Nuclear Spectrometry Users' Forum
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Neutron Spectrometry

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Introduction

- **Why do neutron spectra need to be measured?**
- **Why is it difficult? C.f photon spectrometry**
- **How neutron spectrometry is done**

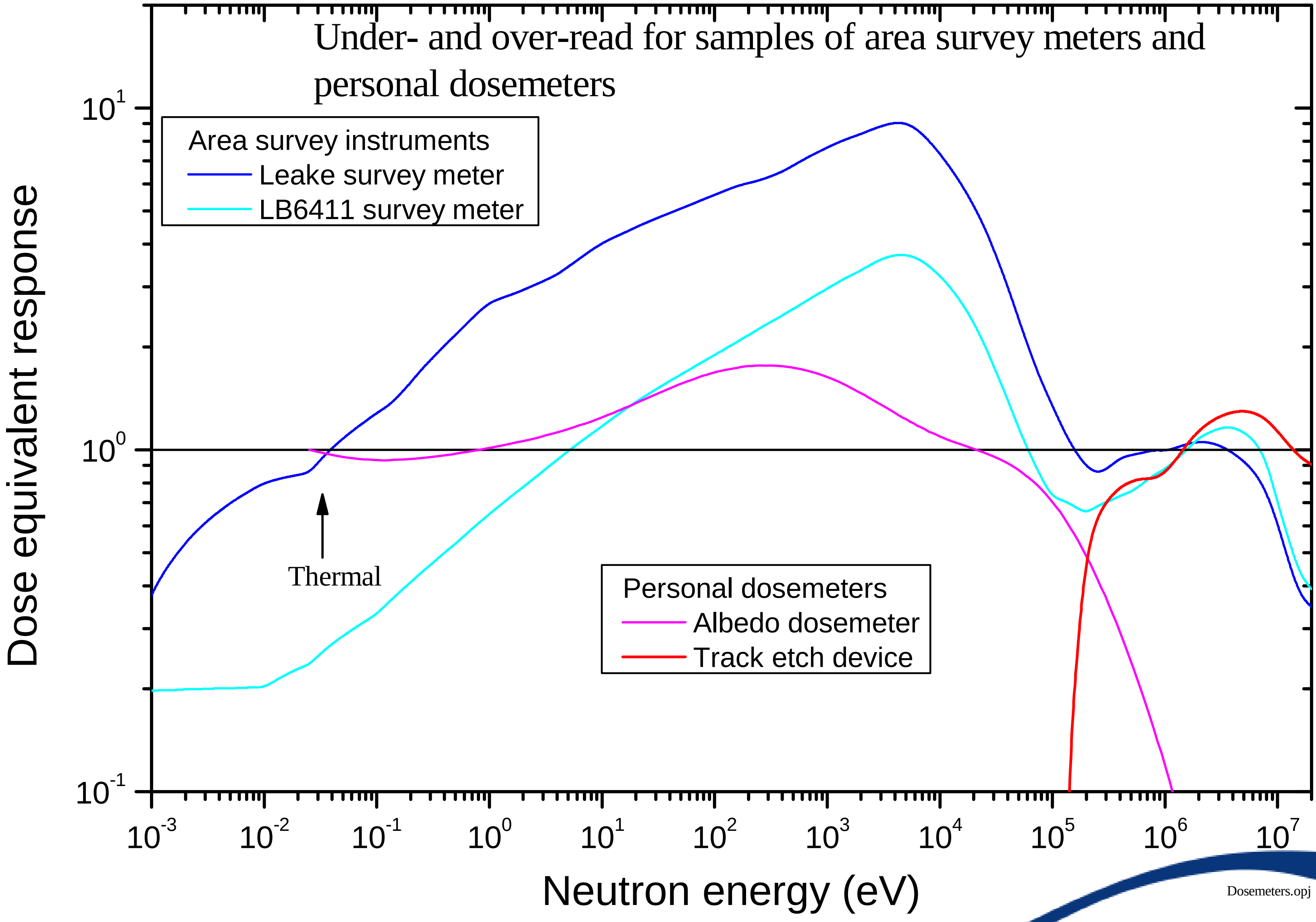
Reasons for making neutron spectrum measurements

- **Photon spectrometry is performed for: radioisotope identification (including absolute measurements), activation analysis, nuclear physics, PIXE, PIGE, etc.**

- **In general neutron spectrometry is performed for different reasons**

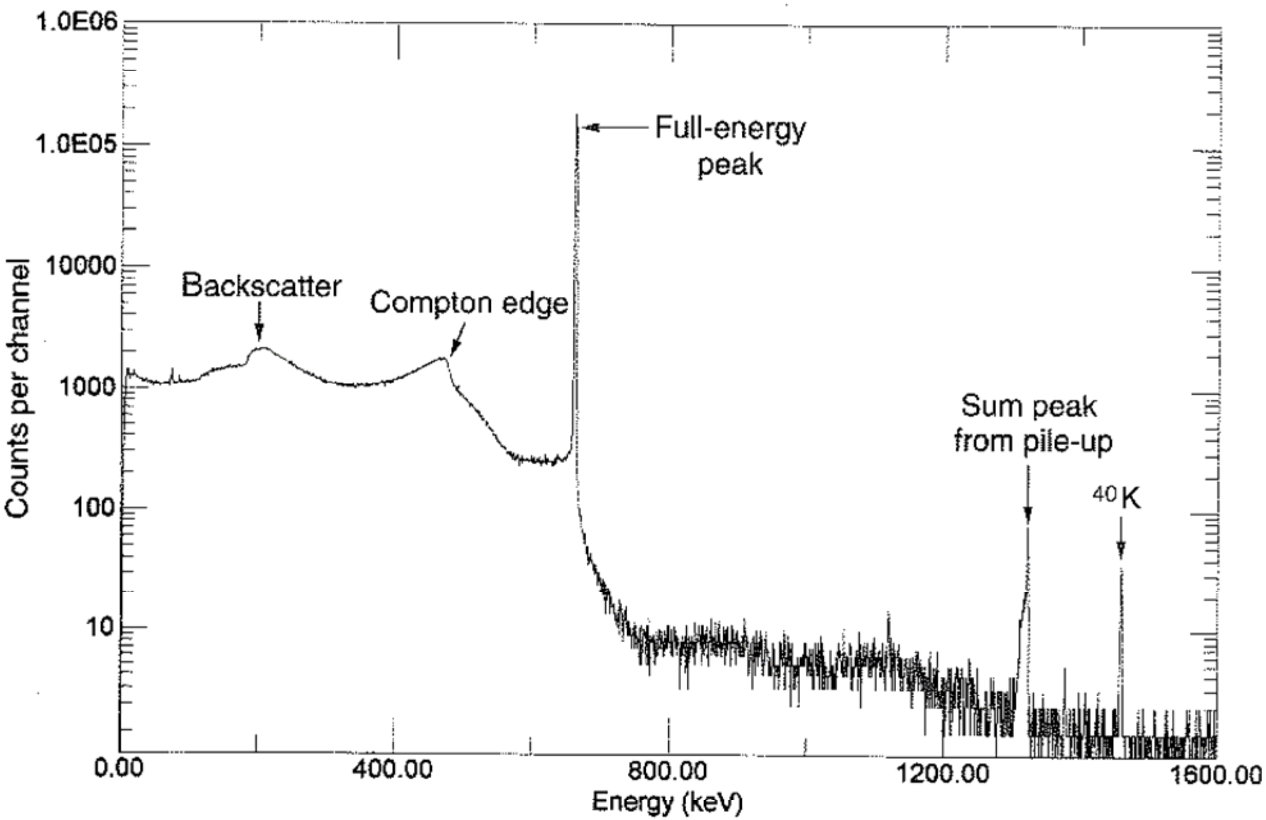
- **Neutron spectrometry measurements may be made, for example, to validate shielding calculations, for nuclear physics experiments, or to characterise calibration fields, but much of the development of neutron spectrometry has been to enable measurements of neutron spectra for radiation protection**

Rationale for neutron spectrometry



Why is neutron spectrometry difficult?
C.f. photon spectrometry

Neither photons or neutrons are directly ionising. To detect them they need to be converted to directly ionising particles



Photons interact primarily with electrons -

importance of photoelectric effect -

electron acquires all the energy of the gamma ray

Neutron spectrometry

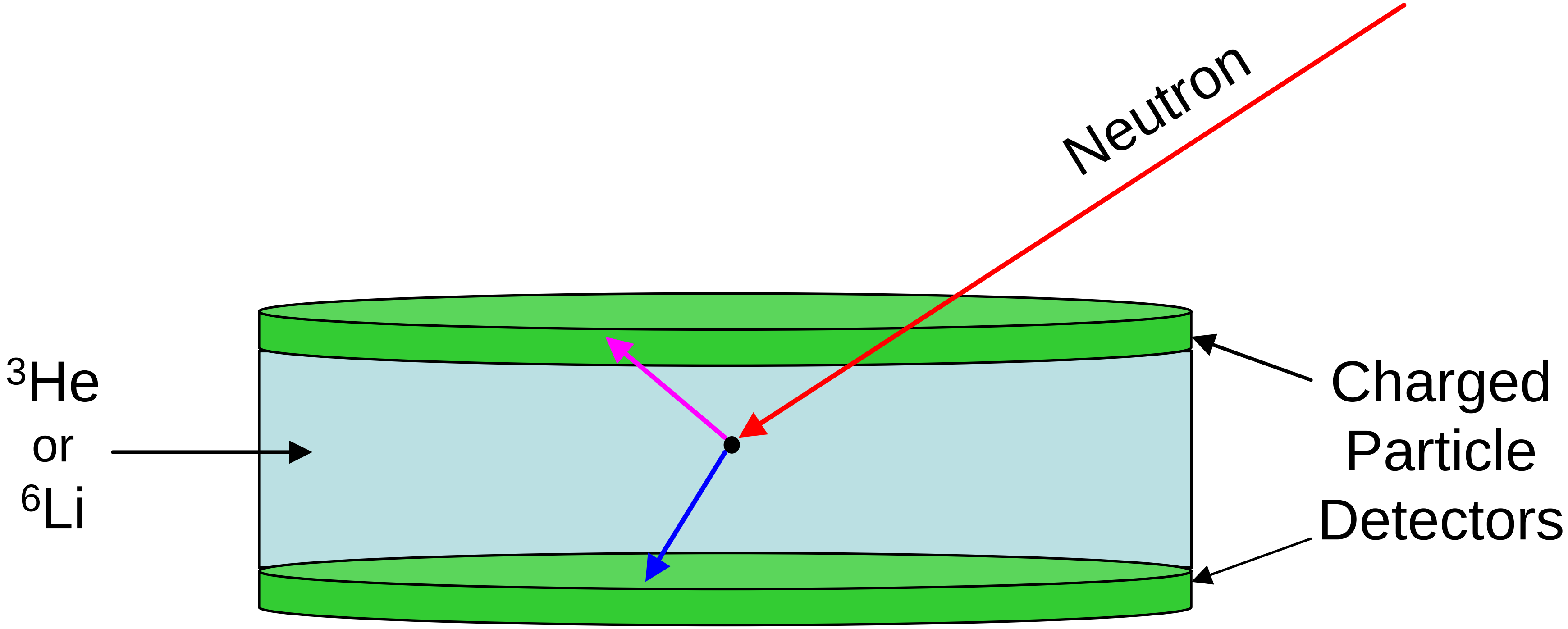
- There is no real equivalent of the photoelectric effect for neutrons

- At low energies some reactions with low-Z nuclei can be used to transfer the neutron energy to charged particles: e.g.

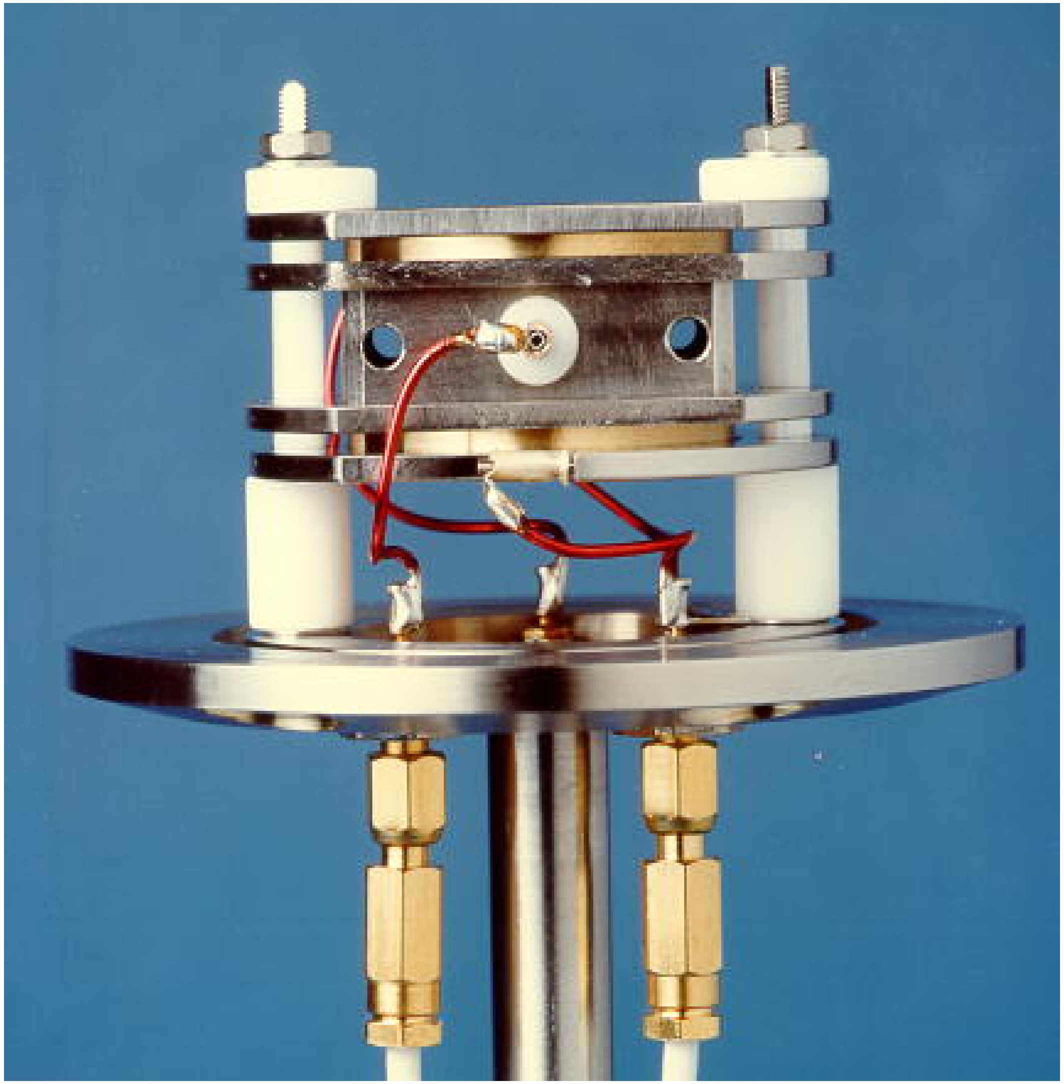
Reaction	Q value
^{3}He(n,p)T	764 keV
^{6}Li(n,α)T	4.78 MeV
^{10}B(n,α) ^{7}Li	2.79 MeV

- Note: both products are charged and can be detected

^3He or ^6Li sandwich spectrometer

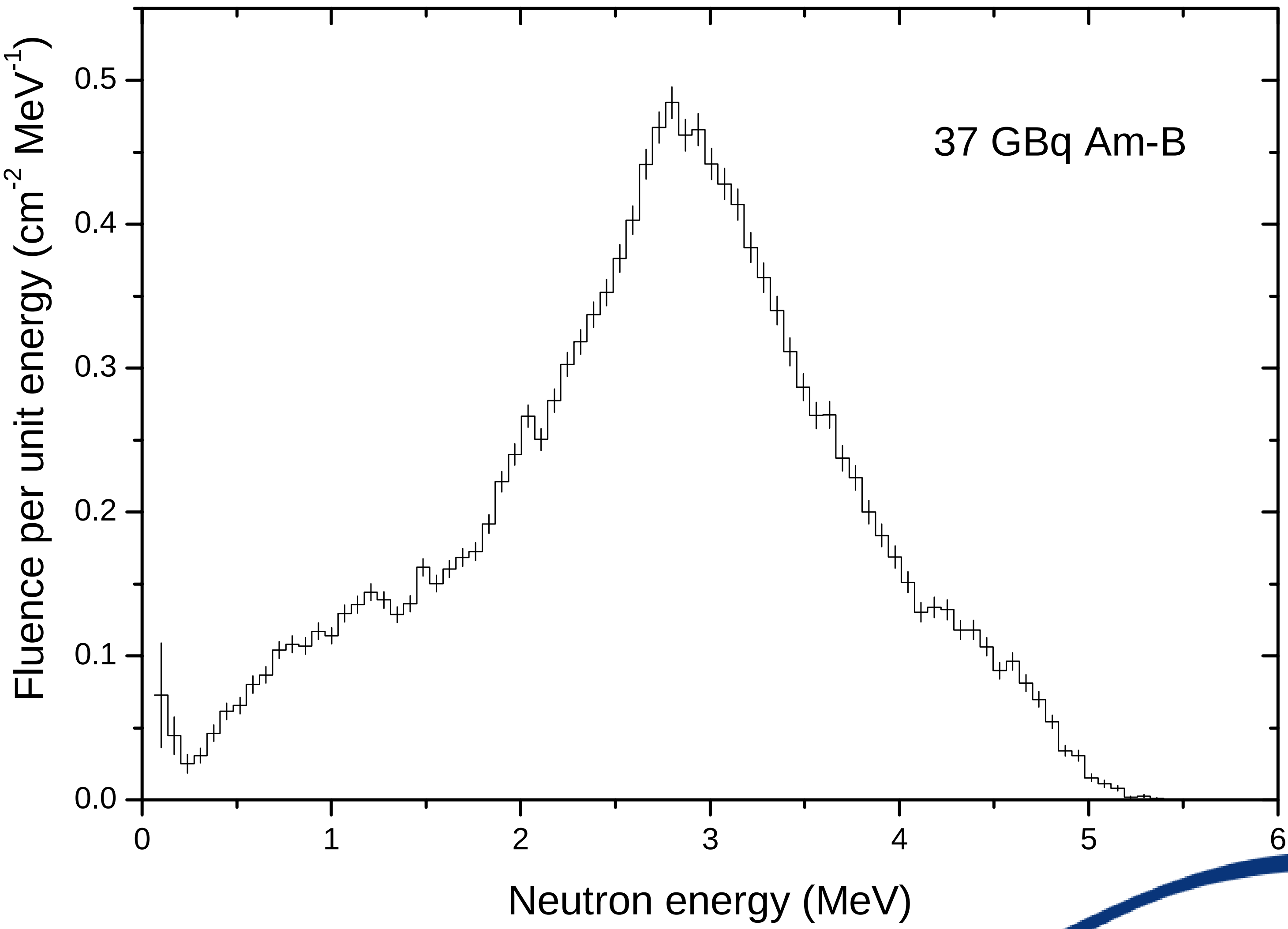


^{3}He Sandwich Spectrometer

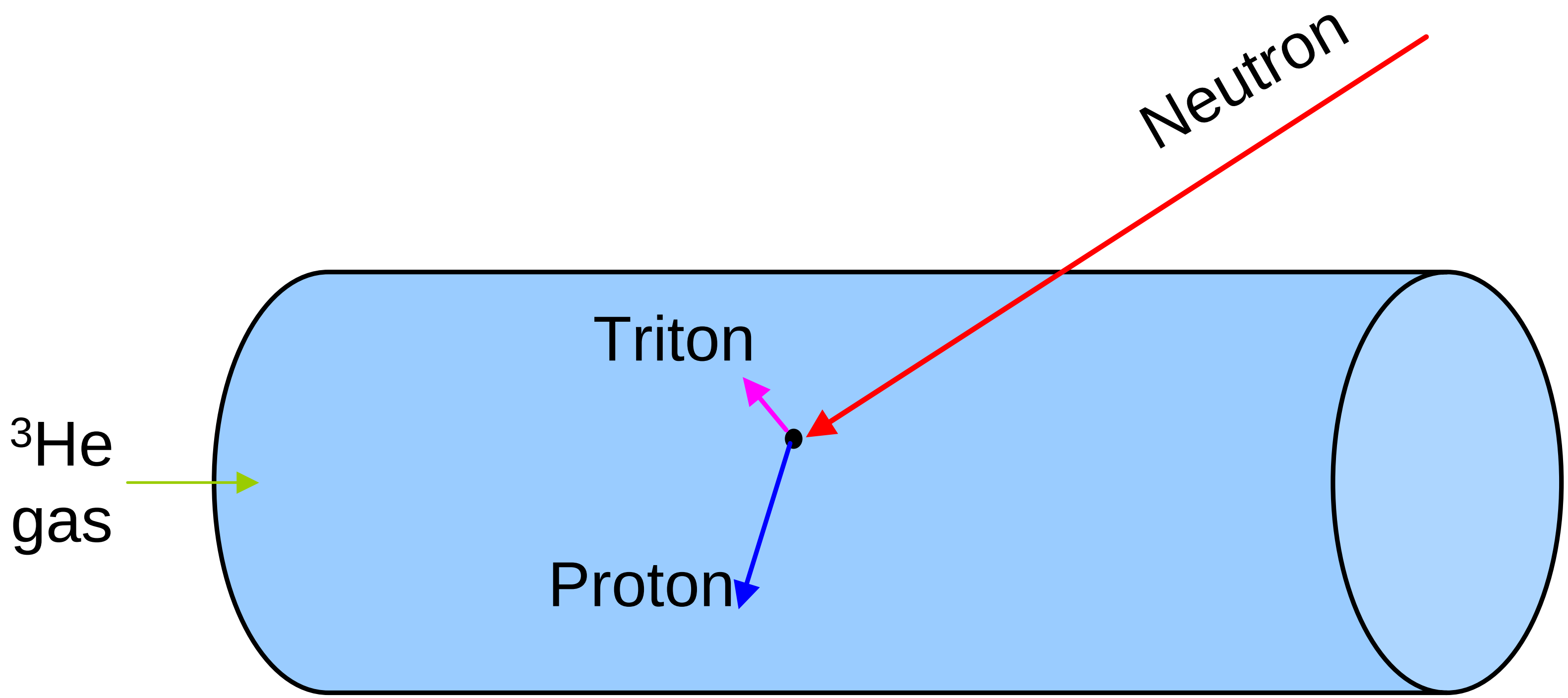


- Complex electronics
- Extremely low efficiency
- In no way is it a field instrument
- But: it works well in the lab

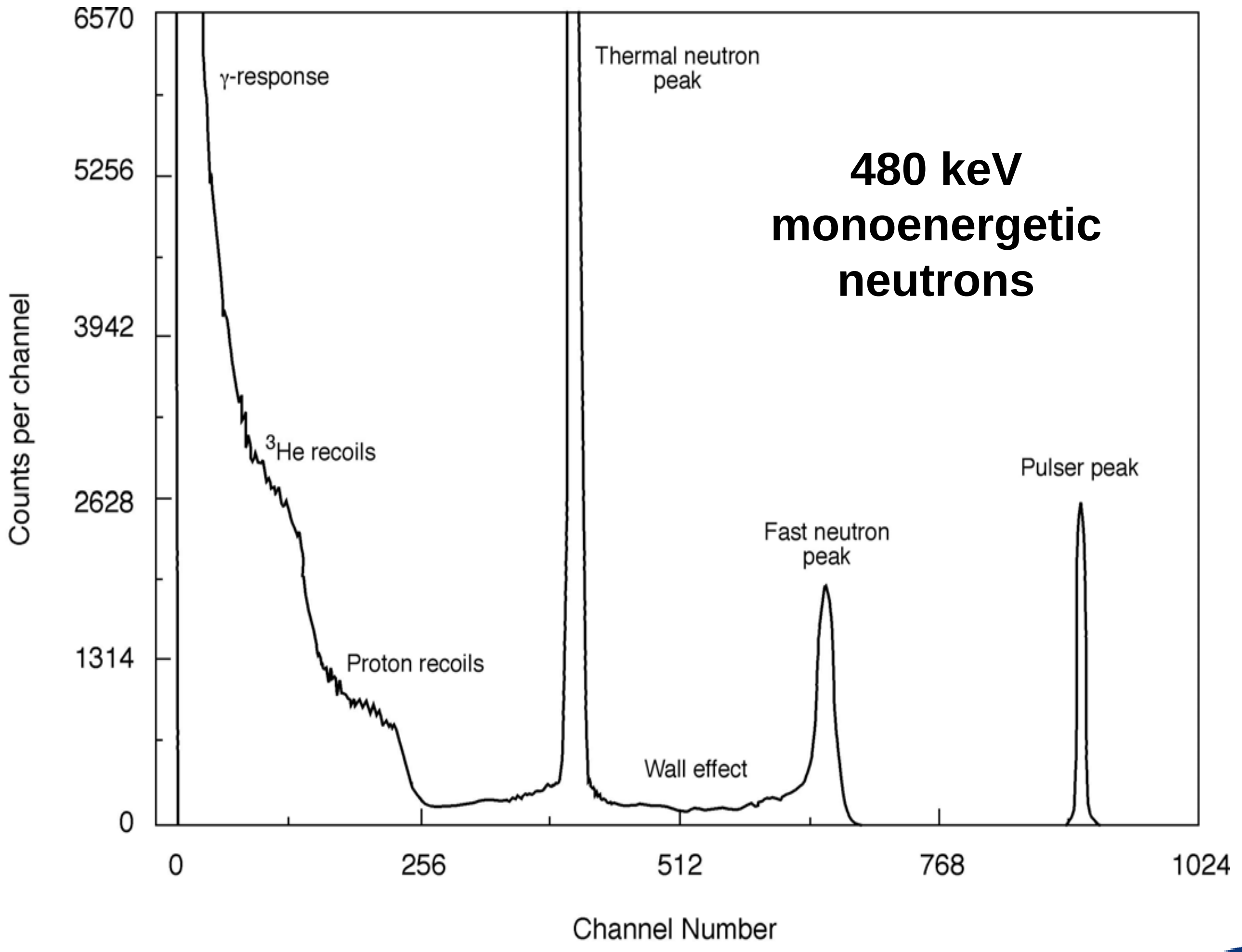
^{241}Am-B spectrum measured with a ^{3}He sandwich spectrometer



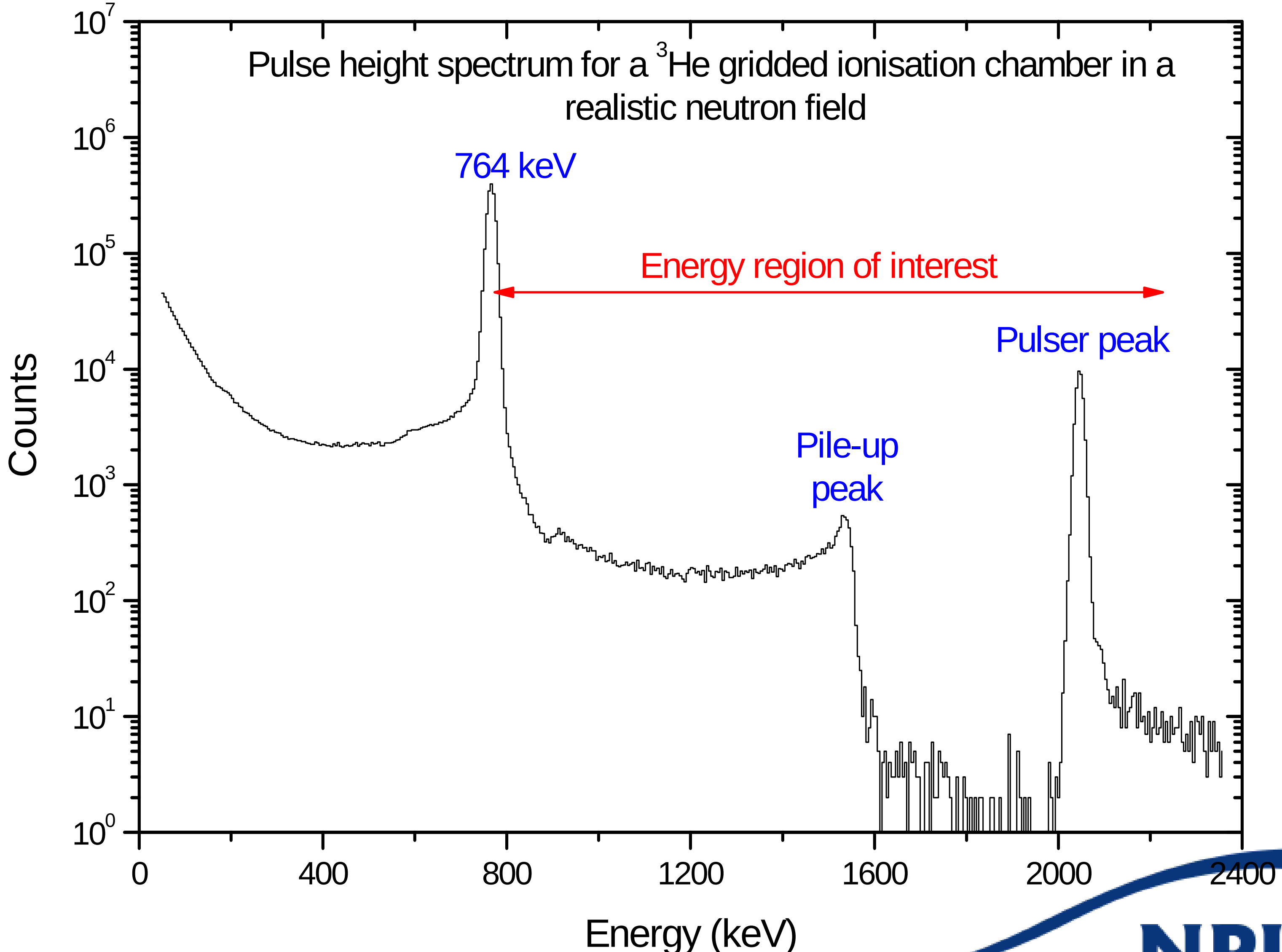
^{3}He Proportional Counter



^{3}He Proportional Counter Spectrum for Monoenergetic Neutrons

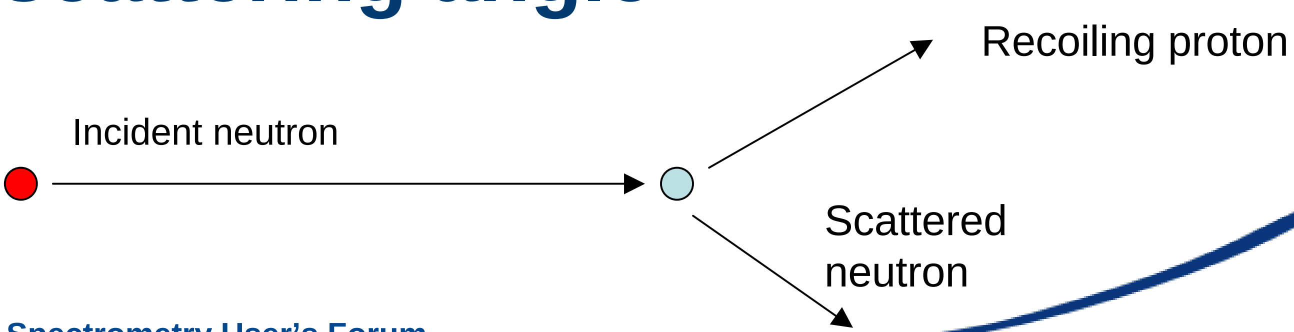


^{3}He Proportional Counter in field with thermal neutrons



Use of (n,p) Scattering in Neutron Spectrometry

- One of the most important reactions in neutron spectrometry is (n,p) scattering
- When a neutron collides with a hydrogen nucleus some of the neutron energy is transferred to the recoil proton
- The actual amount depends on the scattering angle



Use of (n,p) Scattering in Neutron Spectrometry

$$E_p = E_n(\cos^2\theta)$$

$$\theta = \text{recoil scattering angle, when } \theta = 0^{\circ} \quad E_p = E_n$$

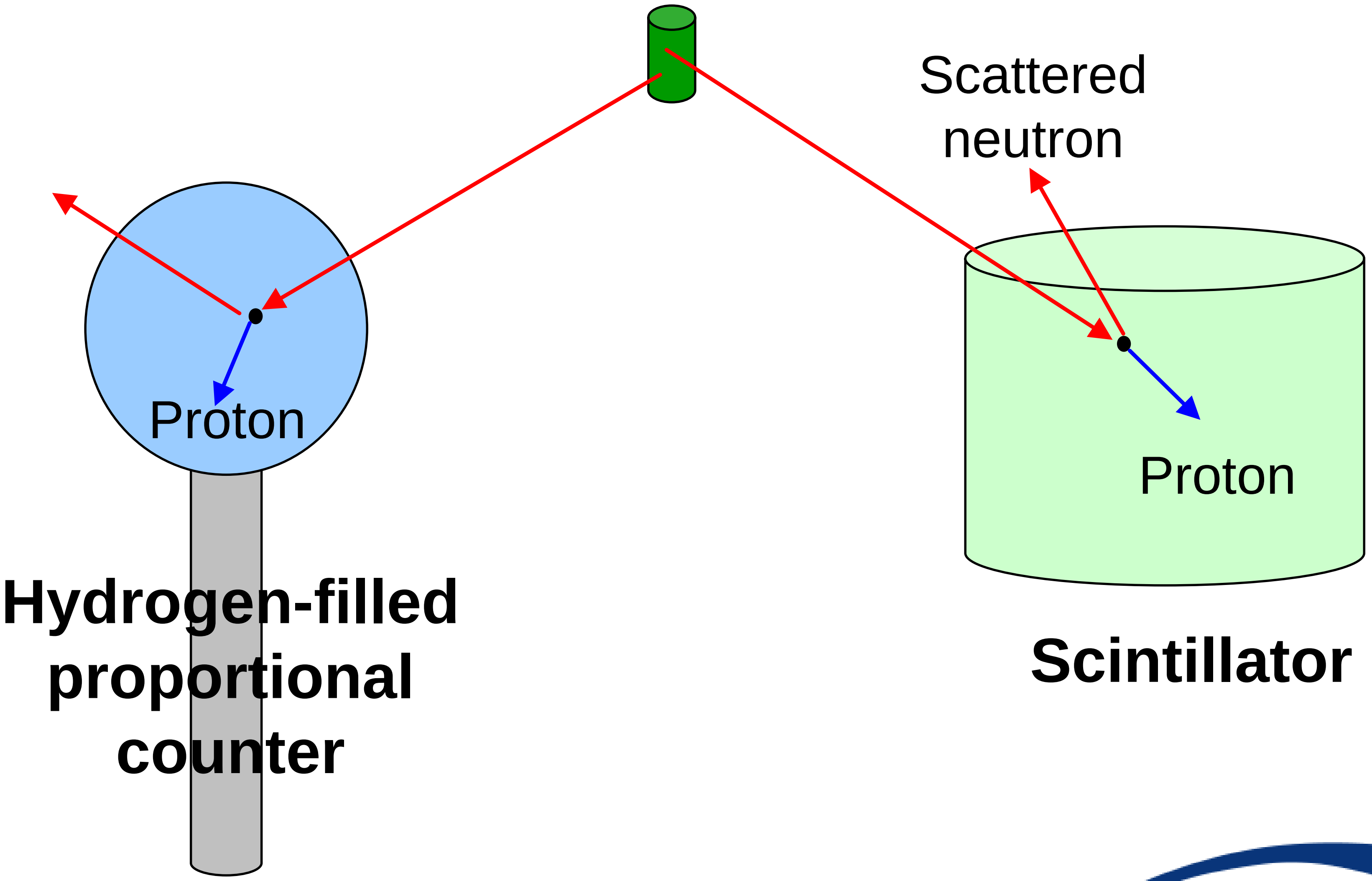
If the recoils can be restricted to those where $\theta \sim 0^{o}$ get a measure of E_n

This is the principle of the proton recoil telescope

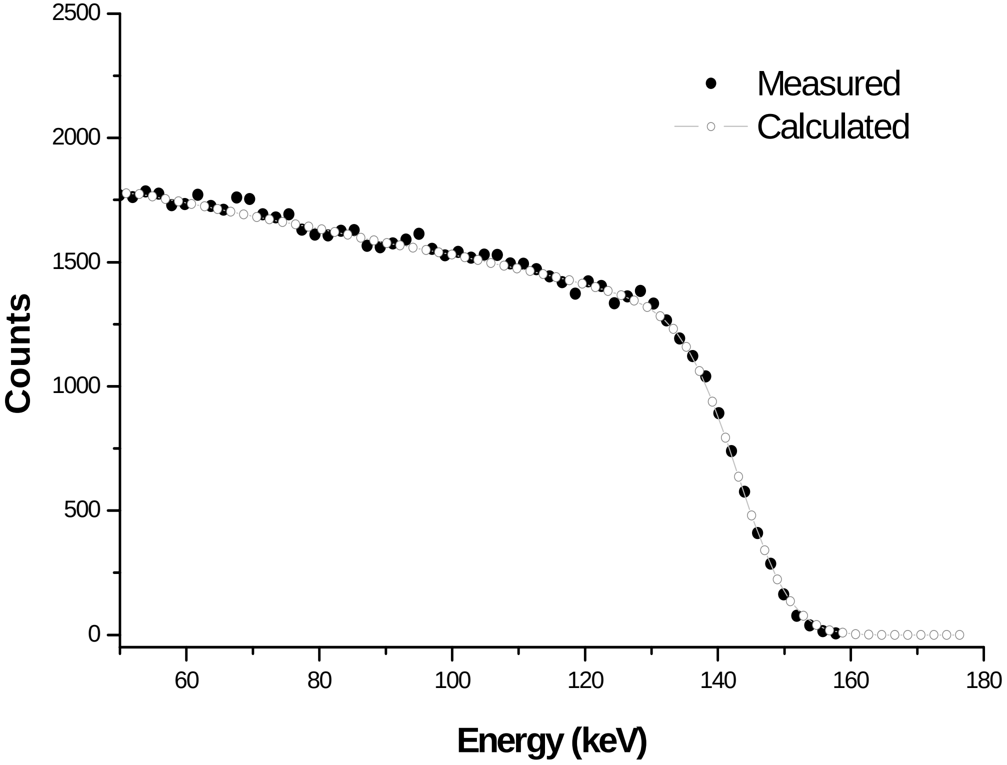
Use of (n,p) Scattering in Neutron Spectrometry

- **If the restriction to $\theta \sim 0^{o}$ is removed get a much higher detection efficiency**
- **However, this introduces the requirement to unfold the spectrum**
- **Nevertheless proton recoil spectrometers are one of the most commonly used**
- **There are two basic types:-**

Use of (n,p) Scattering in Neutron Spectrometry



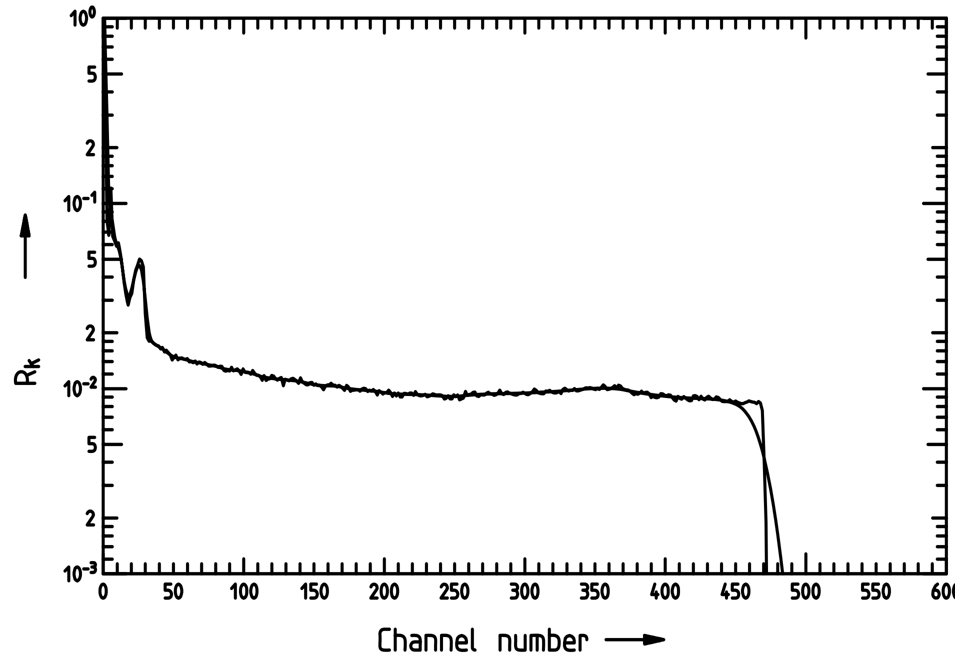
A proton recoil proportional counter



Characteristics of proton recoil proportional counter spectrometers

- Broad pulse height distribution even for monoenergetic neutrons.
- Unfolding needed to derive the neuron spectrum from the pulse height distribution.
- Response functions must be known, but can be derived from measurement and calculation.
- Need several counters (3 or 4) to cover energy range (roughly 50 keV to 1.5 MeV).
- For higher energies can use methane or ^{4}He counters, but scintillators are better.

Scintillator spectrometer e.g. NE213



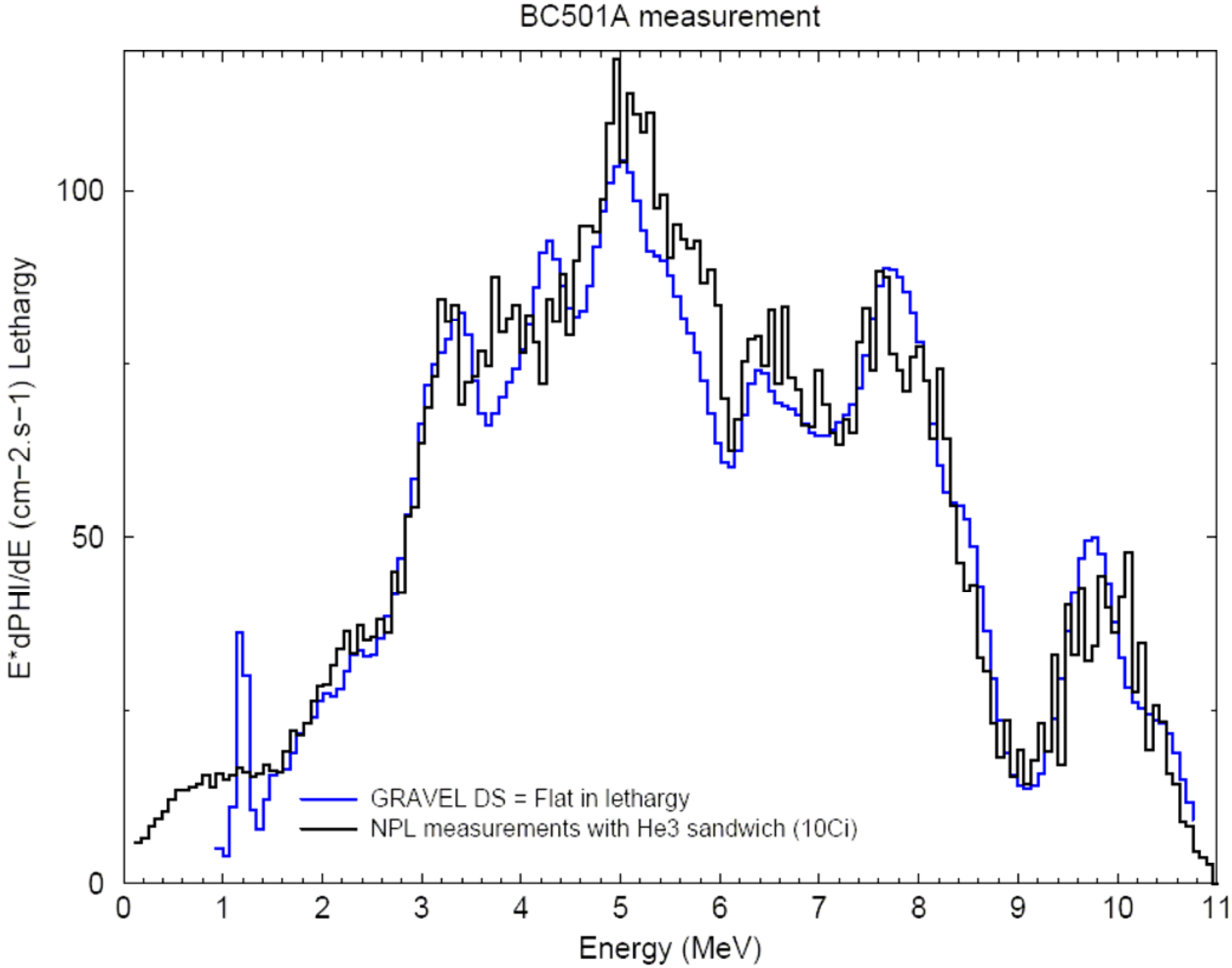
Similarities to proportional counters, but:

- **more efficient,**
- **must have n-γ discrimination, and**
- **only one counter needed to cover 1 MeV to >20 MeV.**

Summary for proton recoil devices

- High resolution.
- Cover an important portion of the neutron energy region where a significant fraction of the dose is often located.
- Not particularly easy to use or unfold – often need to combine data from several detectors.
- Still to some extent under development, digital signal processing being investigated.

Scintillator measurement of ^{241}Am-Be compared with ^{3}He sandwich spectrometer



NPL 10 Ci ^{241}Am-Be source

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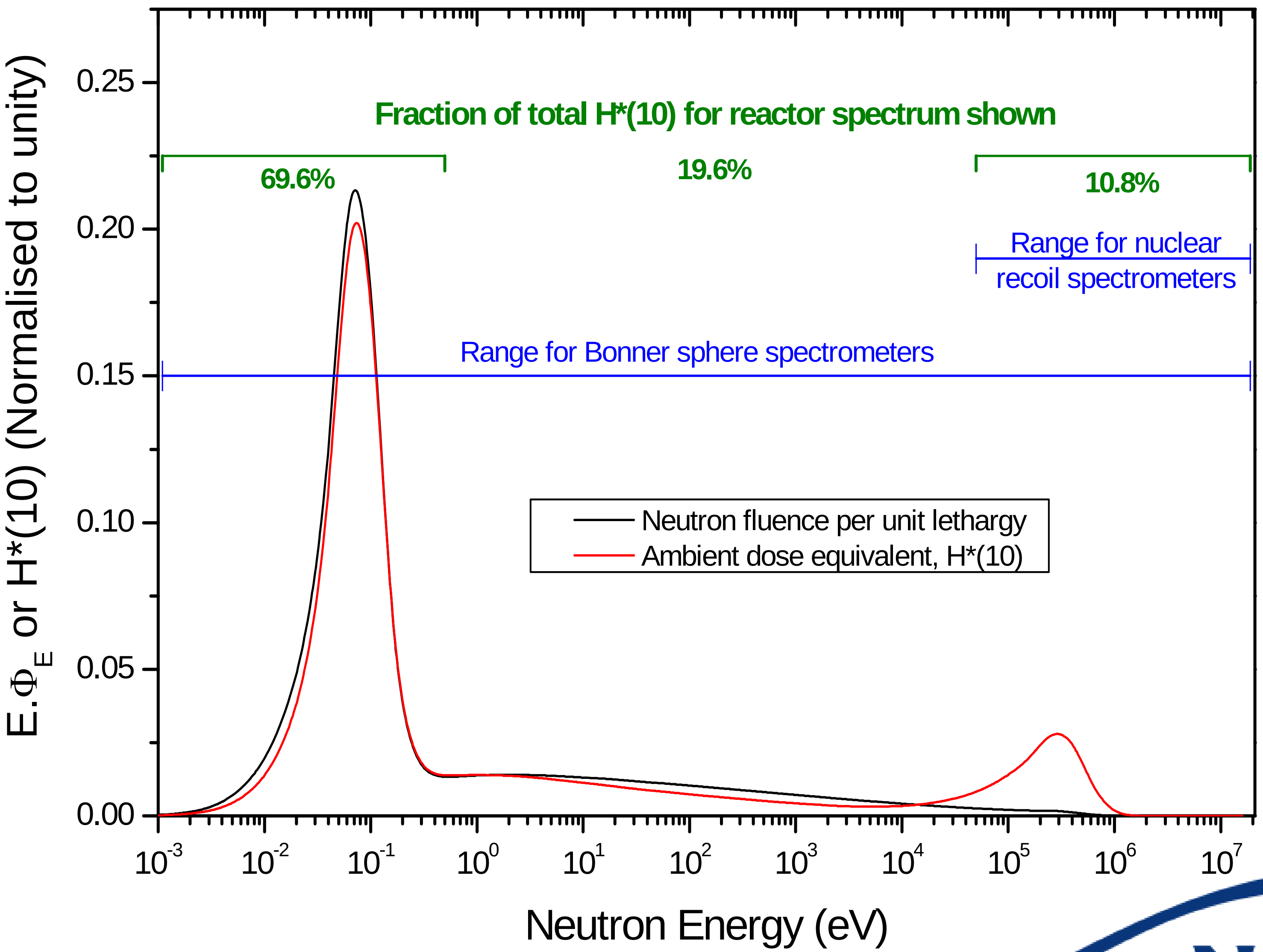
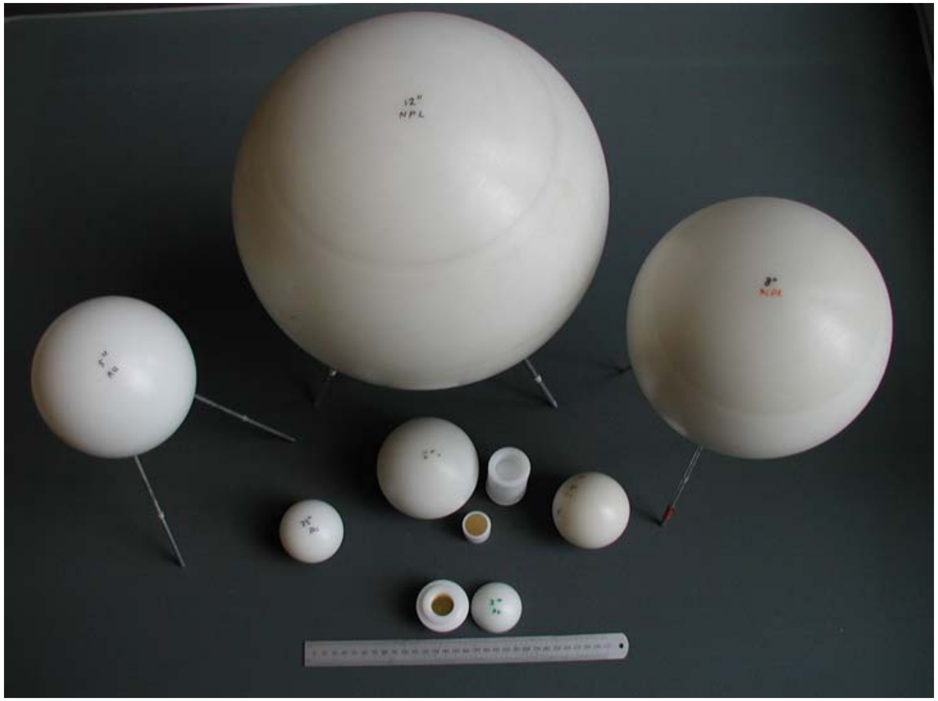
Energy Range for Neutron Spectra

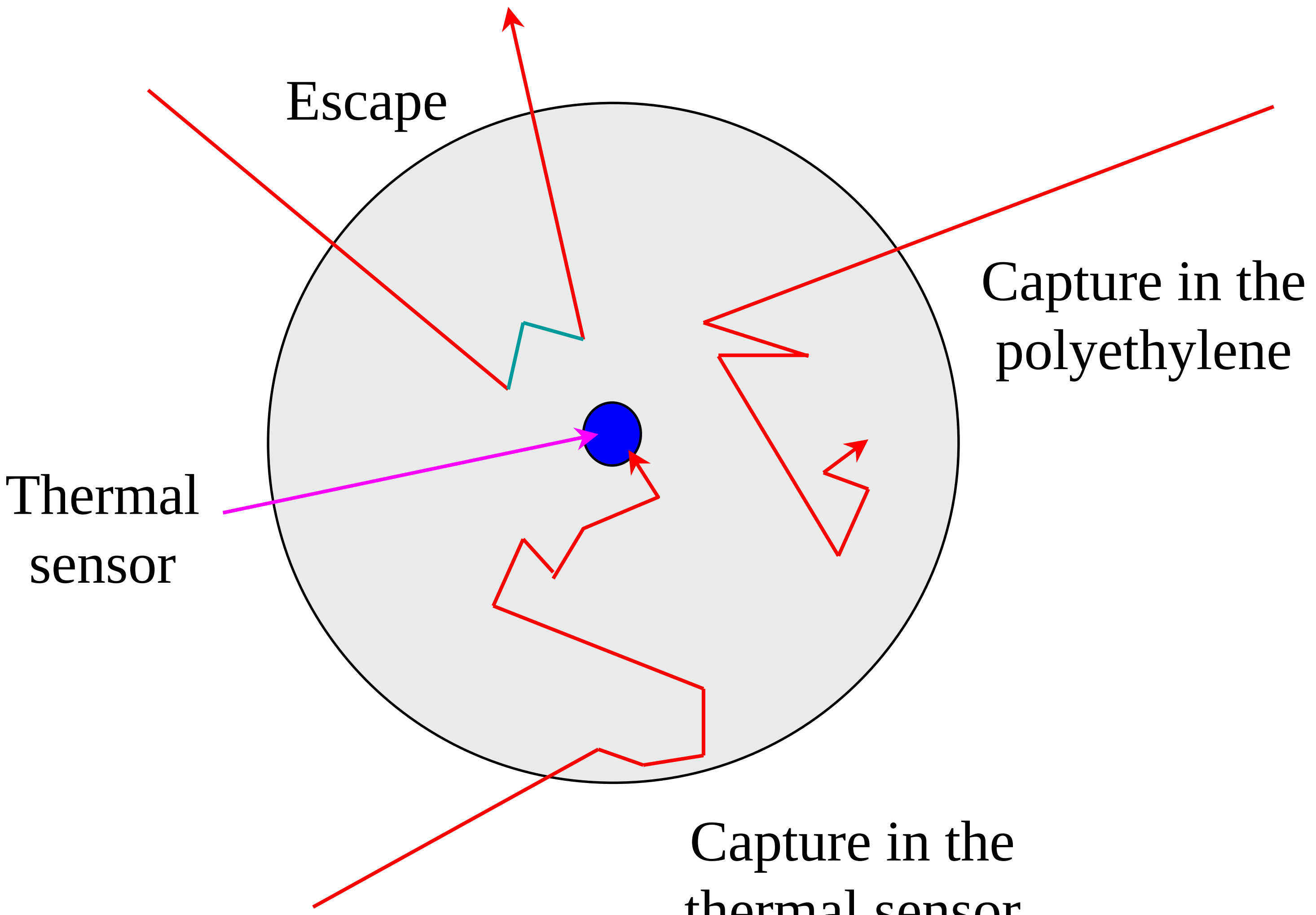


Integral spectrometers

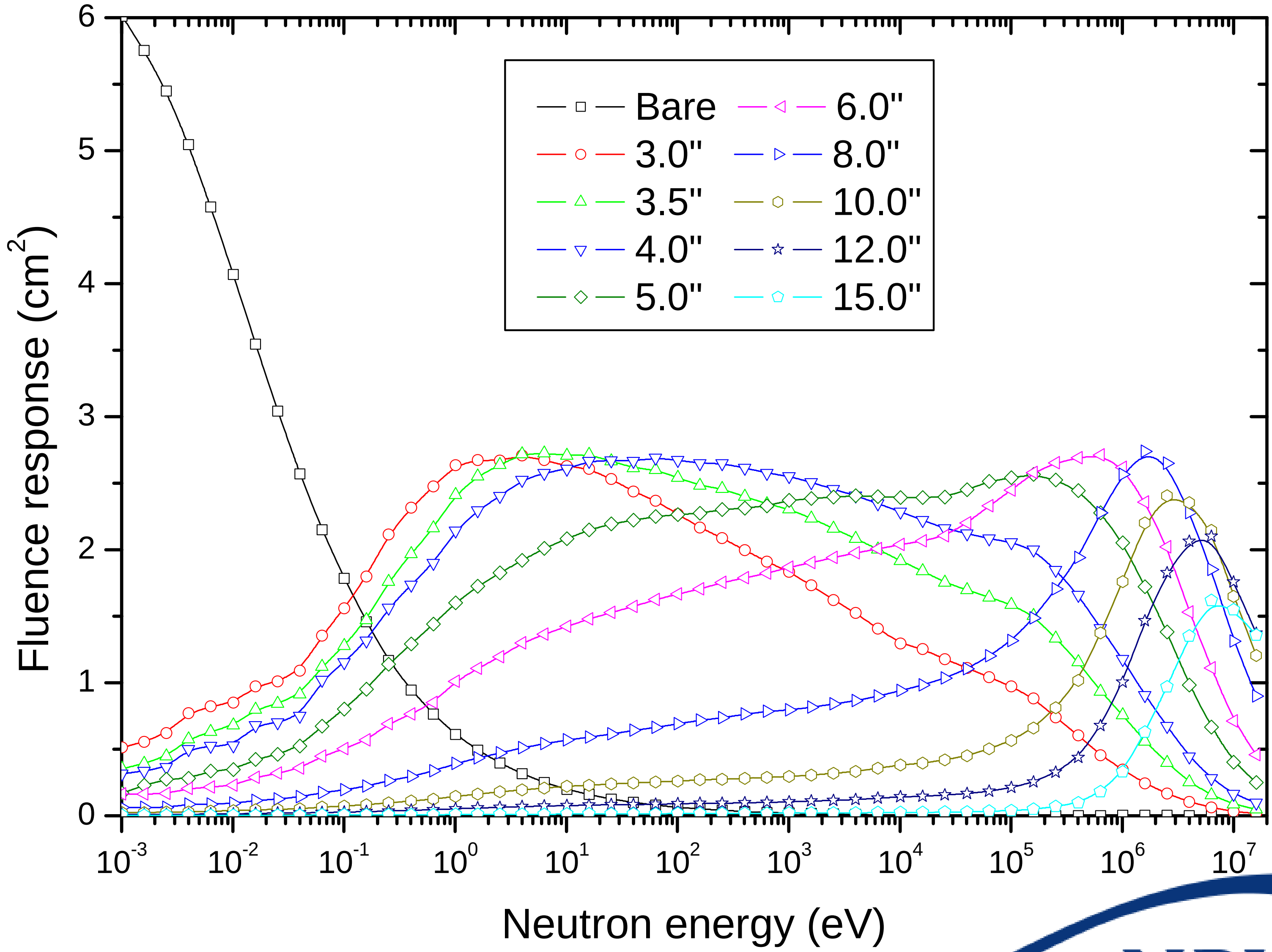
Bonner spheres



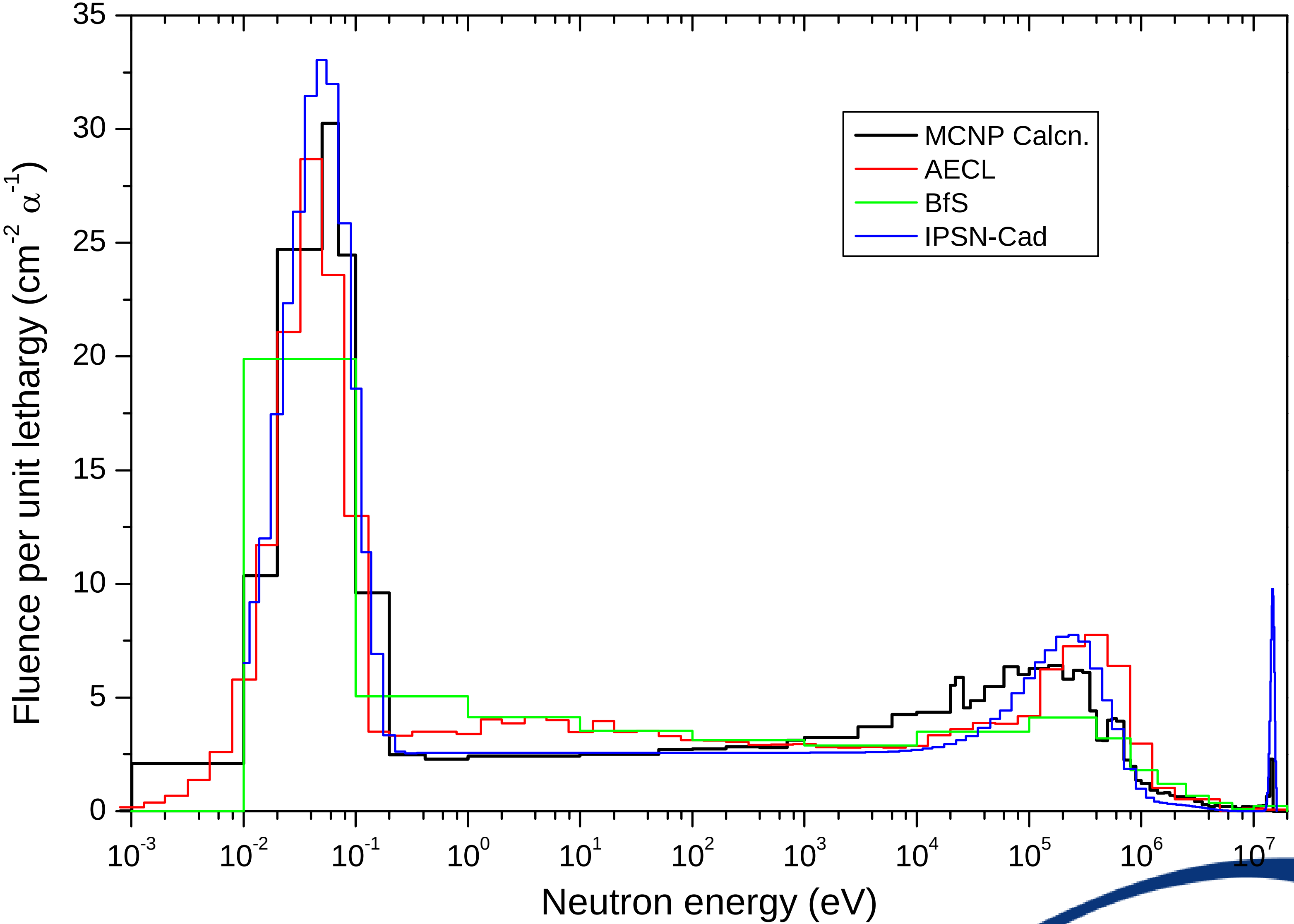
Principle of operation



Response Functions of Bonner spheres



Bonner sphere spectra from comparison exercise



Neutron spectrometry: outside the lab, all Bonner spheres

Characteristics of neutron spectrometers

Property	^{3}He Spectrometers	Nuclear Recoil Devices	Bonner Spheres
Energy resolution	Good	Good	Poor
Energy range	50 keV to ~6 MeV	50 keV to 20 MeV	Thermal to >20 MeV
Efficiency	Low	Low to medium	High
Size & mass	Bulky	Bulky	Large
Operation	Straightforward	Complex	Simple
Photon discrimination	Photons OK Thermals problem	Pulse shape analysis essential for scintillators	Excellent
Angle response	Not very isotropic	Near isotropic	Isotropic
Unfolding	Reasonable straightforward	Solvable but complex	Complex and subjective

Bonner spheres have been used for more field measurements than all the other devices put together

End