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Title: Introduction to neutron spectrometers

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Los Alamos NATIONAL LABORATORY

EST. 1943

Introduction to neutron spectrometers

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CSU neutron detection class
Fort Collins, CO
Oct. 27-29 2014

Introduction: talk outline

- Discussion (brief) of neutron spectrometers for neutrons < 20 MeV
  - Bonner spheres
  - ROSPEC
  - Scintillator-based instruments

Introduction

- Spectroscopic methods of neutron detection provide:
  - Neutron spectral data
  - Neutron dose by folding in fluence-to-dose conversion coefficients

- However spectrometers are more complicated than rem meters
  - Therefore more expensive and usually less reliable
  - More complicated to operate
  - Typically require sophisticated real-time pulse shape discrimination
  - Usually, a method of energy calibration is required
  - Typically they are not portable
  - Typically do not provide real-time information as off-line unfolding or deconvolution of the pulse height data is required.
    - requiring a well-characterized instrument response function

Bonner spheres

- Developed in 1960's
- Based on measurements taken with PE spheres of different diameters (3"-12")
- Typically uses a ^{3}He counter but also TLDs and foils for use in pulsed fields.
- Time consuming and labor intensive measurement process
- Data is unfolded to give the neutron spectrum
  - Spectrum consists of 53 energy bins based on only 10 or fewer measurements !!!

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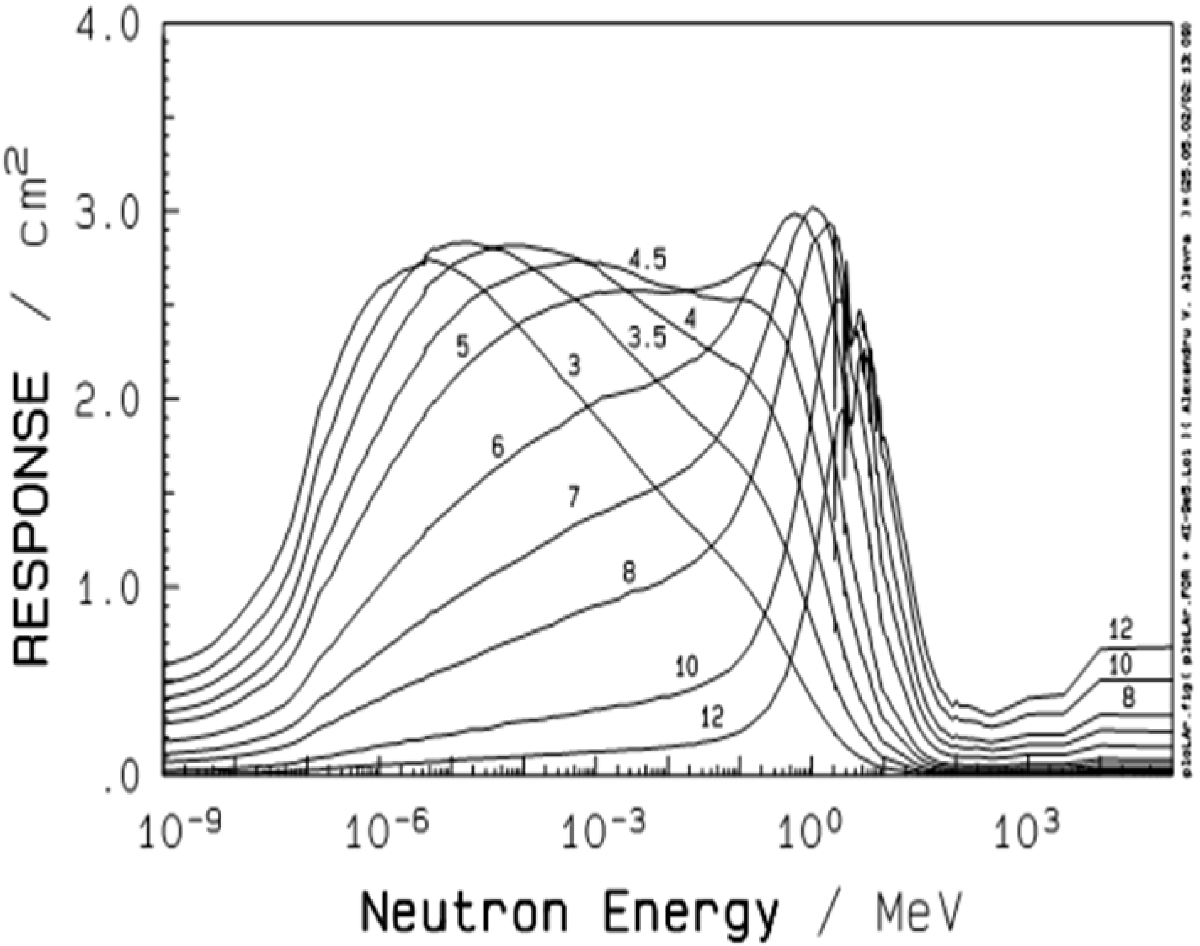
Neutron Spectrometers : BSS



Data also applies to the response of a PE-moderated rem meter

Neutron Spectrometers : BSS

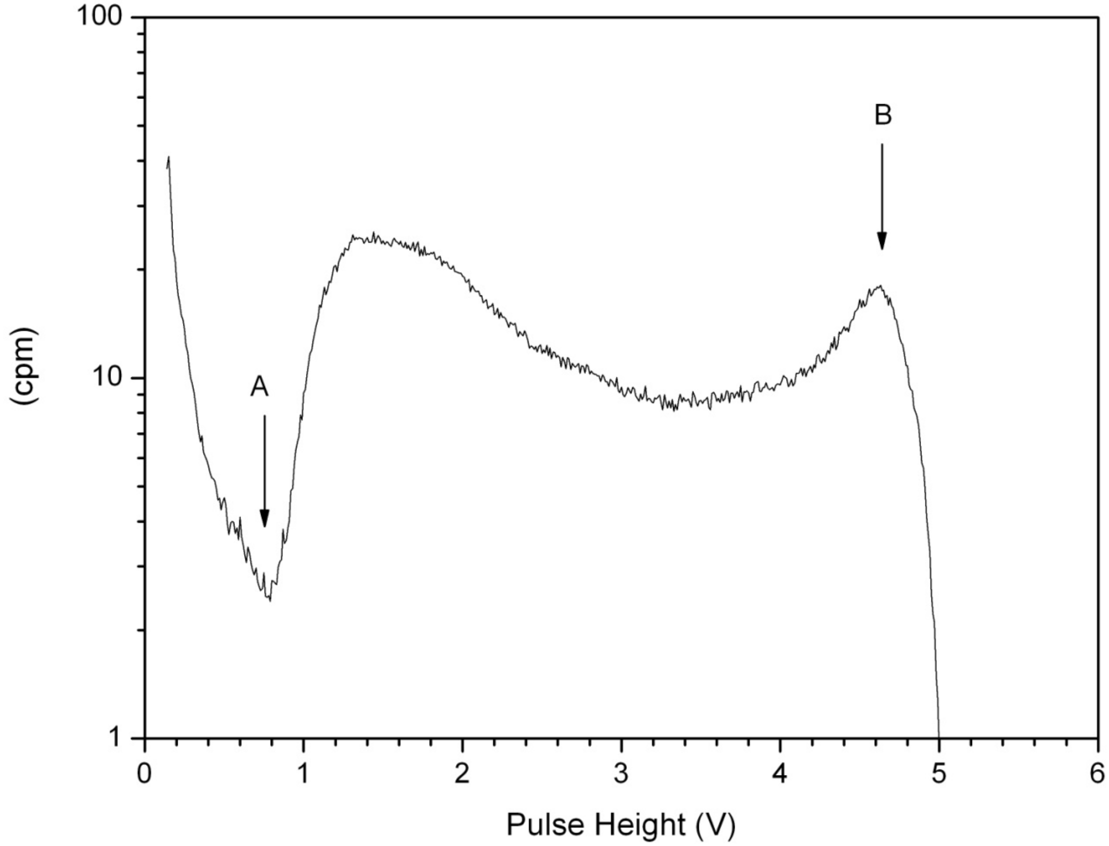
- Broad response functions
  - Calculated using Monte Carlo techniques (*e.g.* MCNP)

- Possible scenarios
  - Neutron escapes after one or more interactions
  - Neutron is thermalized but captured on H (H(n,γ)D)
  - Neutron is thermalized and enters counter

- Increasing PE sphere diameter :
  - Allows thermalization of increasingly higher energy neutrons
  - Decrease in detection efficiency for lower energy neutrons
  - 8”-10” diameter response approx. dose equivalent curve

Neutron Spectrometers : BSS

Typical BSS pulse height spectrum



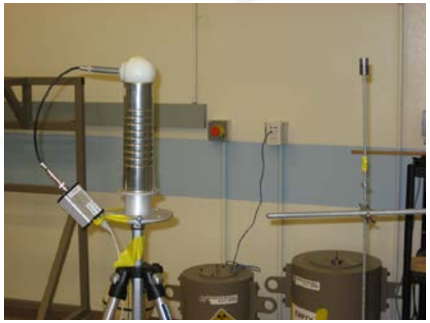
Uses pulse height to discriminate against gammas

Integrate count rate above “A” to get response of the sphere in the neutron field being measured.

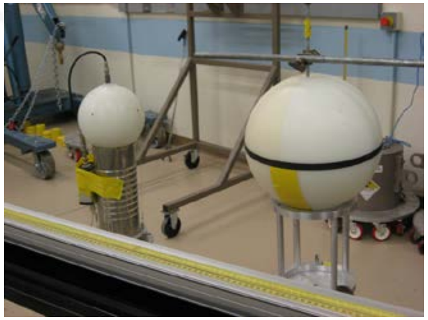
Neutron Spectrometers : BSS

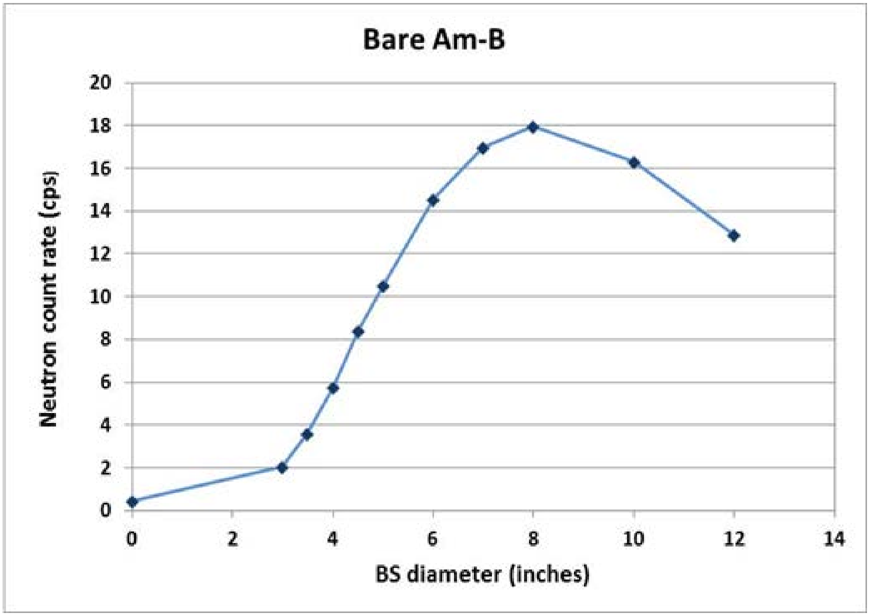
- Unfolding the BSS data is not straightforward due to the under determined nature of the measurements (i.e. fewer measurements than neutron energy bins)
- Therefore a unique solution is not possible
- However, a solution spectrum that is most consistent with an initial guess spectrum is possible
- A variety of unfolding codes have been developed over the years
- Notable new codes include MAXED and GRAVEL developed by PTB

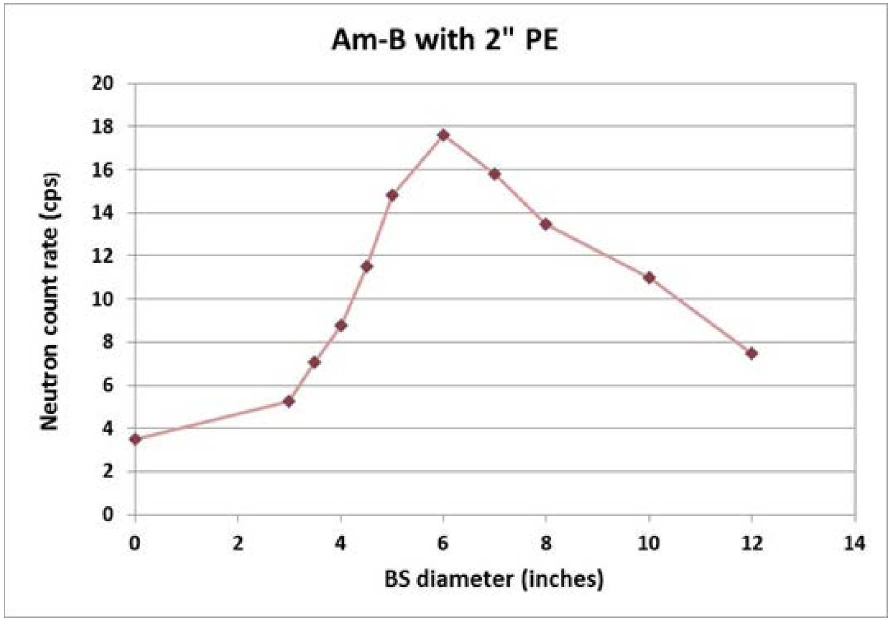
Neutron Spectrometers : BSS



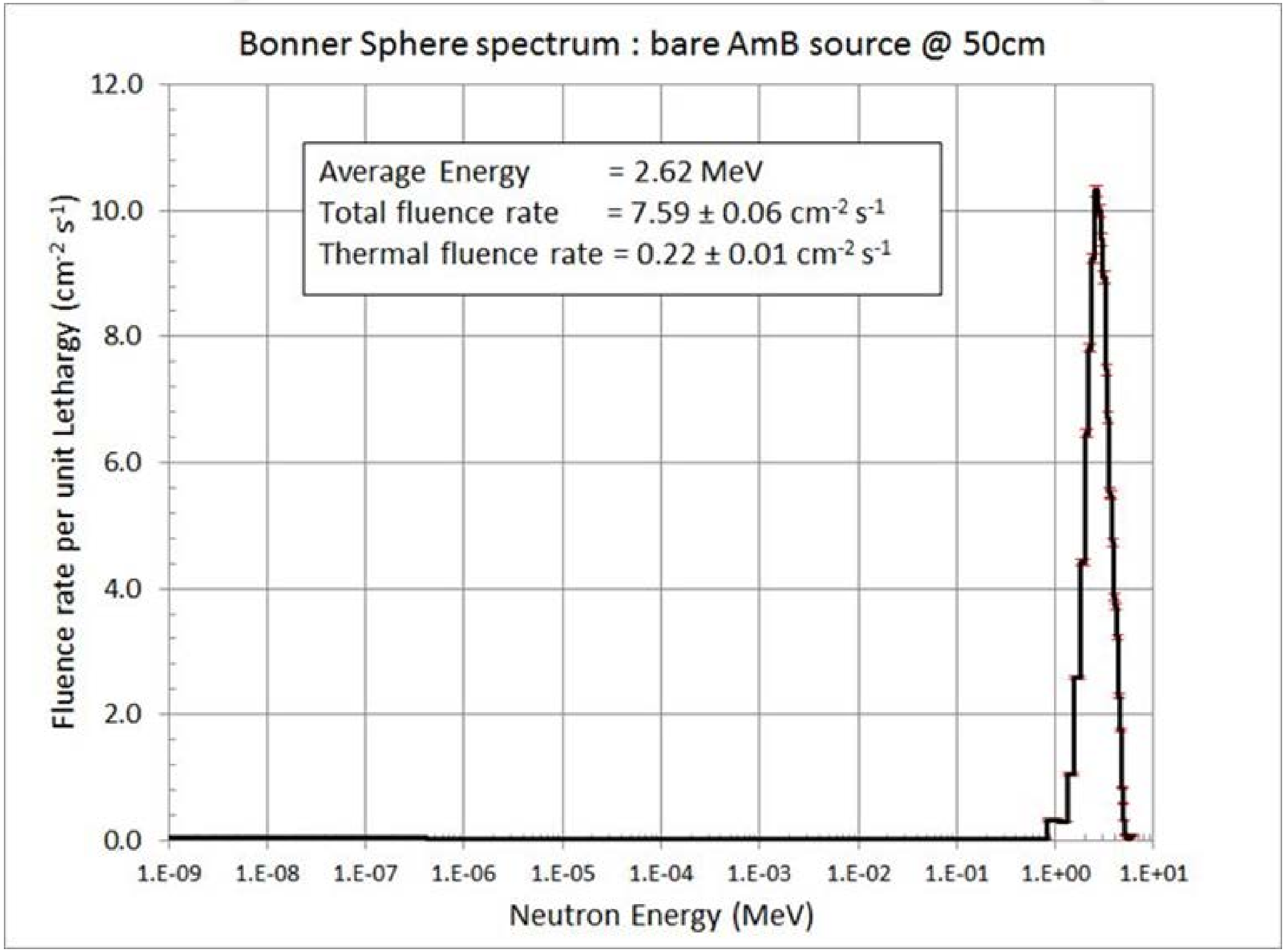
Count rate data





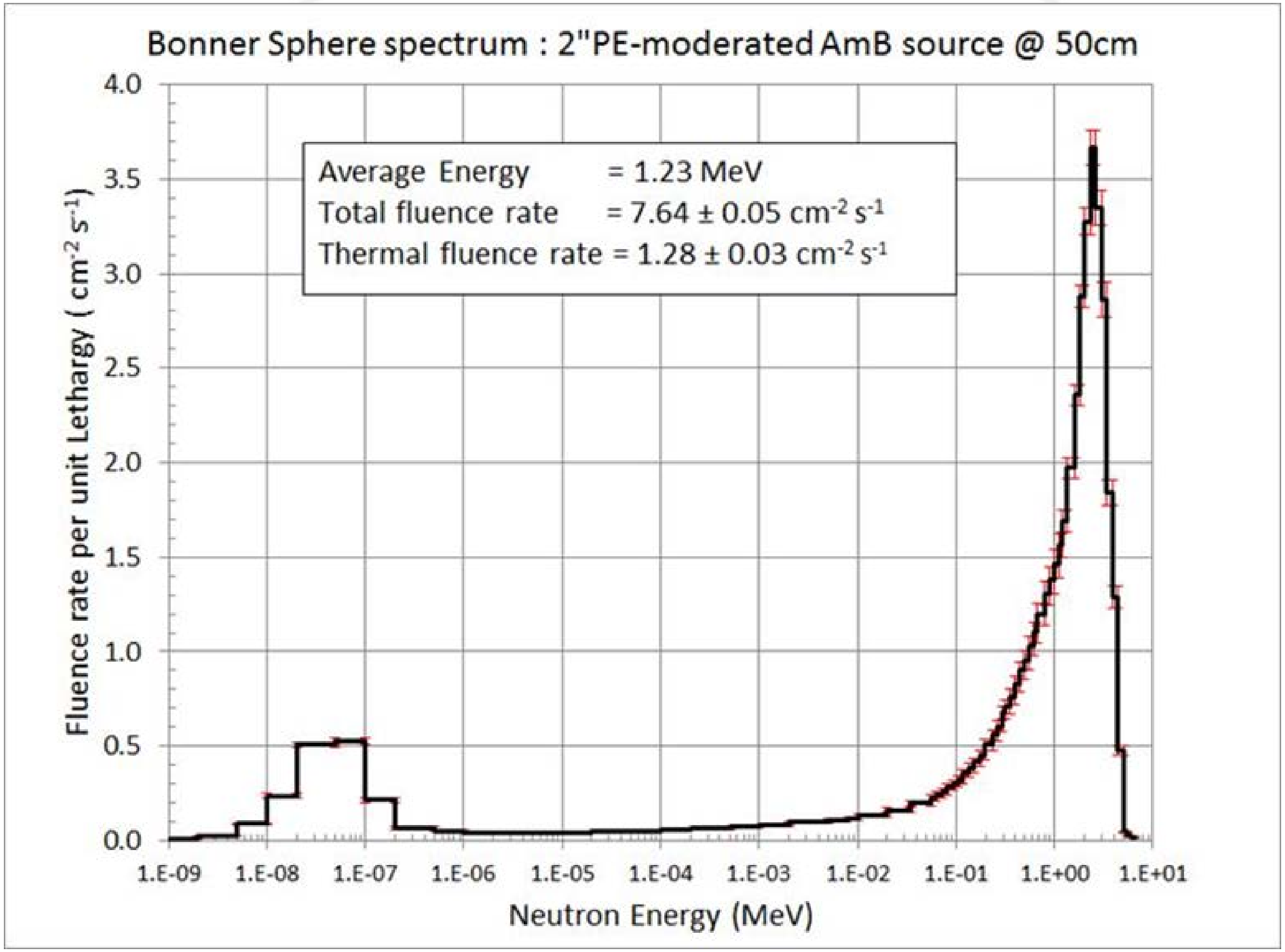


Neutron Spectrometers : BSS



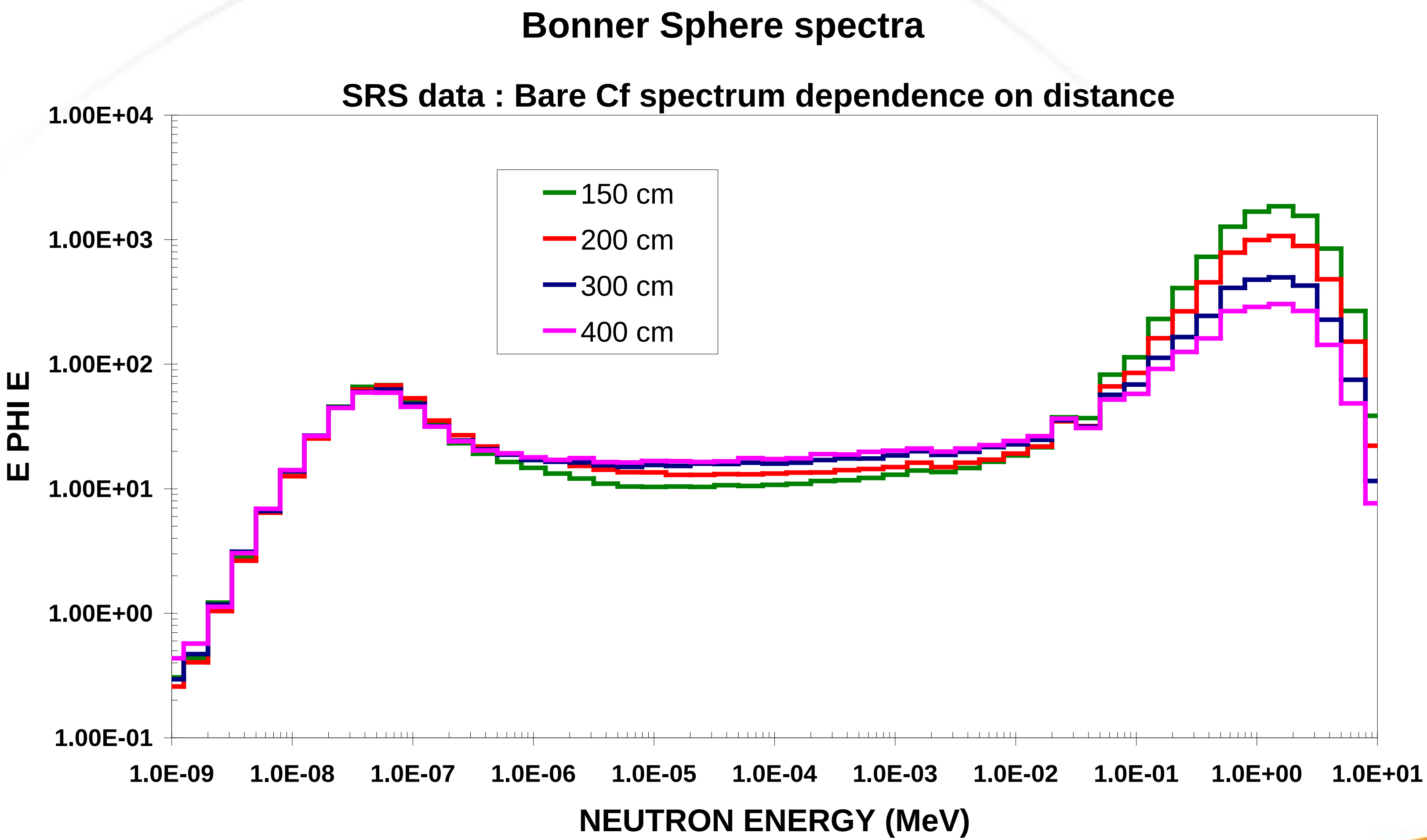
MAXED solution

Neutron Spectrometers : BSS



MAXED solution

Neutron Spectrometers : BSS



Neutron Spectrometers : ROSPEC

6 gas proportional counters on rotating platform

- 4 based on hydrogenous detector medium (proton recoil)
  - 3 2 inch diameter (different pressures)
  - 1 6 inch diameter
- 2 ^{3}He counters
  - 2 2 inch diameter
  - Bare for thermal neutrons
  - ^{10}B-shielded for epi-thermal detection

Neutron Spectrometers : ROSPEC

- Pulse height spectrum
  - 256 channels per counter
  - Each counter has limited dynamic range
    - Gamma contribution at low energies
    - Wall effects at higher energies

- Unfold (deconvolute)
  - Using Benjamin code (SPEC) 1970 vintage
  - Adequate for our purposes (improvements have been made)
  - Better codes available
  - Recoil proton response functions
    - Ideally rectangular but resolution and wall effects perturb

Neutron Spectrometers : ROSPEC

CTR#	CTR name	Diameter (inches)	Gas	Pressure (atm)	Range (MeV)
0	SP2-1[a]	2	H_2	0.75	0.05-0.25
1	SP2-4	2	H_2	4.0	0.15-0.70
2	SP2-10	2	H_2	10.0	0.40-1.50
3	SP6	6	P10	5.0	1.20-5.0
4		2	^3He	0.08	$<0.5x10^{-6}$
5		2	^3He	0.5	$0.5x10^{-6}$-$1x10^{-2}$

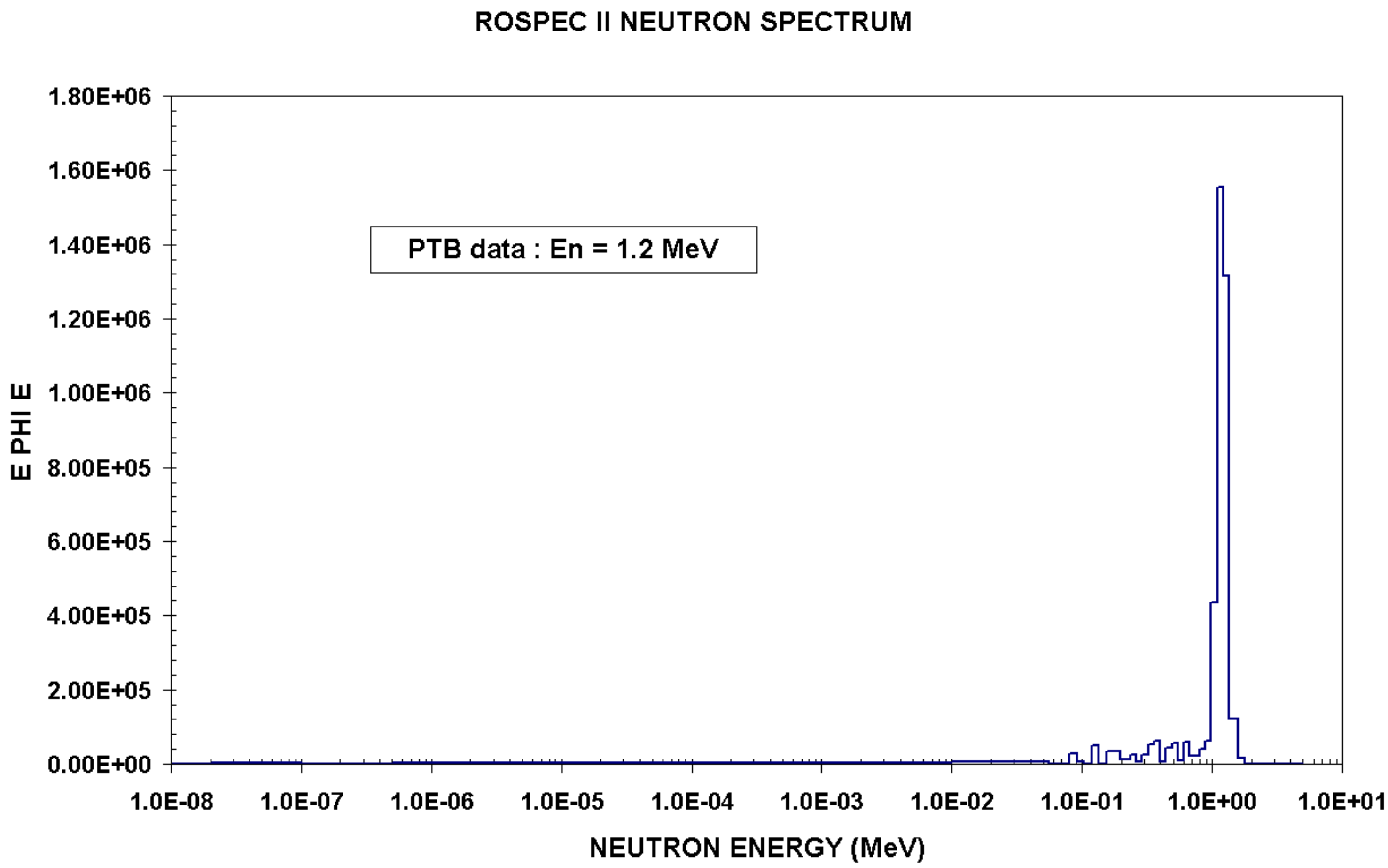
notes: a - **Sp**herical **2** inch **- 1** atmosphere b - 90% Ar + 10% CH_4

Neutron Spectrometers : ROSPEC

Monoenergetic neutron

E_n = 1.2 MeV

Neutron Spectrometers : ROSPEC



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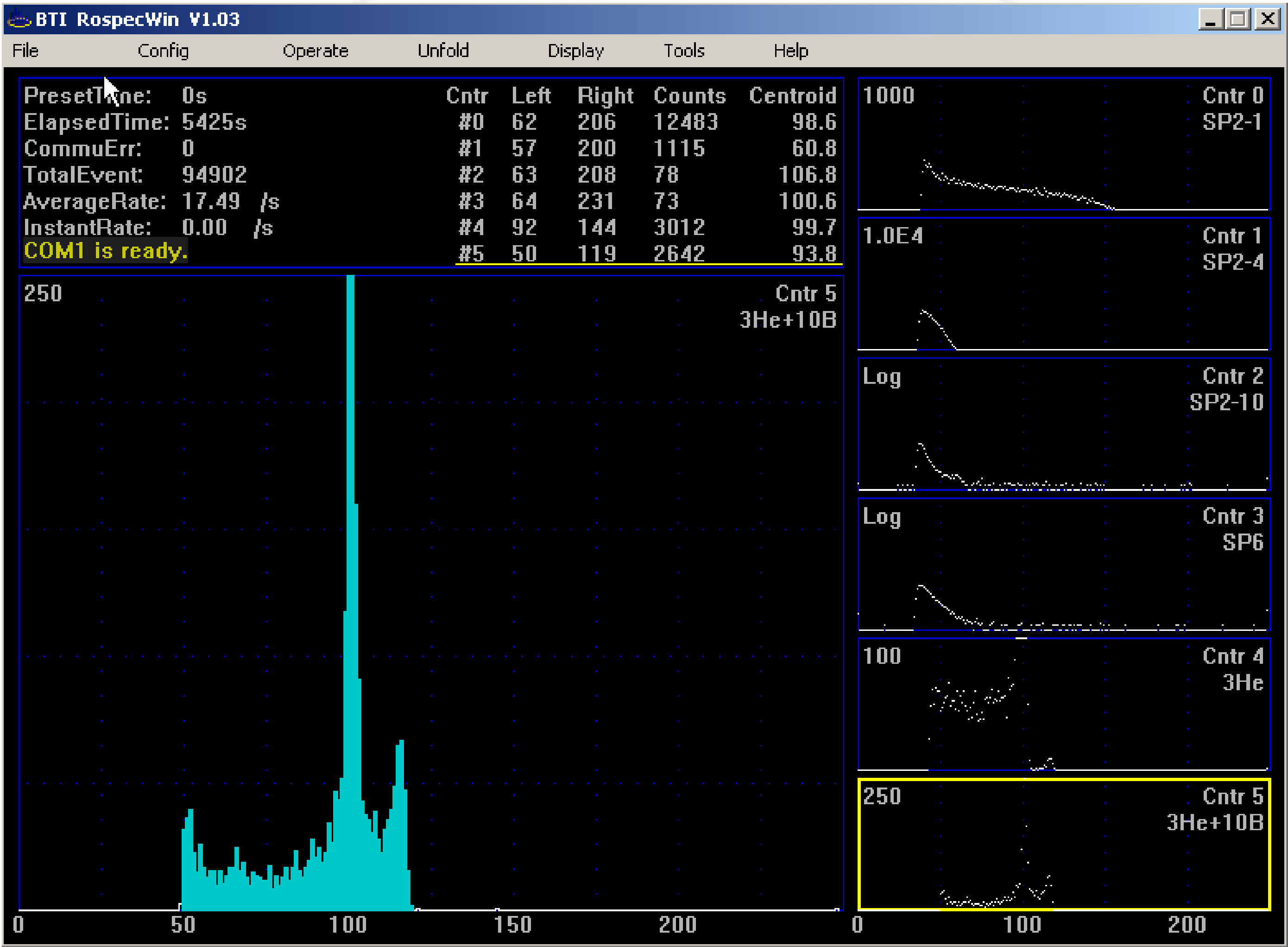
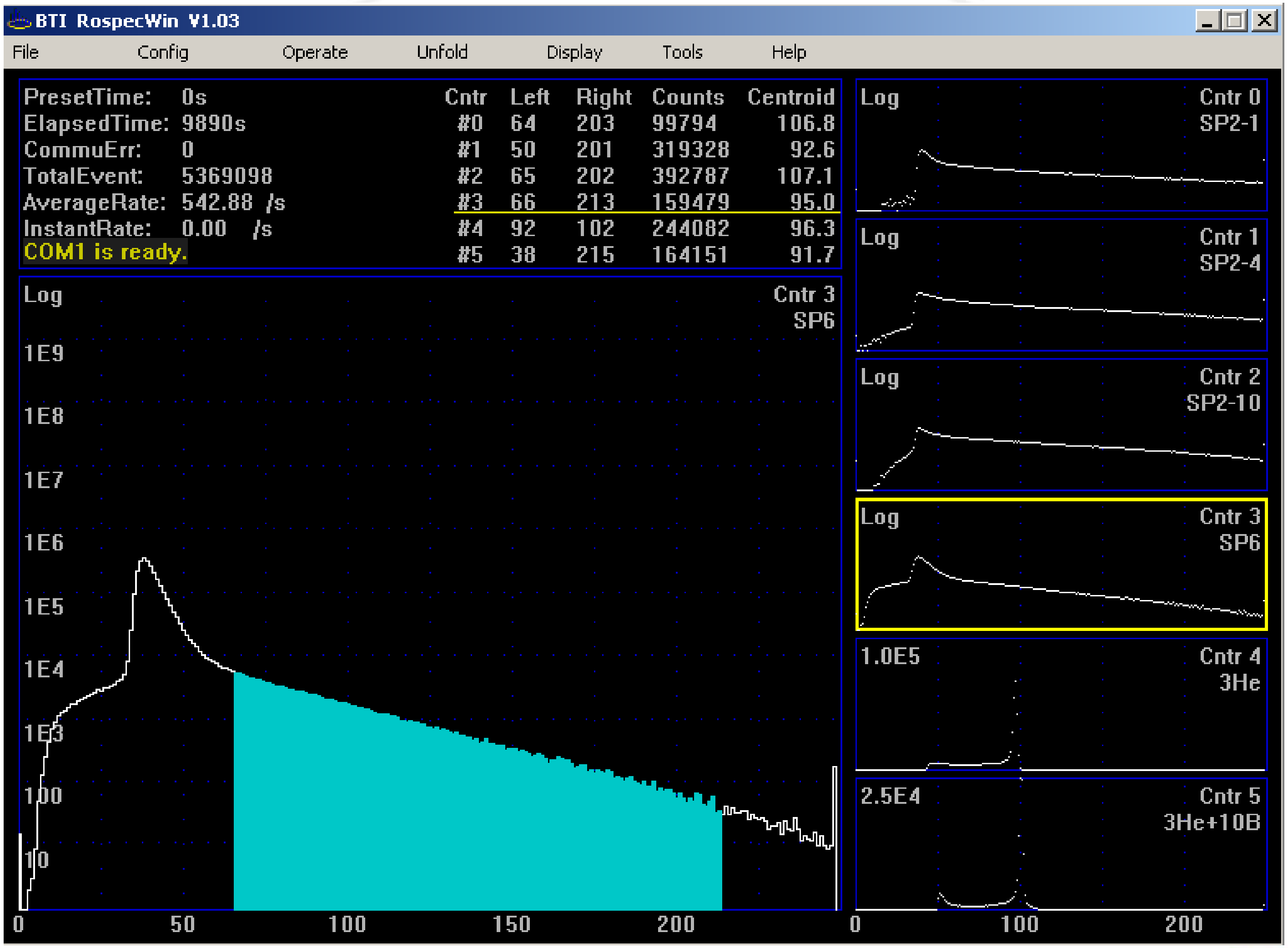


Monoenergetic neutron

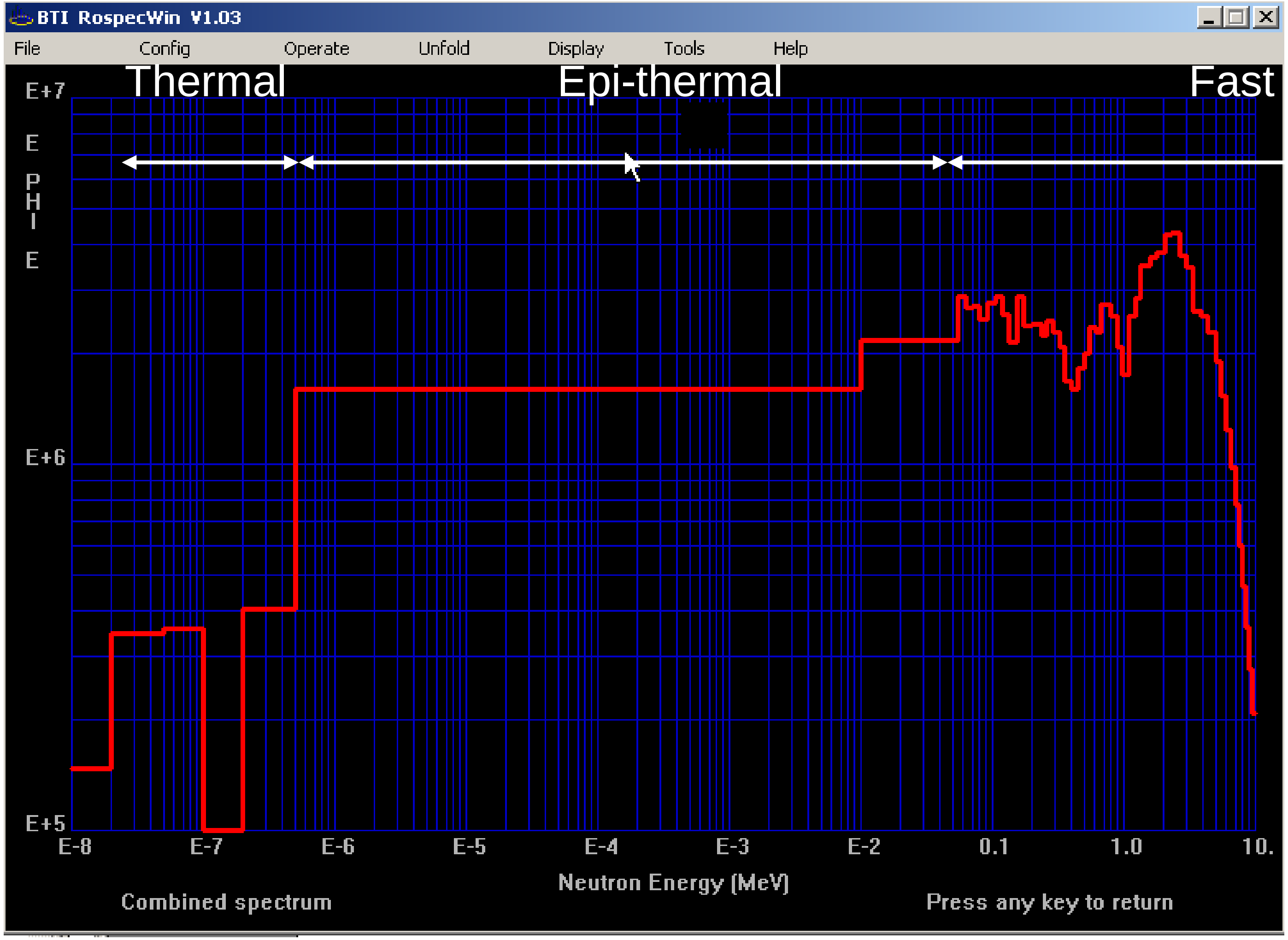
E_n = 146 keV

Neutron Spectrometers : ROSPEC



D_2O-Cf

Neutron Spectrometers : ROSPEC



D_2O-Cf

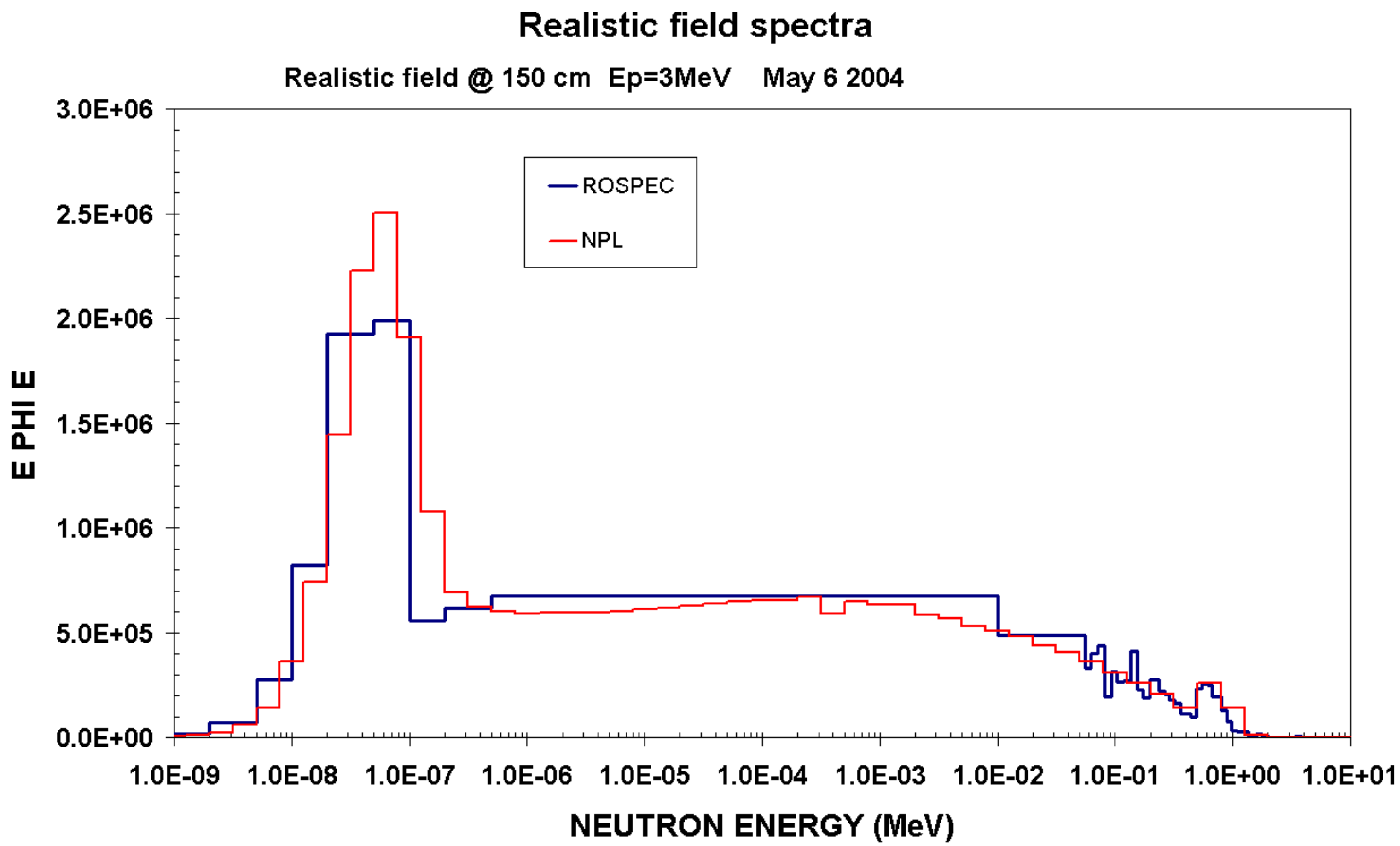
Neutron Spectrometers : ROSPEC

- Not necessary to get “publication” quality spectrum to determine dose accurately

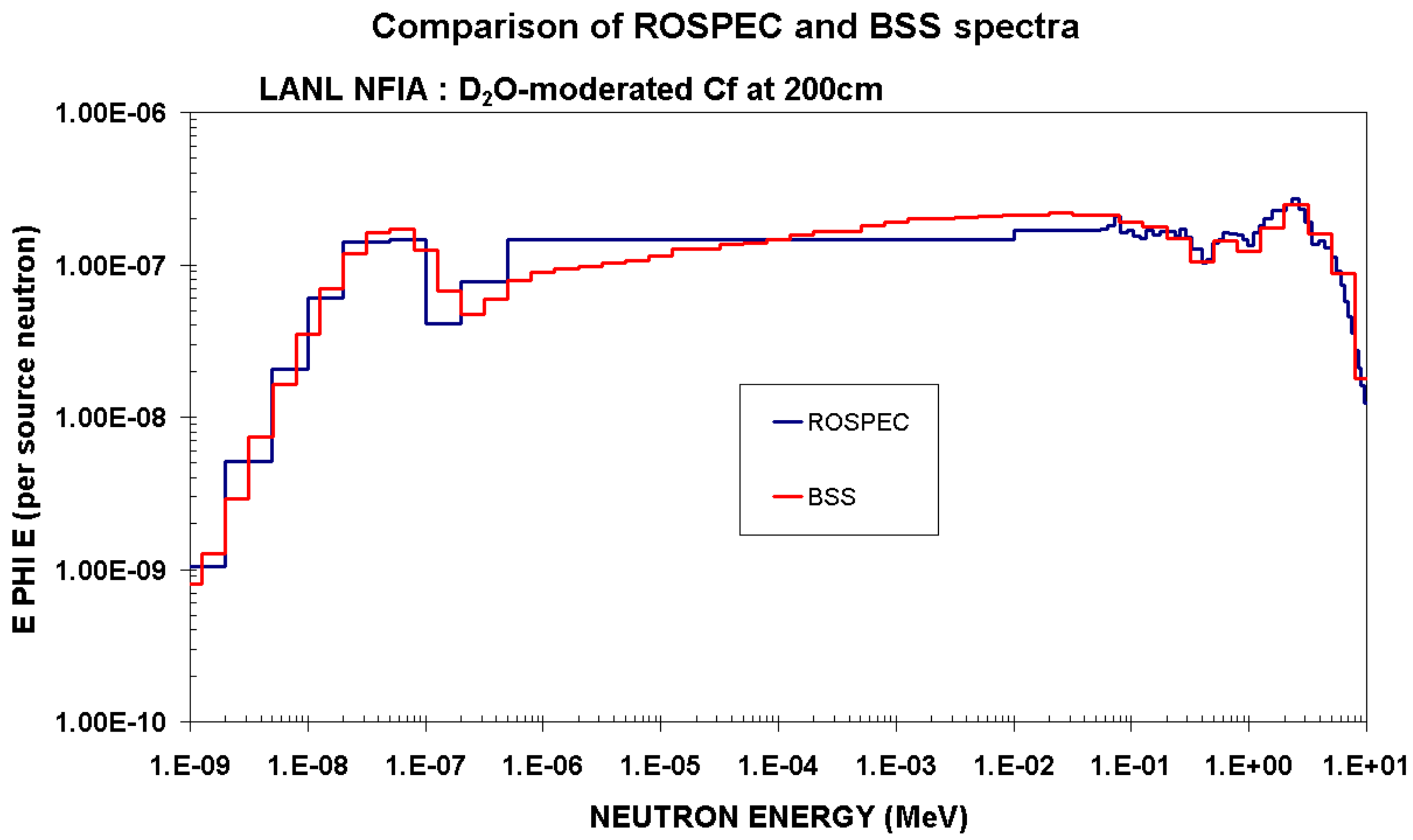
- Because :
  – Even unsophisticated unfolding codes conserve fluence

  – Dose curves also insensitive to fluence distribution above 1MeV

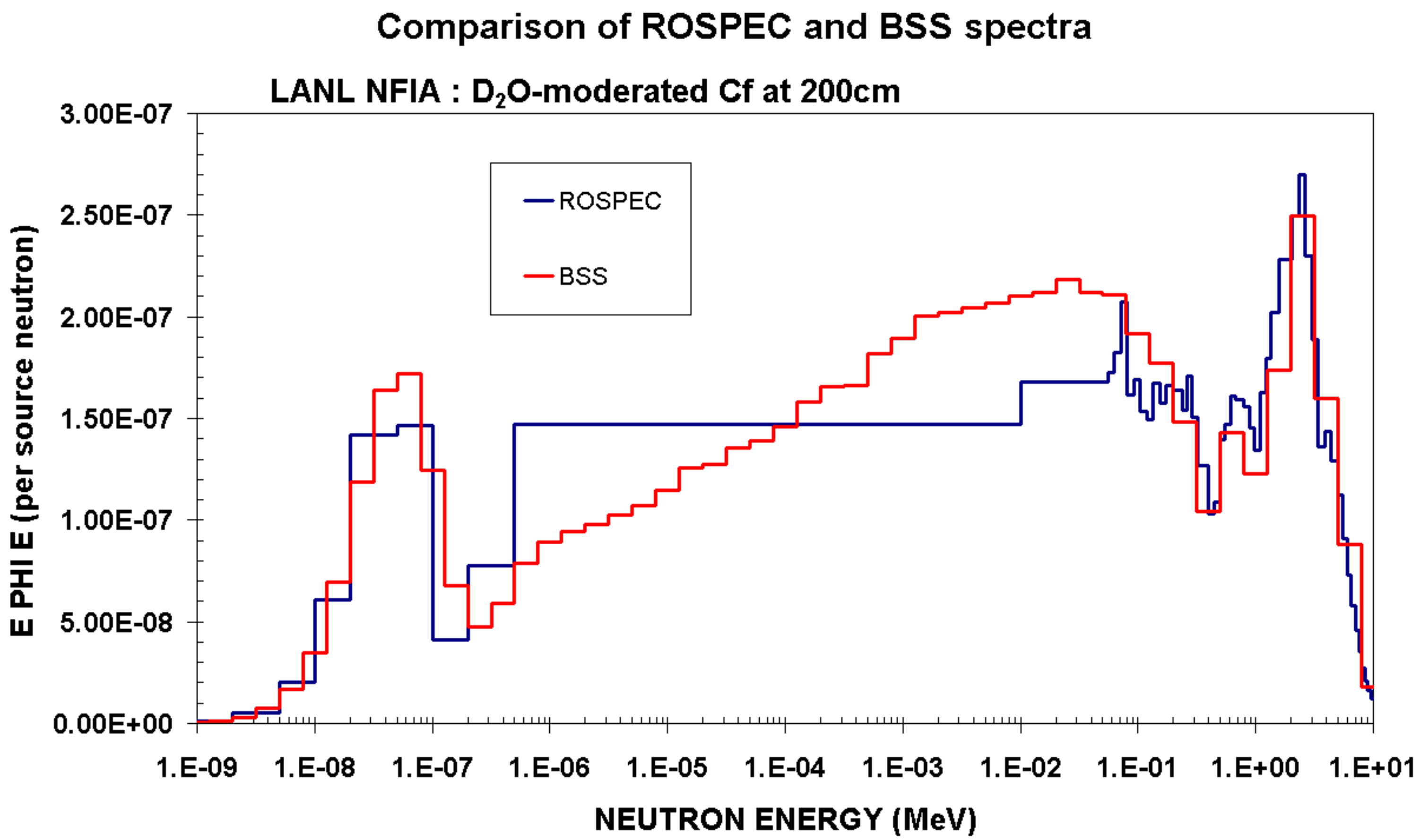
Neutron Spectrometers : ROSPEC



Neutron Spectrometers : BSS vs ROSPEC



Neutron Spectrometers : BSS vs ROSPEC



Neutron Spectrometers : N-Probe

-Manufactured by BTI

-Detectors :

1”x1” NE213 (E>800 keV)

^{3}He (boron covered)

-Portable (incl. analyzer unit)

-Active (n,γ) discrimination (>1000:1 at low rates)

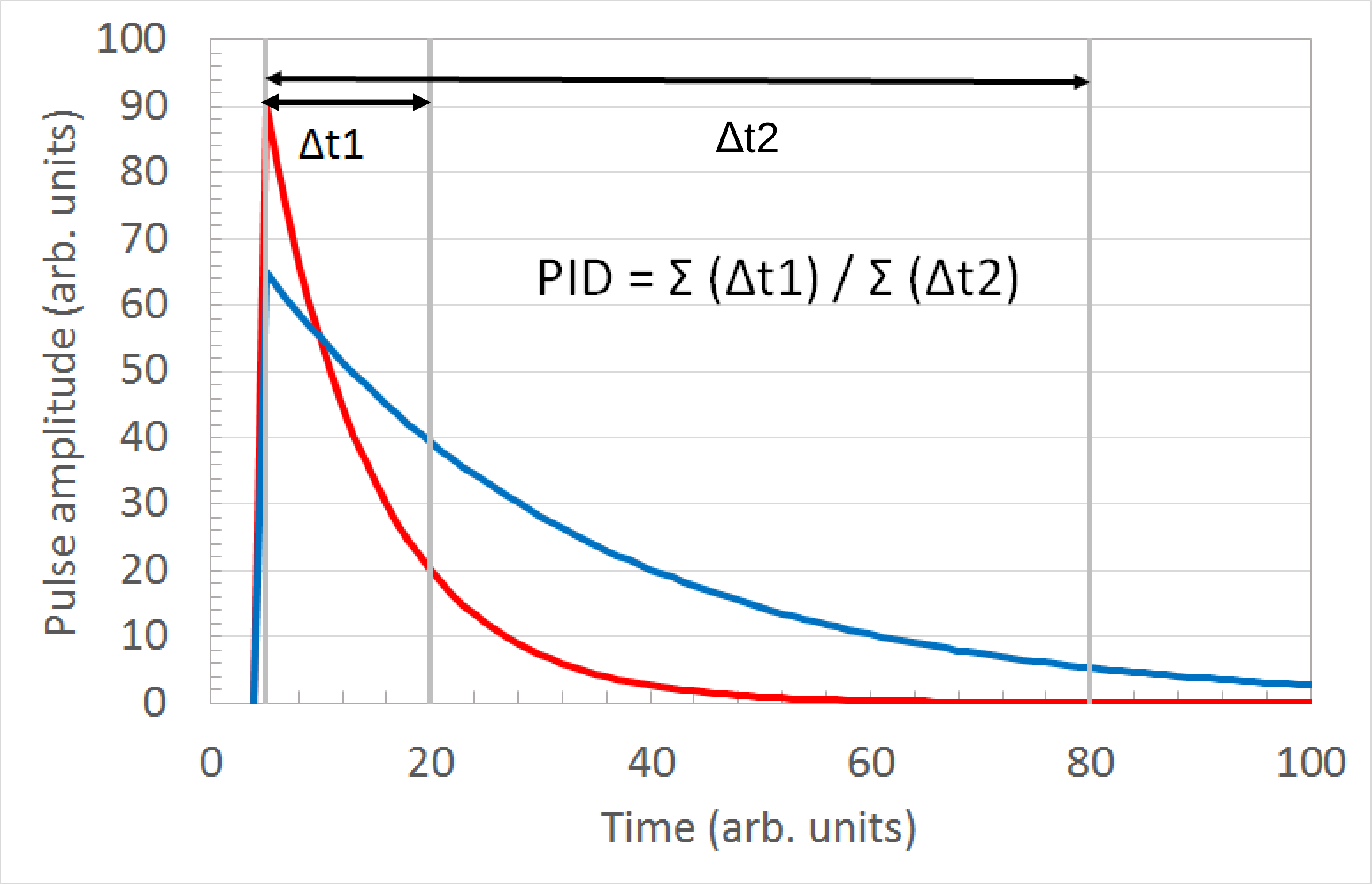
-Real time dose data

-Crude (but adequate) spectroscopy

Neutron Spectrometers : N-Probe

- NE213 (aka BC501A)
  - Xylene-based liquid scintillator
    - Proton recoil and reactions on Carbon
  - Two principal decay times
    - 30ns & 300ns
    - Slow component fraction is proportional to particle dE/dx
    - Excellent PSD properties
  - Non-linear light output
    - dE/dX dependent saturation effect
  - Limited lifetime due to O_2 quenching

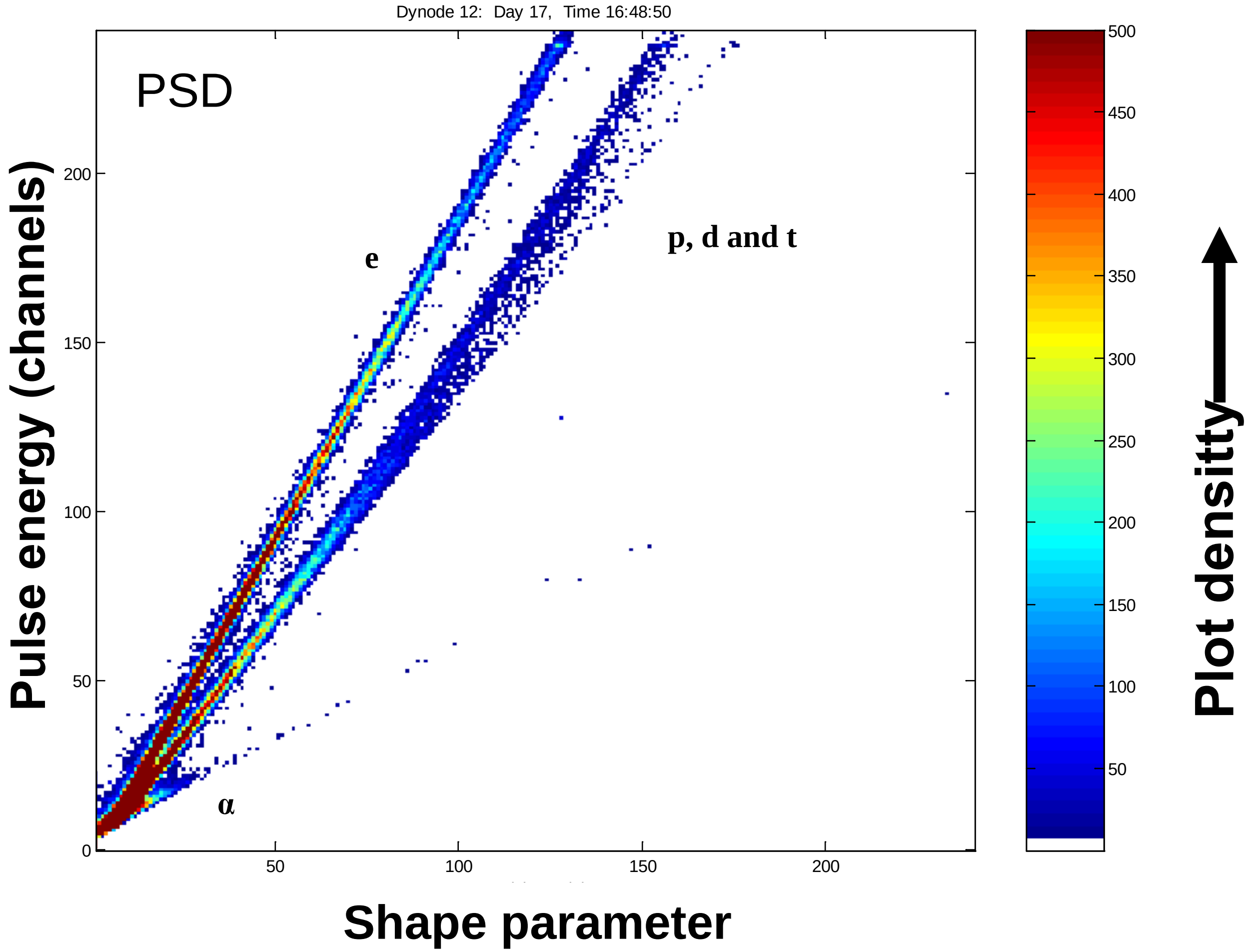
Neutron Spectrometers : N-Probe



Neutron Spectrometers : N-Probe

Pulse shape discrimination

En=19.6 MeV



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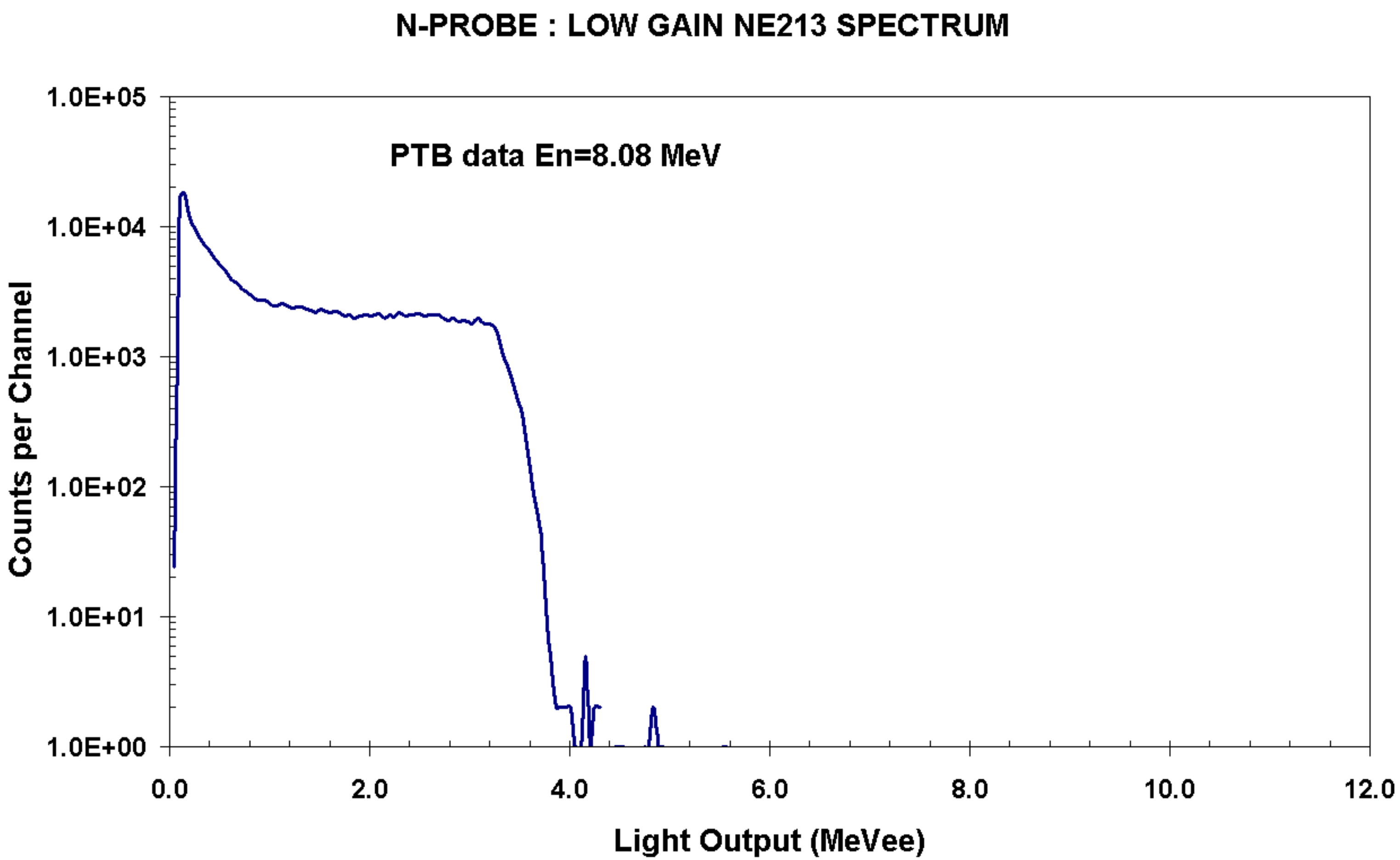
Neutron Spectrometers : N-Probe



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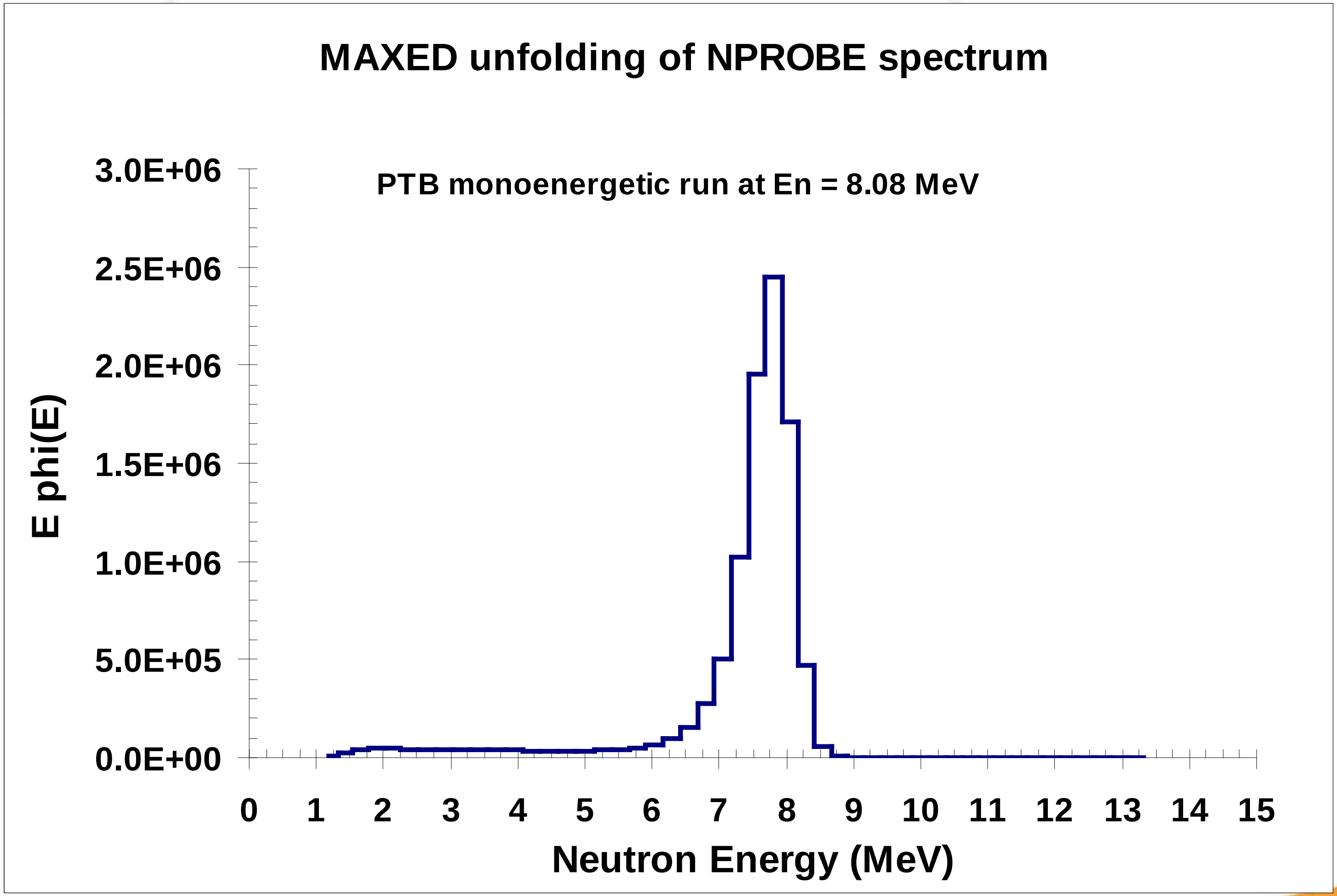

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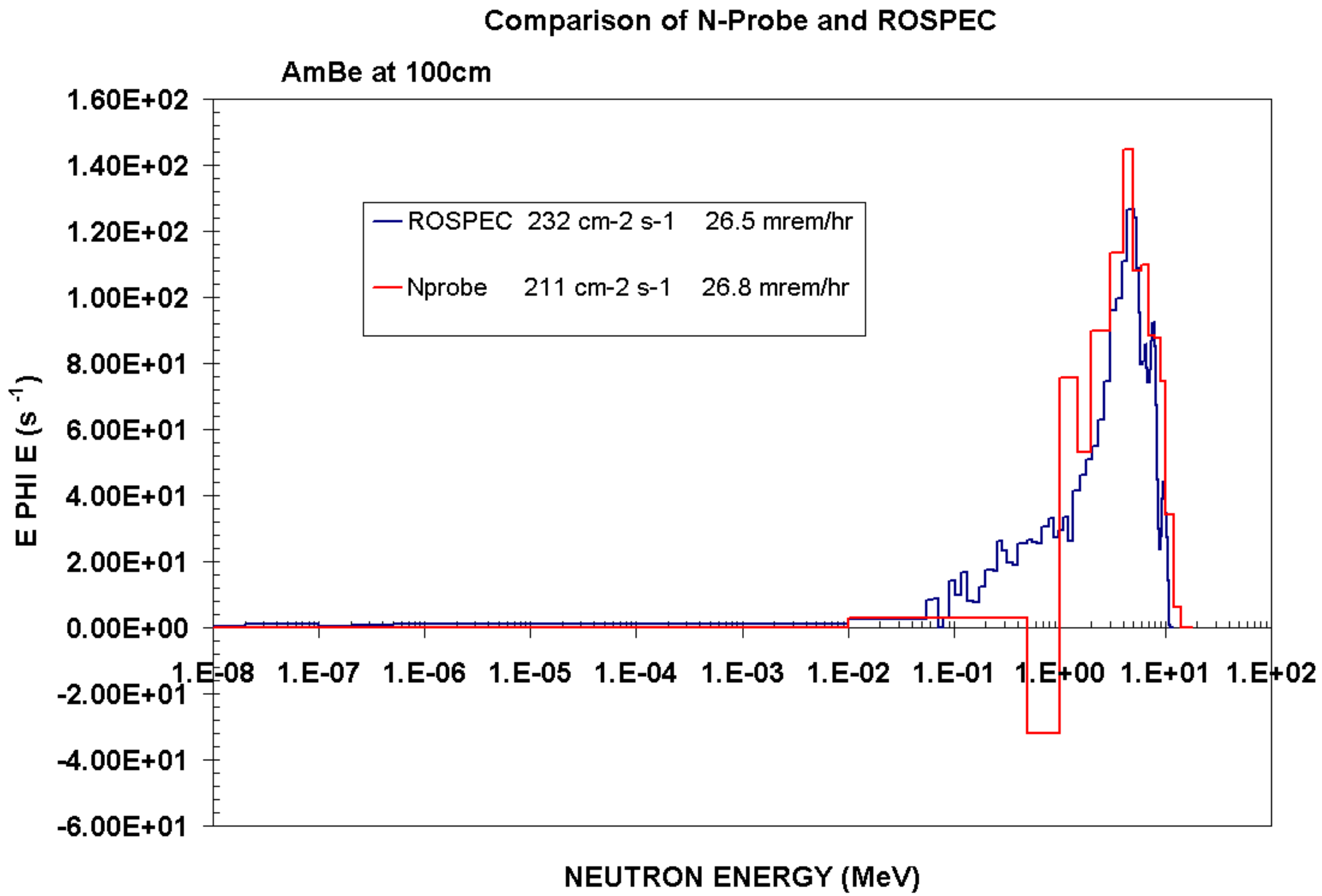
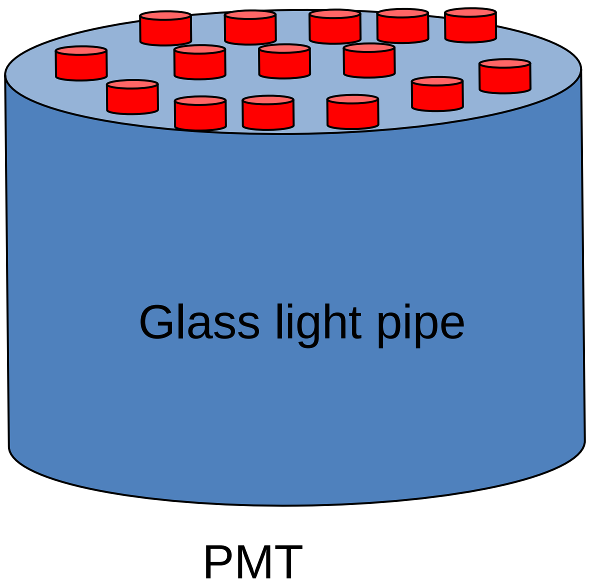


Neutron Spectrometers : SSS



-Manufactured by BTI

-Detector :

16 3x3mm plastic scintillators

(recoil protons produced)

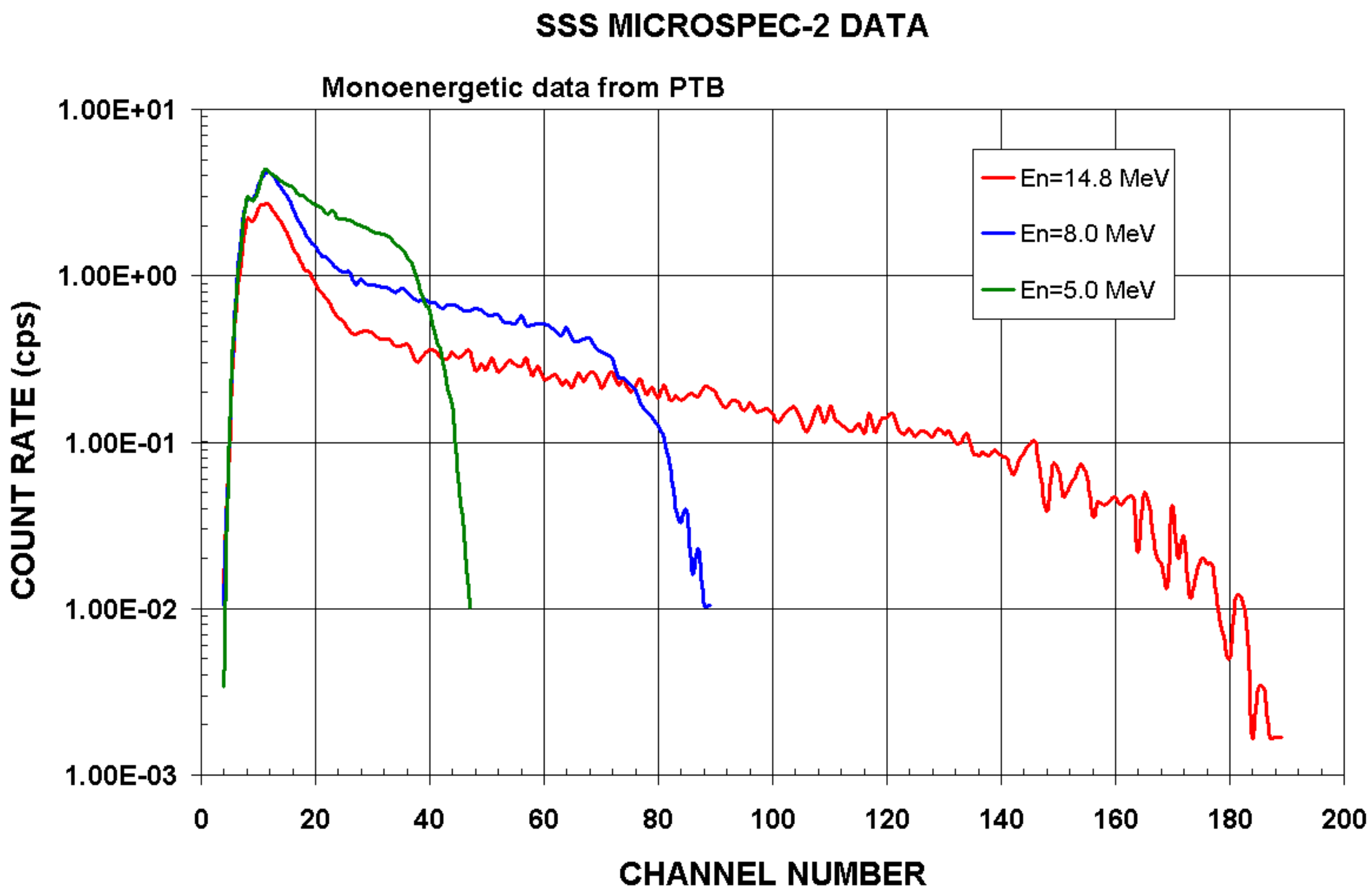
-Portable (incl. analyzer)

-High-energy extension to ROSPEC

-Passive n,γ discrimination

-Low efficiency

Neutron Spectrometers : SSS



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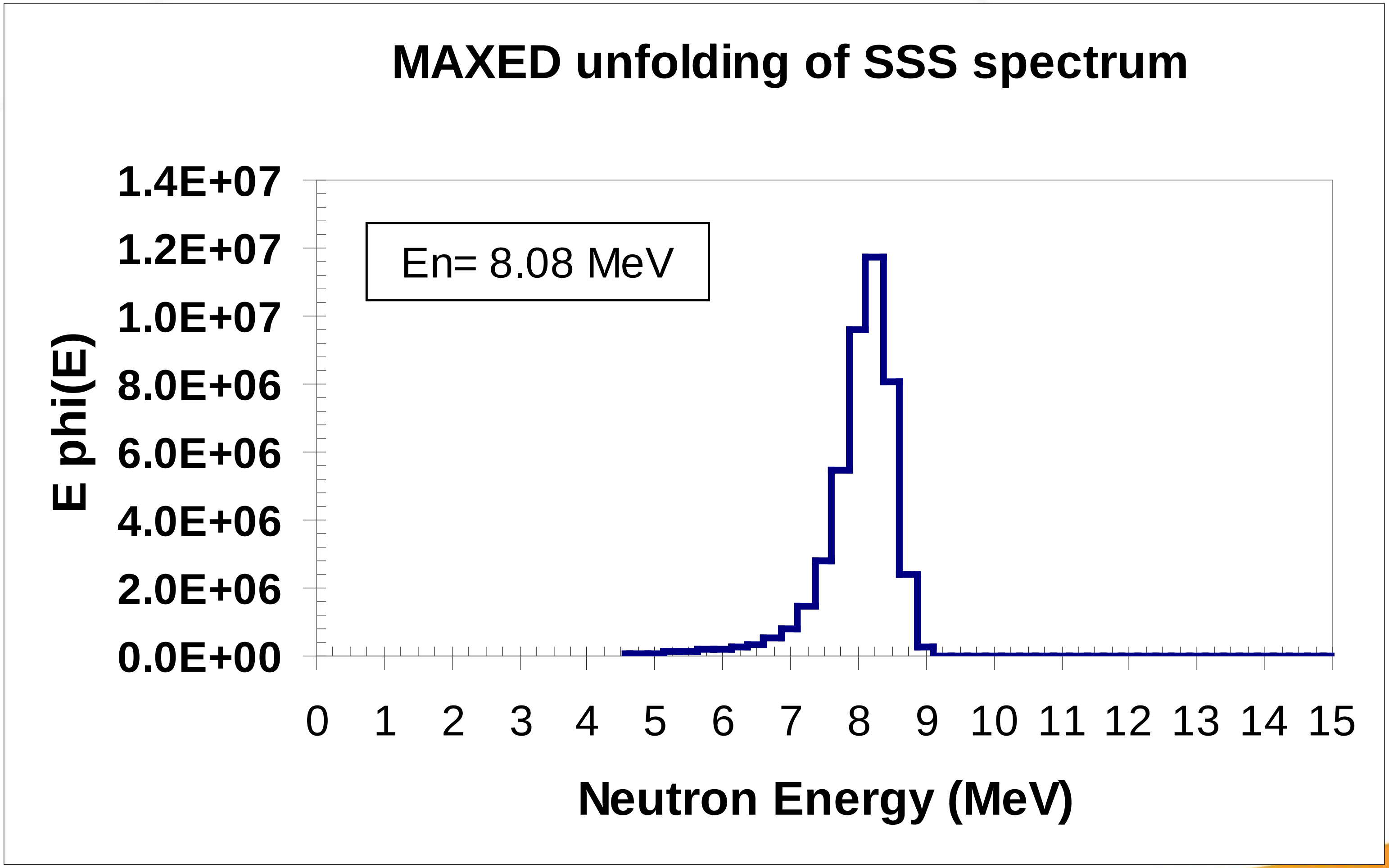

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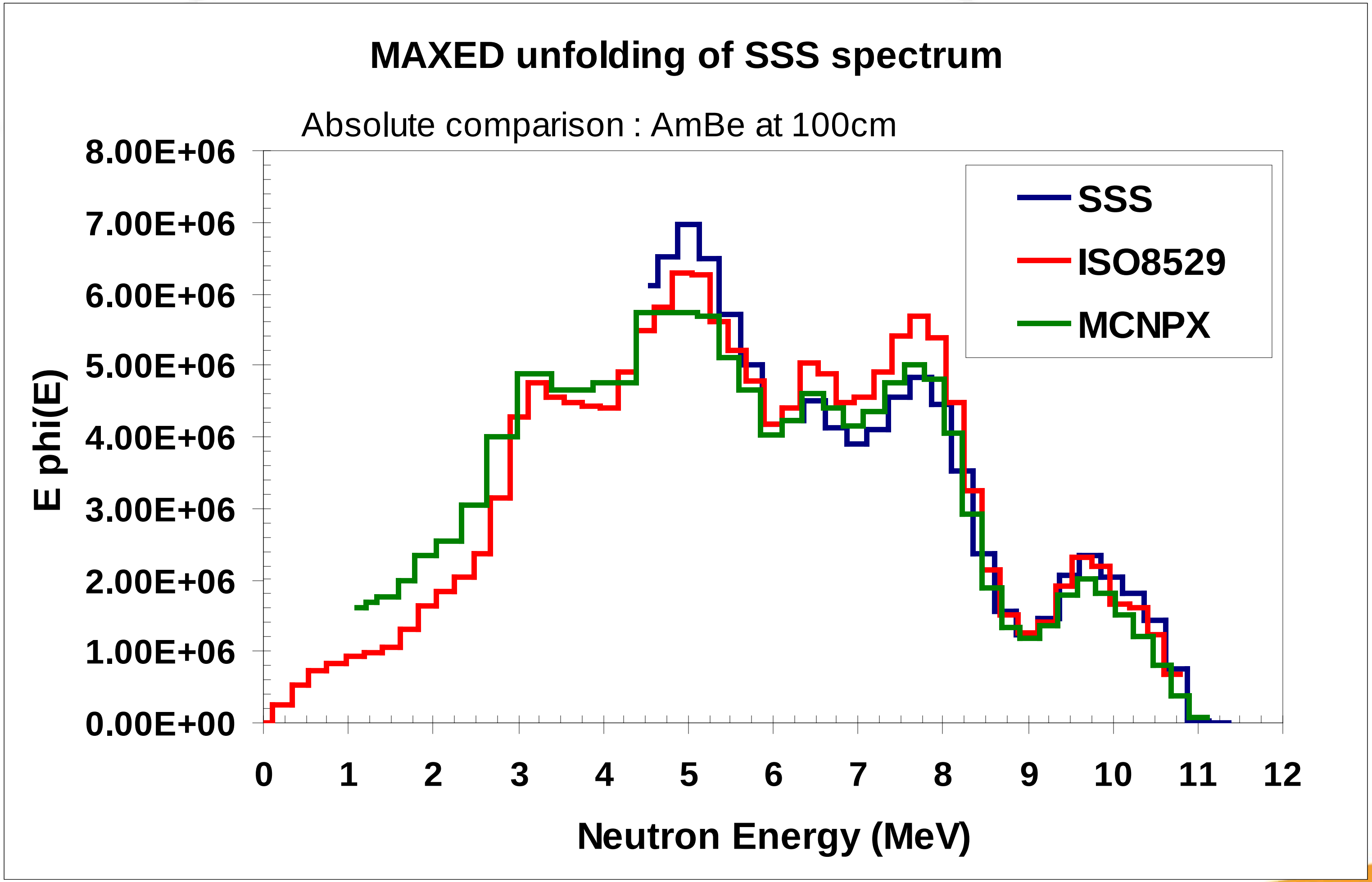

Summary of spectrometer properties

Instrument	Detectors	Energy range (MeV)	Max. dose rate (mrem/hr) for bare Cf	Comments
ROSPEC	Gas proportional + $^{3}He(n,p)$	Thermal – 5 MeV	200	Pulse height n,γ discrimination
Bonner spheres	$^{3}He(n,p)$	Thermal – 30 MeV	1000	Pulse height n,γ discrimination
N-Probe	Liquid scintillator + $^{3}He(n,p)$	Thermal – 20 MeV	100	Pulse shape n,γ discrimination. Real-time dose
SSS	Plastic scintillator	5 - 15 MeV	>1000	Pulse height n,γ discrimination

Other methods of interest

- $Cs_2LiYCl_6:Ce$ (CLYC) scintillator
  - Gamma spectroscopy (high resolution)
  - Thermal neutron detection
  - Fast neutron detection

- LLNL-developed scintillators commercialized by Eljen Technology
  - Excellent n/gamma discrimination
    - Better than NE213

- Time of flight techniques
  - Take advantage of relatively slow neutron velocities