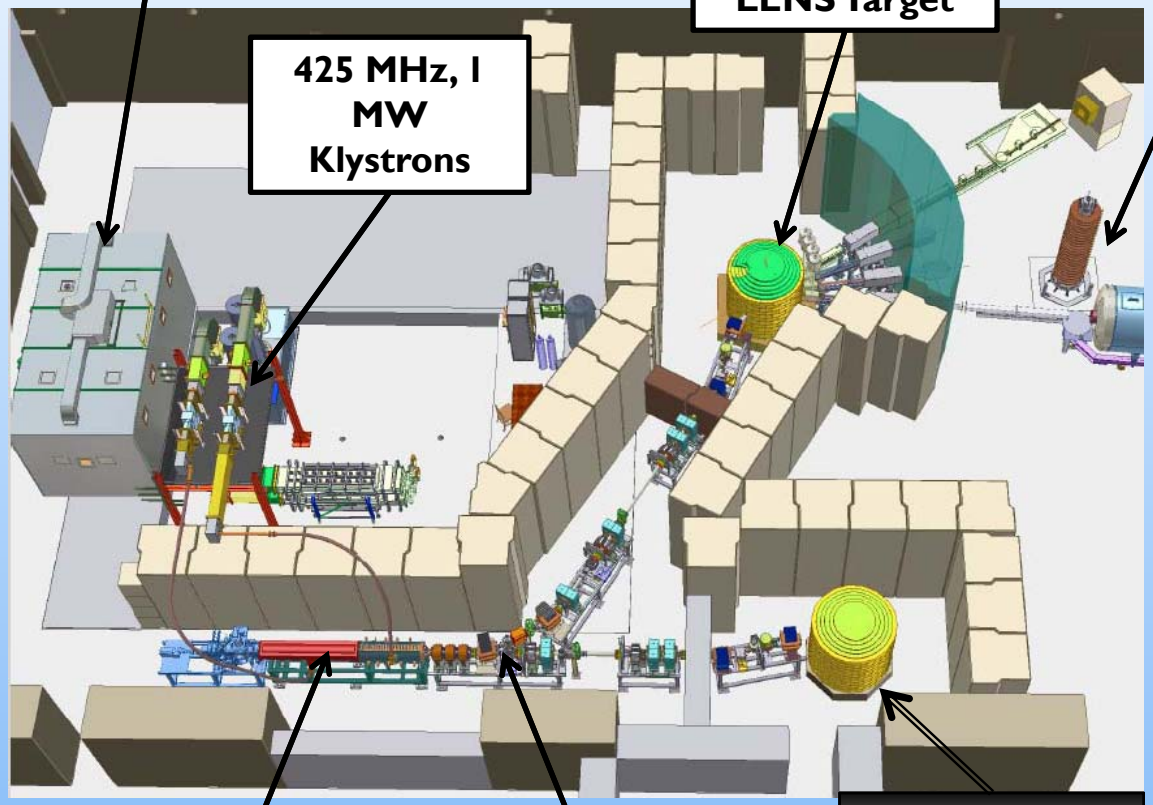
- Introduction
- Simulation
- Experiment Set-up & Results
- SAND-II Spectrum Unfolding
- Conclusions & Way Forward



Introduction

- NREP Neutron source (TMR-1) at Indiana University not yet fully characterized
- Sponsored by Naval Surface Warfare Center, Crane
- Understanding spectrum leads to a better tool for use by organizations conducting nuclear survivability studies.

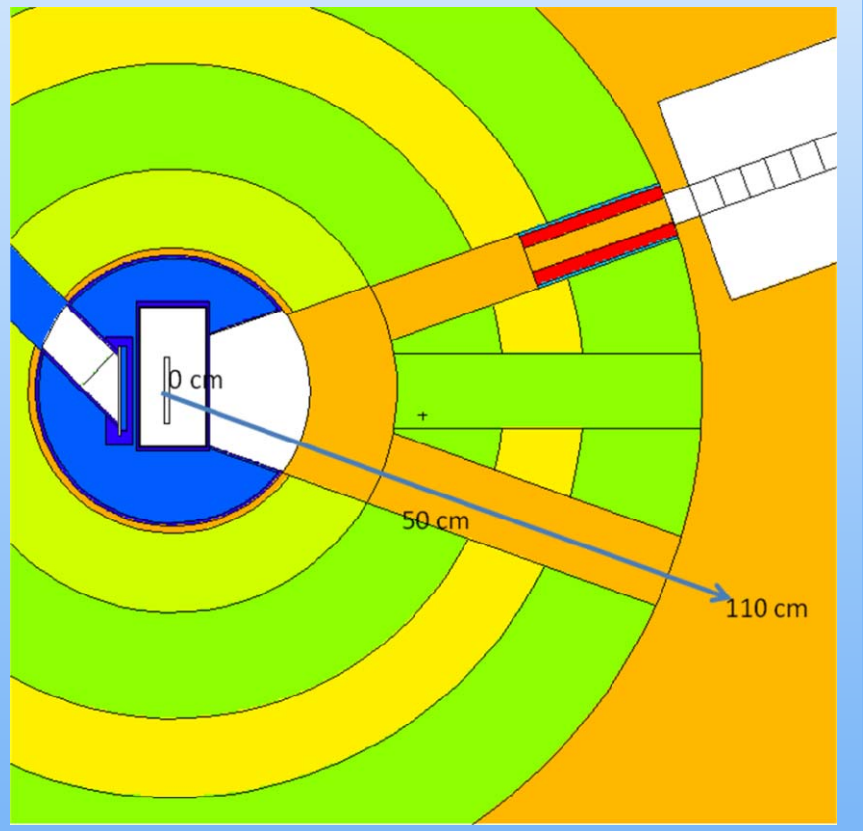
Facility Background



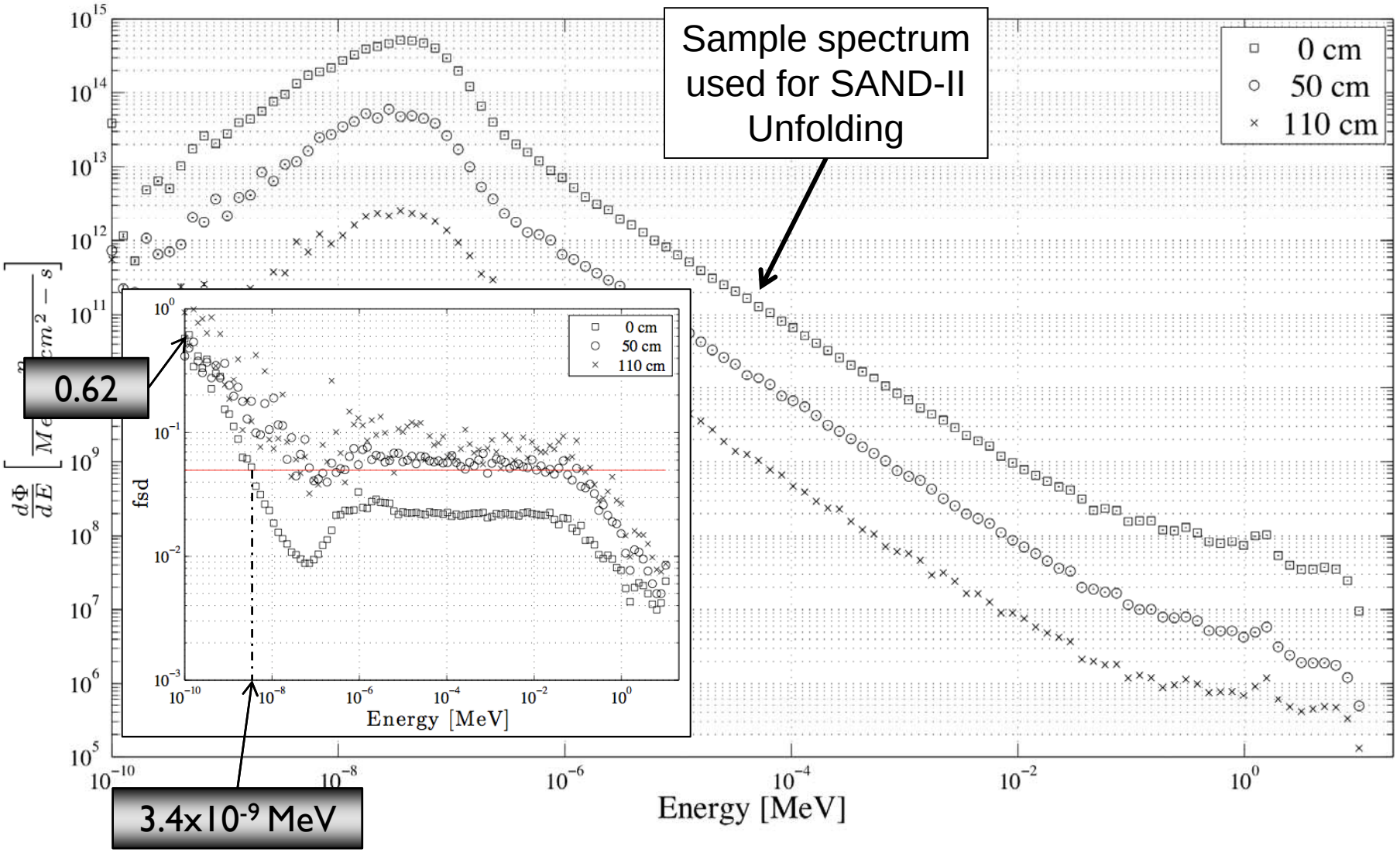
- LINAC (RFQ / 2 DTL)
- Typical H^+ Beam Characteristics:
  - E = 13 MeV
  - I_p = 20 mA
  - f_p = 20 Hz
  - PW = 425 µsec
- ^{9}Be Target
- H_20 coolant and reflector

Monte Carlo Simulation

- Monte Carlo model built and modified by IU personnel
- Included all relevant components
  - 13 MeV incident protons
  - ^{9}Be target
  - Water reflector
  - TMR layers
  - Beam port
- 12 point detector flux tallies
  - Initial at sample loc.
  - 10 cm increments

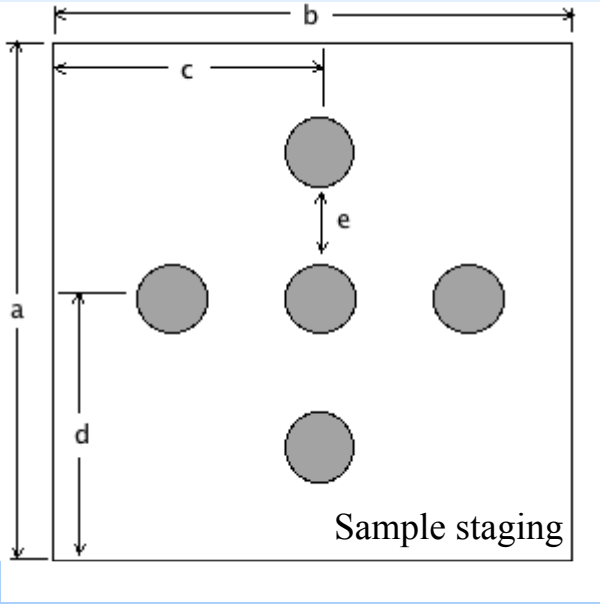


MC Results for Spectrum Unfolding



Experiment

- Designed to collect as much data as possible
- Irradiated for ~2 hr at a time
- Canberra HPGe detector for γ counting
  - 1 hr. background count calibration
  - 1 hr. energy calibration w/NIST-traceable source (Eu / Cs)
  - Efficiency calibration
    - 3 sample heights (minimize dead time)
    - 8, 15, 23 cm
- Calibration constants automatically applied to data sets

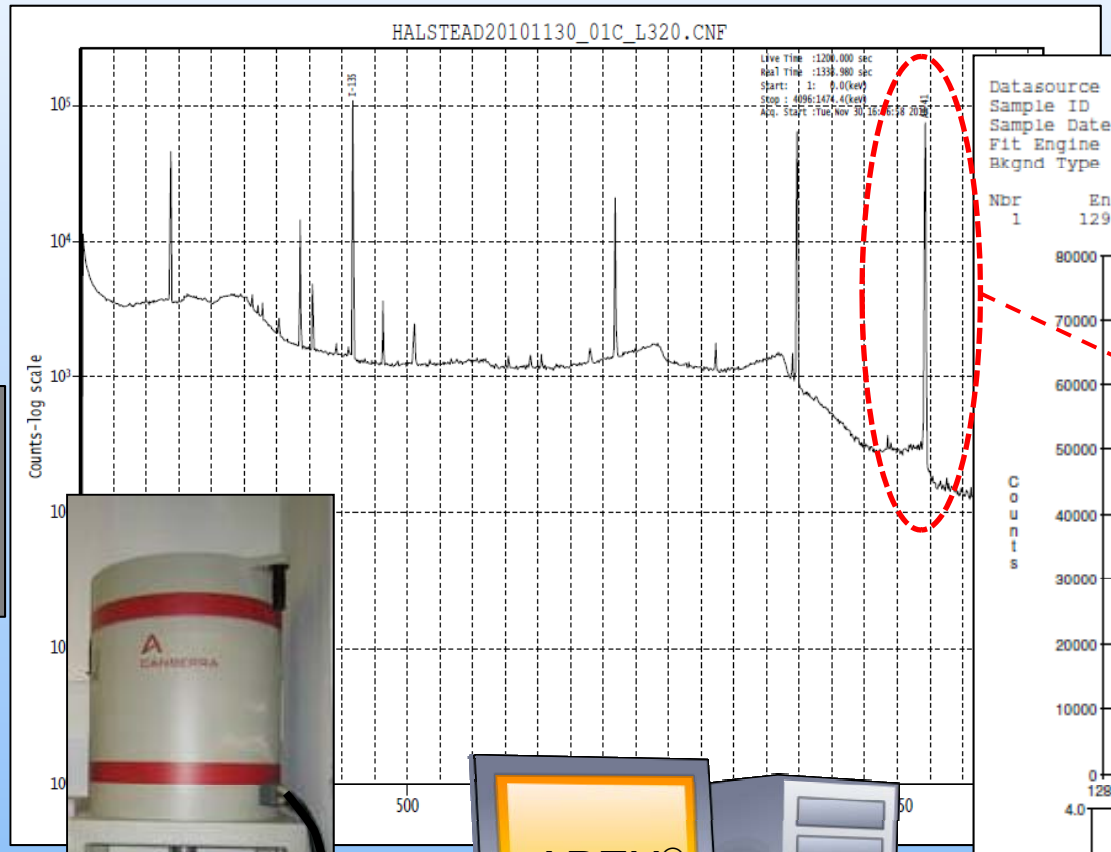


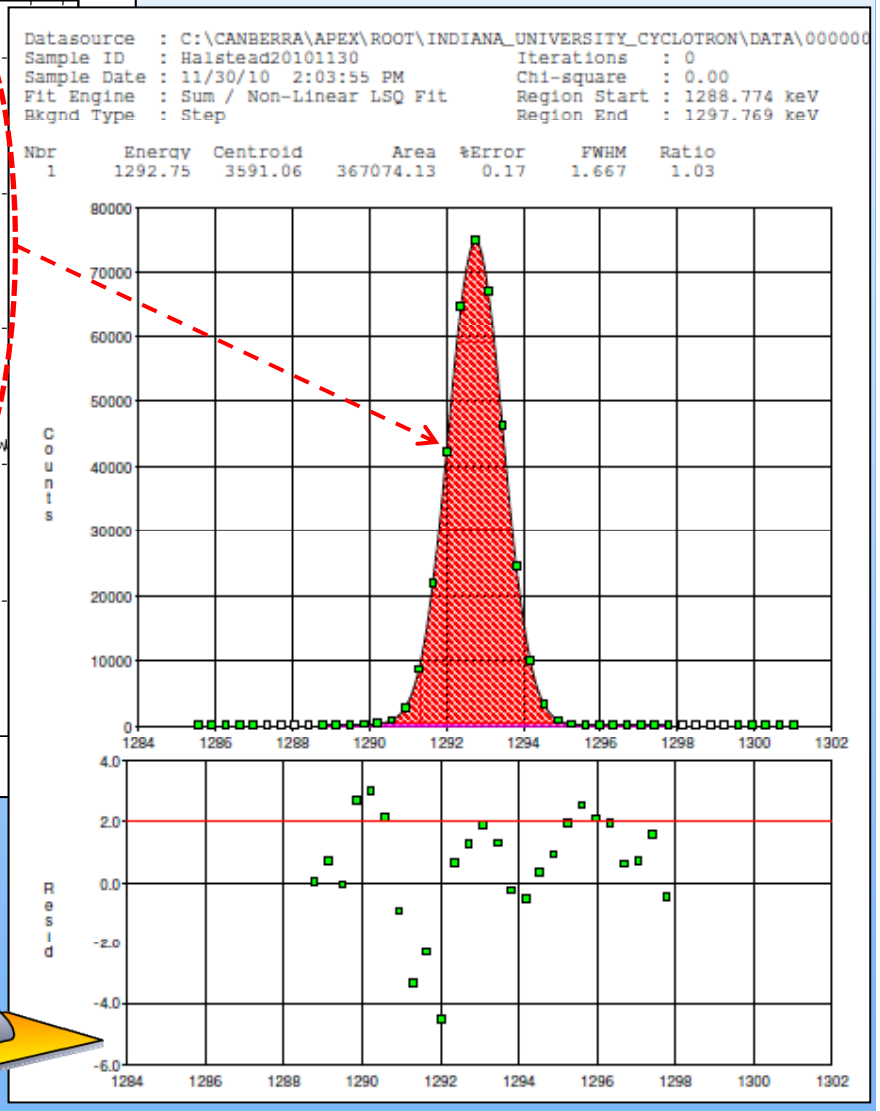
Dimensions:
a = 12.7cm
b = 14.6 cm
c = 7.3 cm
d = 6.8 cm
e = 3.8 cm

Reaction[1]	Half–life	Threshold Energy (MeV)[2]	Geometry
^{27}Al(n,p)^{27}Mg	9.46 min.	1.89632	Wire
^{27}Al(n,α)^{24}Na	15 hr.	3.24900	Wire
^{59}Co(n,α)^{56}Mn	2.5785 hr.	N/A	Wire
^{59}Co(n,γ)^{60}Co	5.2714 yr.	N/A	Wire
^{63}Cu(n,γ)^{64}Cu	12.700 hr.	N/A	Wire
^{115}In(n,n')^{115}In	4.486 hr.	N/A	Foil
^{115}In(n,γ)^{116}In	54.29 min.	N/A	Foil
^{56}Fe(n,p)^{56}Mn	2.5785 hr.	2.96566	Foil
^{54}Fe(n,p)^{54}Mn	312.3 d.	N/A	Foil
^{58}Fe(n,γ)^{59}Fe	44.503 d.	N/A	Foil
^{58}Ni(n,p)^{58}Co	70.86 d.	1.00000	Wire
^{109}Ag(n,γ)^{110m}Ag	249.79 d.	N/A	Foil
^{197}Au(n,γ)^{198}Au	2.69517 d.	N/A	Foil

Note:
[1]Each reaction includes a bare and cadmium covered scenario.
[2]Data collected using Qtool [47]

DGNAA Counting





Experiment Results

- Preliminary gold foil measurement showed center was location of highest total induced activity
- Collection of activity data points for multiple foil elements
  - Corrected to saturation

$$A_{\infty} = \frac{\lambda C}{\left(1 - e^{-\lambda t_0}\right) e^{-\lambda t_0} \left(e^{-\lambda t_1} - e^{-\lambda t_2}\right)}$$

λ = decay const.
C = peak counts
t_0= irradiation time
t_1-t_0= wait time
t_2- t_1 = count time

  - Adjusted Irradiation time = total beam *on* time because pulse duration was << Half life
  - QED: Decay between pulses neglected
- Foil activity used as input for the SAND-II computer code along with initial spectrum provided by Monte Carlo simulations

Thermal Flux Measurements

- Bare and cadmium-covered measurement at center position
- Utilized boron thermal capture factor of 1.056

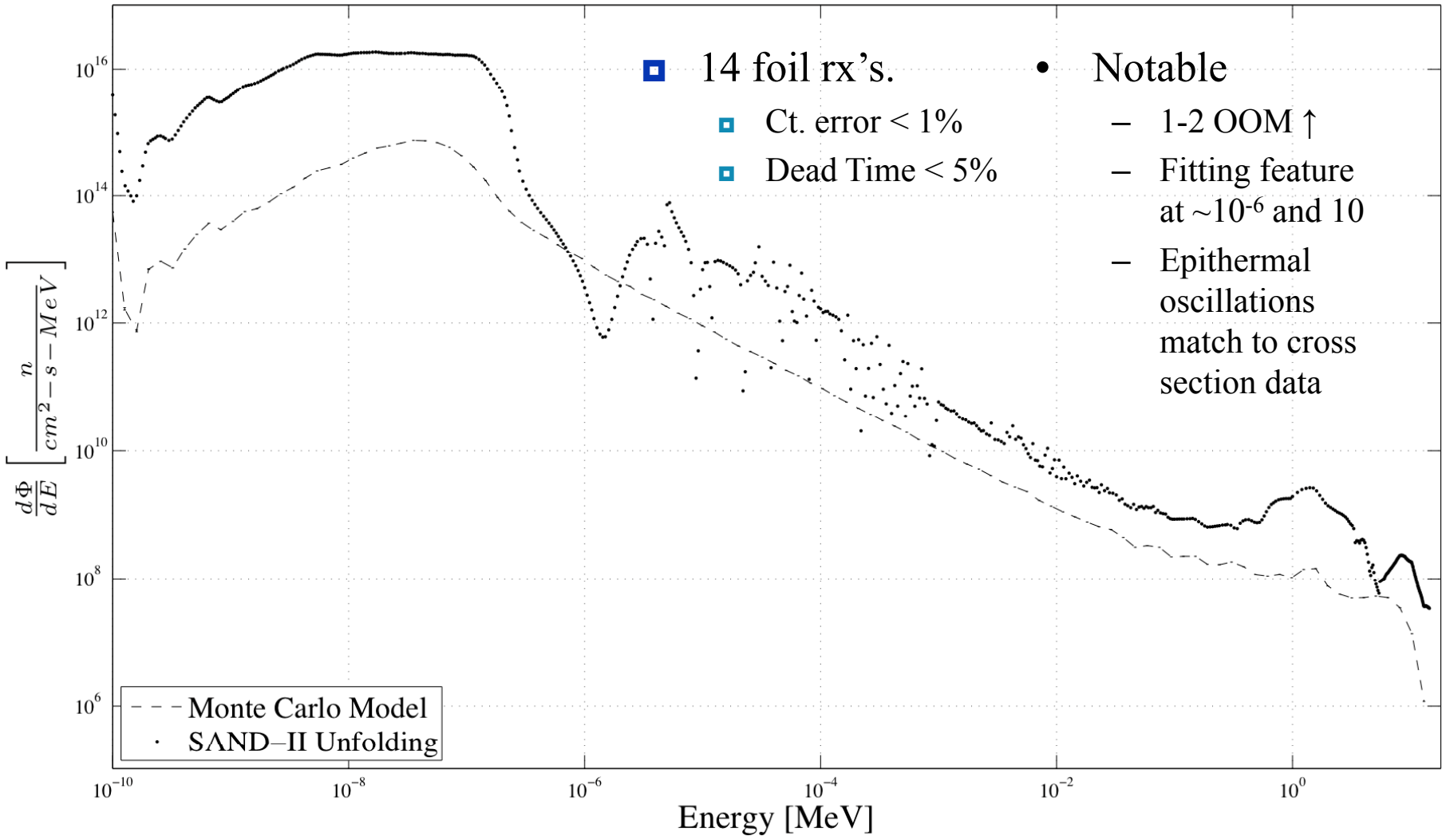
$$A_{\infty,th} = A_{\infty,tot} - FA_{\infty,Cd}$$

$$\Phi = \frac{A_{\infty,th}}{\Sigma_{th} V}$$

	Value	Uncertainty	Units
V	1.47×10^{-3}	$\pm0.087\times10^{-3}$	cm^3
Σ_{th}	5.815	±0.0053	cm^{-1}
A_{th}	1.35×10^{8}	$\pm0.0009\times10^{8}$	dps
Φ_{th}	1.58×10^{10}	$\pm0.093\times10^{10}$	n cm^{-2} s^{-1}

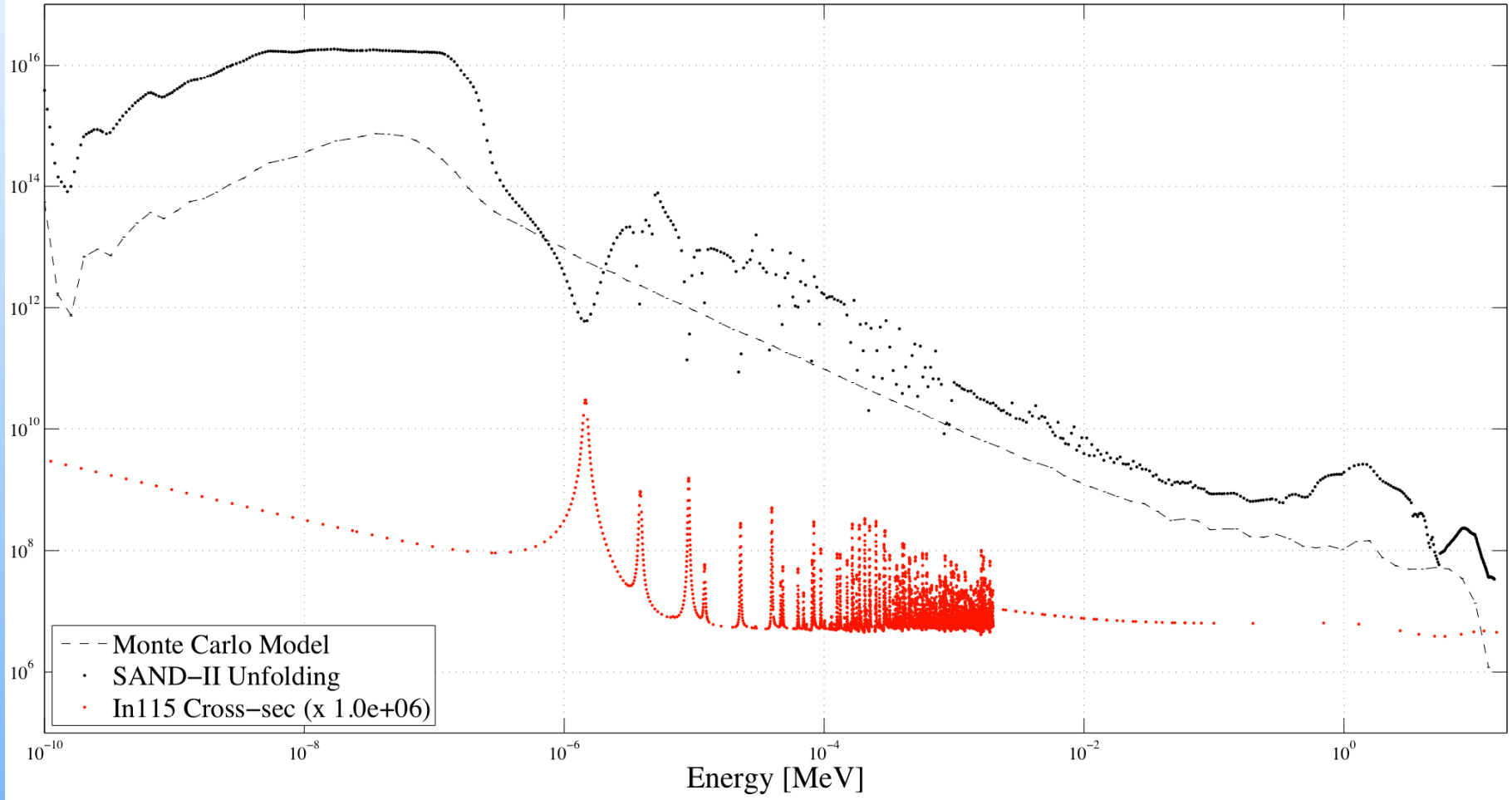
$A_{\infty,th}$= Sat. Thermal Act.
$A_{\infty,tot}$= Sat. Act. for bare
$A_{\infty,Cd}$ = Sat. Act. For Cd-covered
F = boron thermal capture factor
Φ_{th} = thermal flux
Σ_{th} = thermal neutron macroscopic cross section for gold
V = volume of gold foil

SAND-II Results



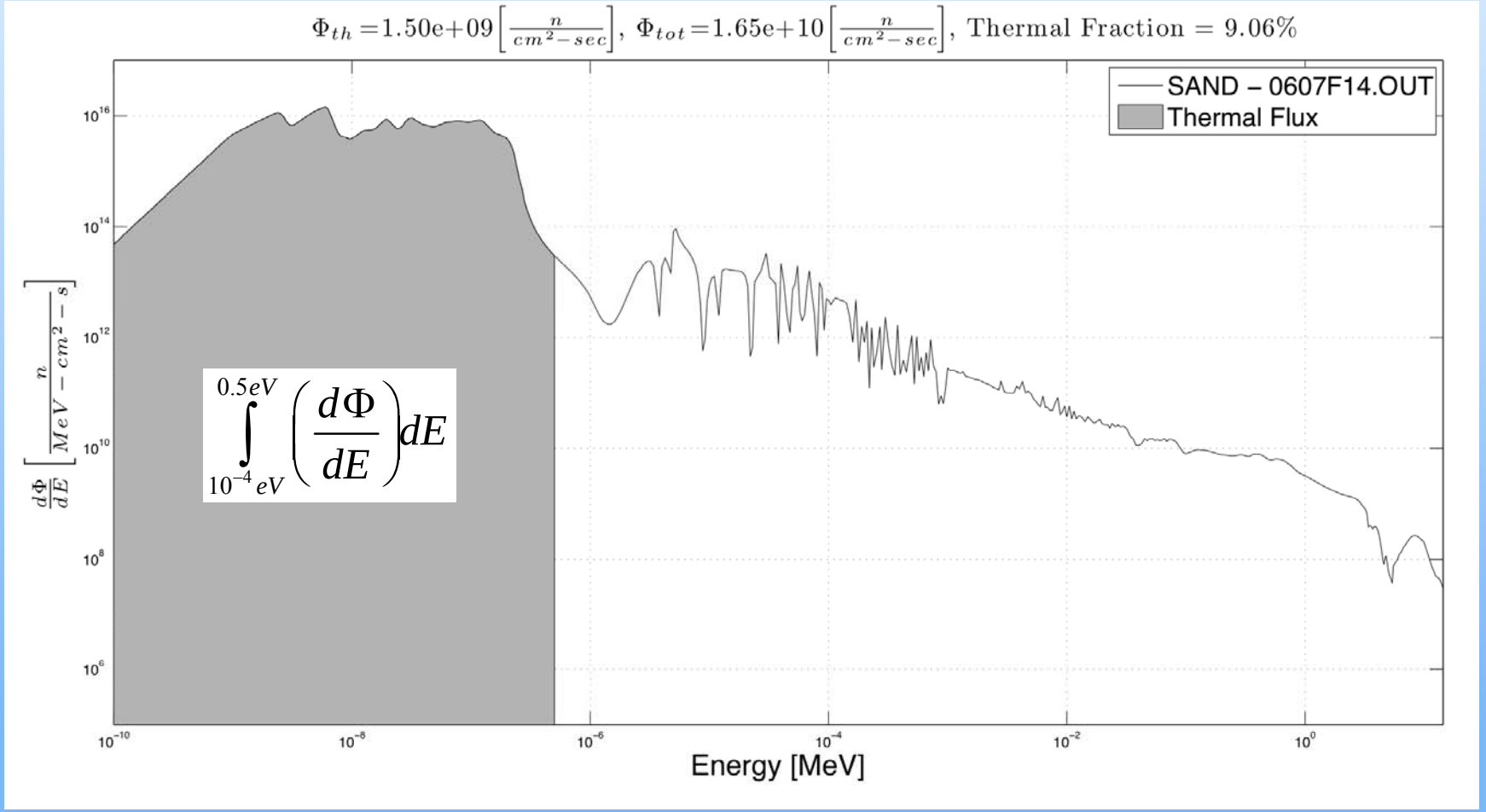
- 14 foil rx's.
  - Ct. error < 1%
  - Dead Time < 5%
- Notable
  - 1-2 OOM ↑
  - Fitting feature at ~10^{-6} and 10
  - Epithermal oscillations match to cross section data

SAND-II Results



Thermal Flux Comparison

- Calculated from experiment: (1.58±0.093)x10^{10} [n cm^{-2} s^{-1}]



Conclusions

- Simulation
  - Monte Carlos simulation provides adequate initial spectrum
  - Correlation with GEANT (vector Monte Carlo) ongoing
  - Used as baseline for future modifications
- Experiment
  - Target total flux distribution measured.
  - Significant amount of DGNAA data recorded, processed, and stored (5 locations, 8 materials)
  - Counting error and dead time minimized
  - Developed method of characterization
- SAND-II
  - Results strongly dependent on initial guess spectrum (further analysis ongoing)
  - Understand code and methodology developed for better for future use

Way Forward

- Further clarify energy spectrum
  - Time of Flight to provide low-energy correlation
  - Monte Carlo particle transport vs. GEANT correlation
- Future work
  - Build baseline for modifications to target
    - Geometry
    - Material
    - Thermal Management
  - Increase flux and shape spectrum to improve flexibility of beam line to accommodate multiple user groups