LA-UR-14-28492

Insights into previous PFNS uncertainties from the Chi-Nu project

Robert Haight

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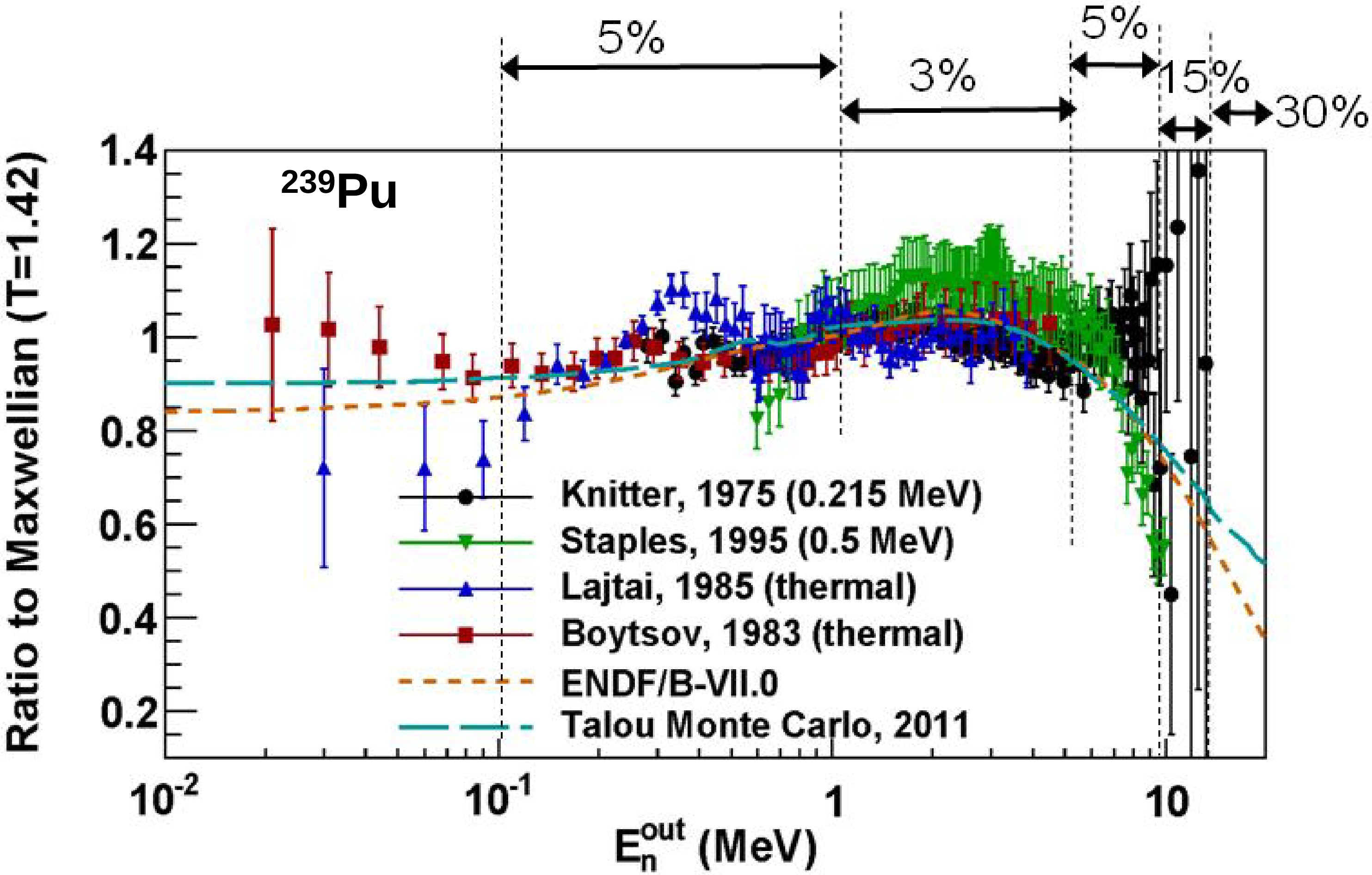
Literature data, discrepancies and target accuracies in PFNS for ^{239}Pu(n,f)

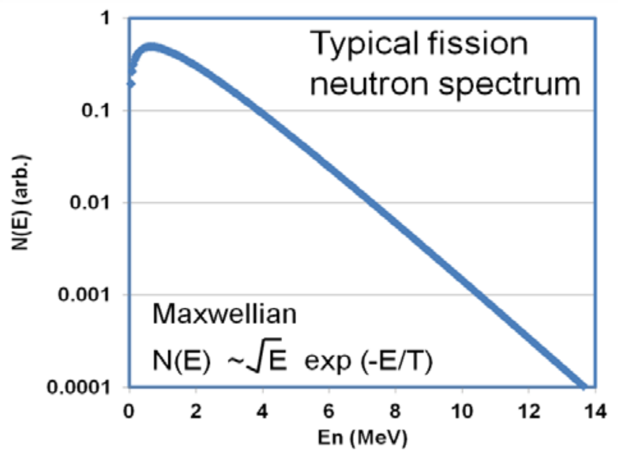


Some issues in PFNS measurements

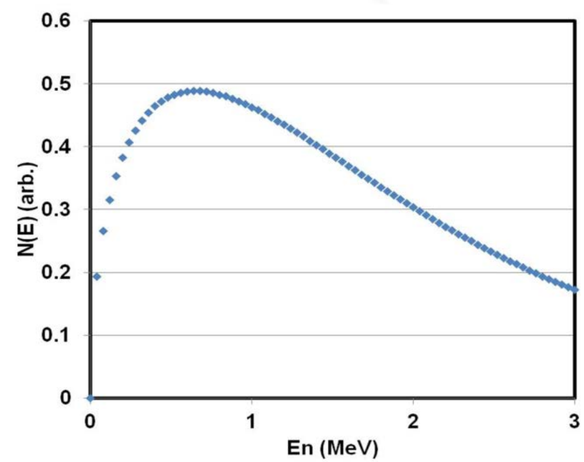
- Multiple scattering
  - In sample
  - In collimators
  - In detector
- Detector response
  - Including scattering
  - Light curves for scintillators
- Calibration problems

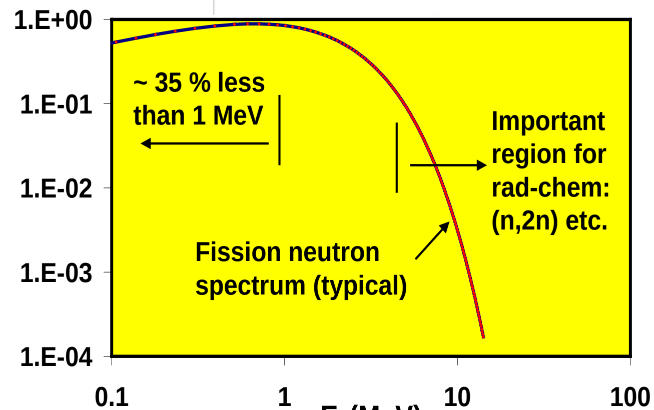
Reminder – Shape of PFNS is approximately Maxwellian

Semi-log

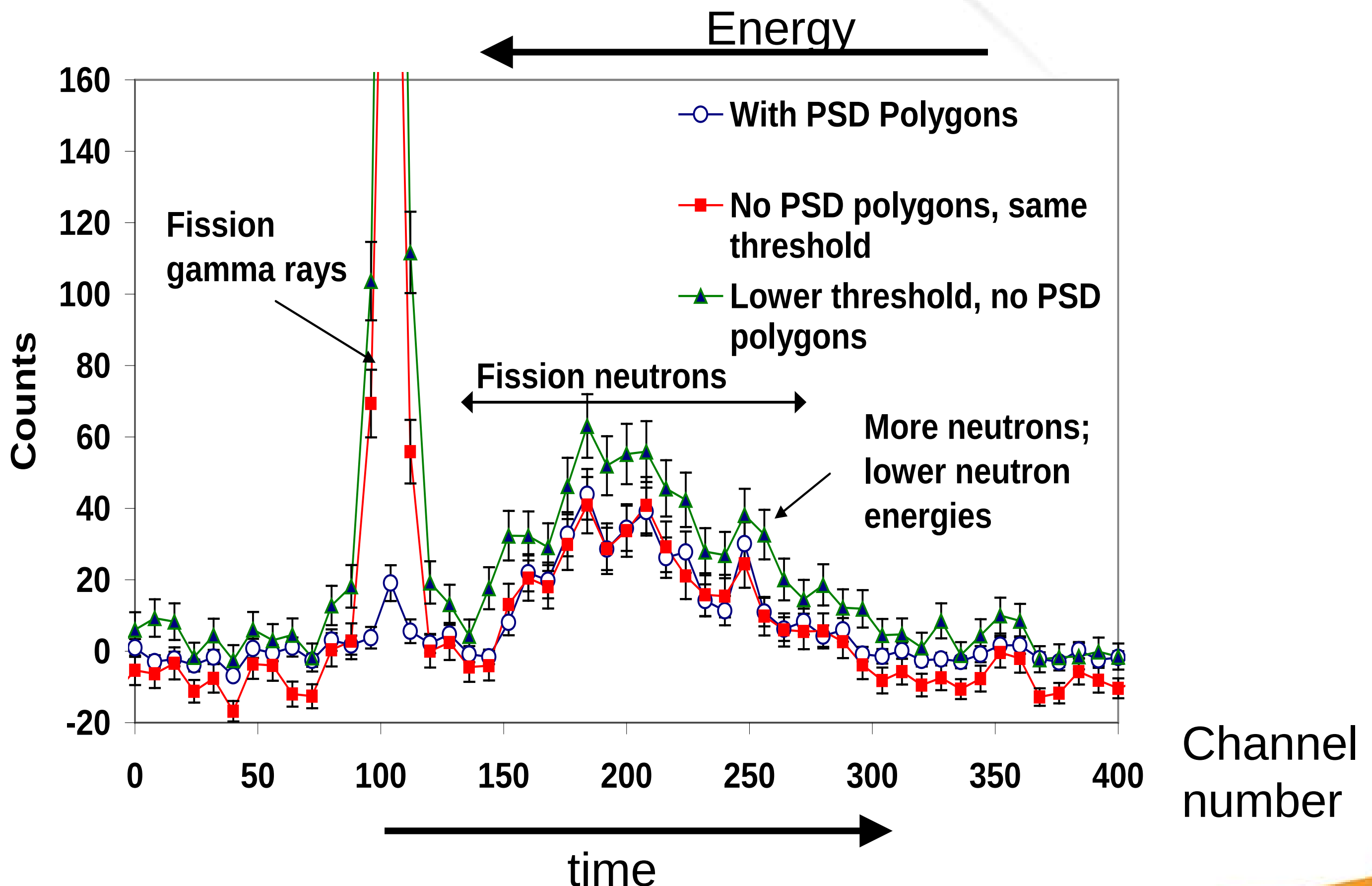


Linear





Second reminder - energy of emitted neutrons is calculated from time of flight



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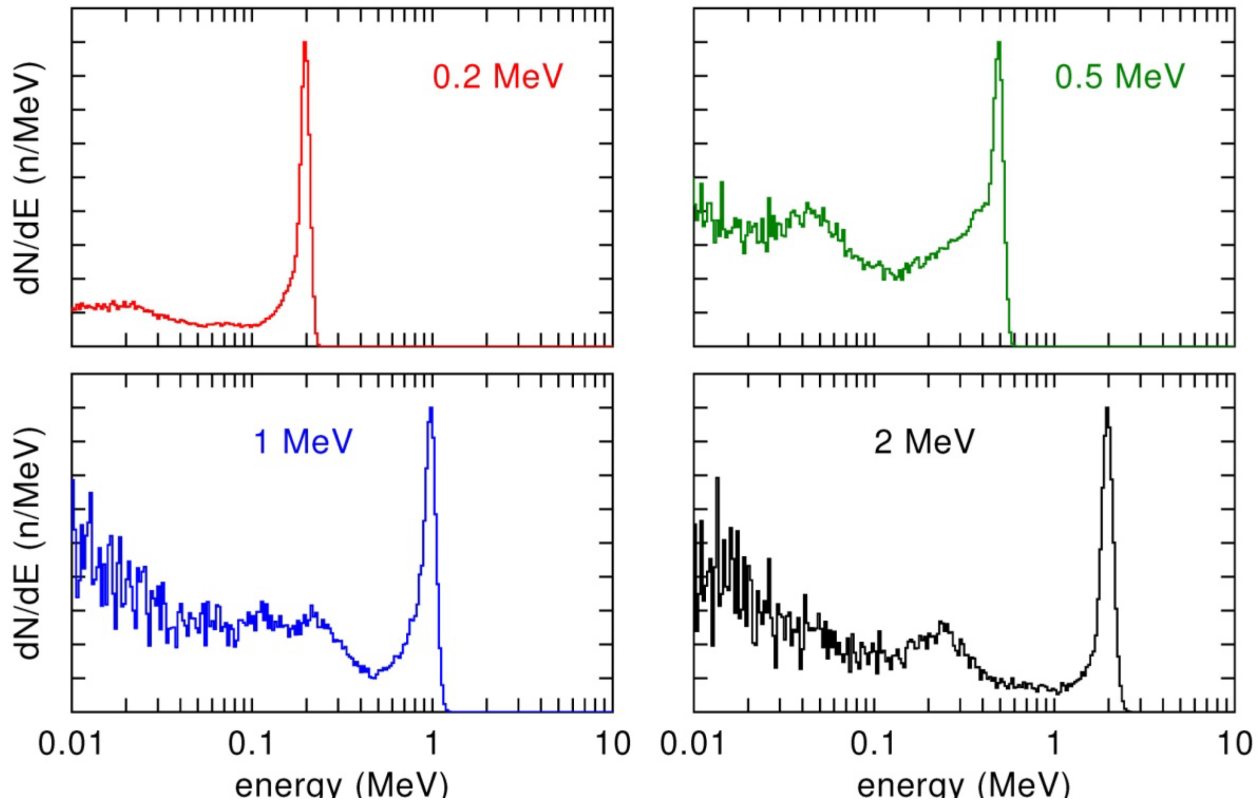
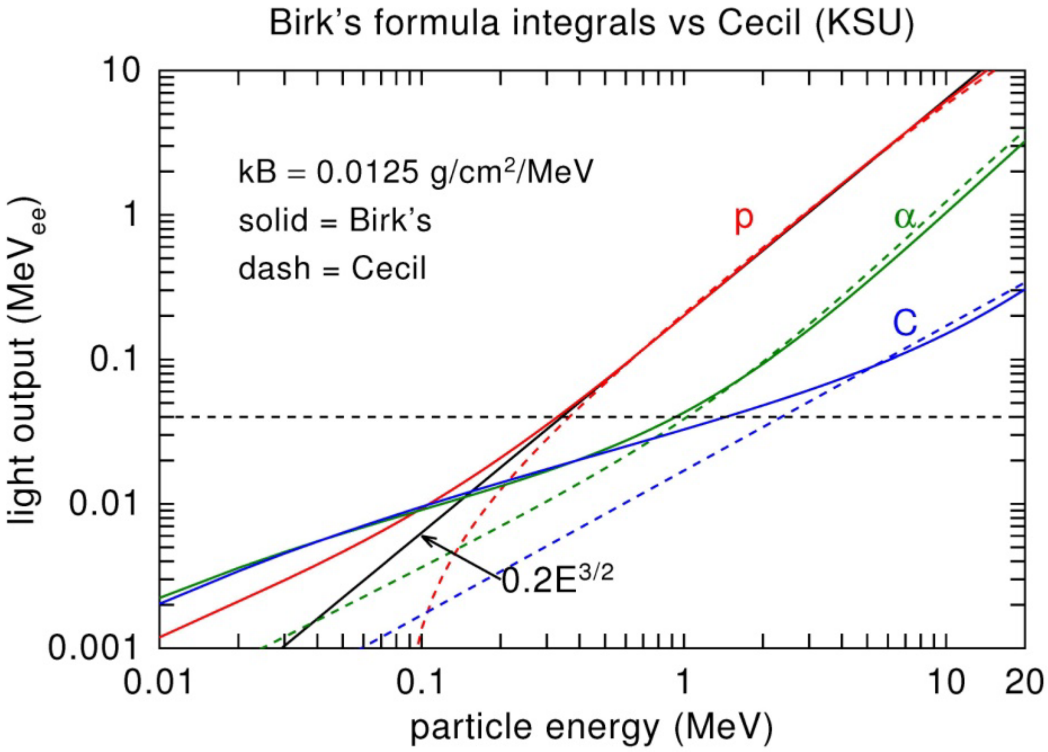
Response function can be calculated for the system



Physical processes in neutron detector are also important – e.g. light curve in scintillators

Light output in EJ-301 (NE-213, BC-501A)



Some of the PFNS experiments in $^{239}Pu(n,f)$ are discussed here

- Einc = thermal
  - Starostov et al. (Boytsov)
- Einc = 0.215, 0.5, 1.5, 2.5, 3.5
  - Knitter et al.
  - Staples et al.
- Einc = ~1.0 – 200 MeV
  - Noda
  - Chatillon

MCNP calculations (and much insight)

by Terry Taddeucci (LANL)

Starostov – One of the many experimental configurations

plastic scintillator at 6.1 m

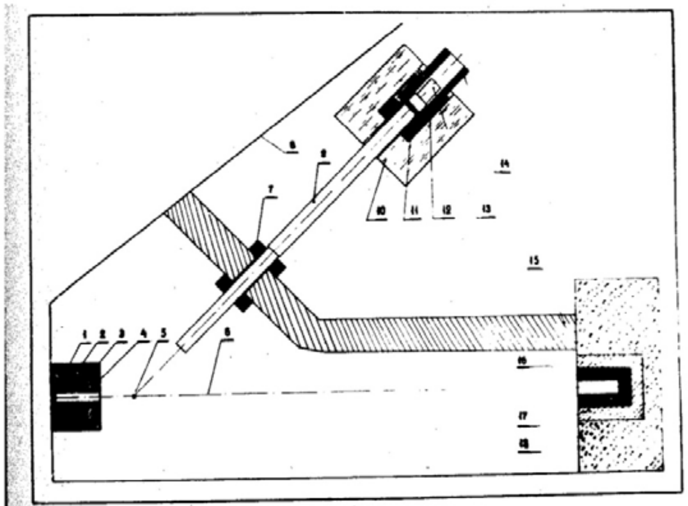


Рис.I. Геометрия опыта: I – коллиматор; 2 – парафин с карбидом бора; 3-4 – свинец; 5 – ионизационная камера; 6 – пучок тепловых нейтронов; 7 – свинец; 8 – стена помещения; 9 – вакуумная труба; I0 – бак с водой; II – свинец; I2 – карбид бора; I3 – детектор нейтронов; I4 – свинец; I5 – стена из чугунных кирпичей; I6 – ловушка тепловых нейтронов и γ-квантов, свинец; I7 – карбид бора; I8 – бетон

from:

Starostov-Kiev83_290(rus)-2.pdf

B.I. Starostov, V.N. Nefedov, A.A. Boytsov

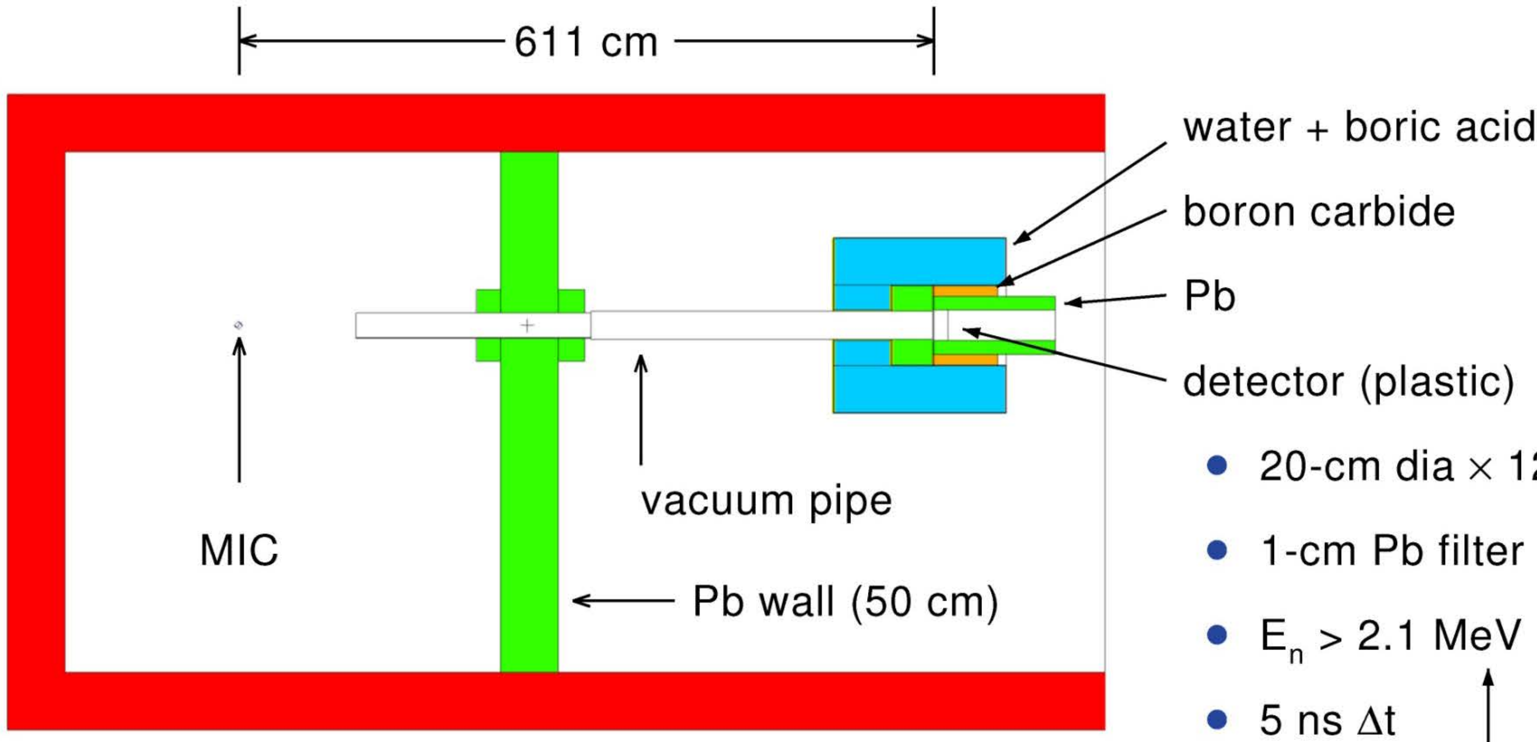
NIIAR 1983

translated by Roberto Capote

Fig. 1

NIIAR = V.I. Lenin Scientific Research Institute of Atomic Reactors

The MCNP interpretation of Starostov Fig. 1 requires many guesses

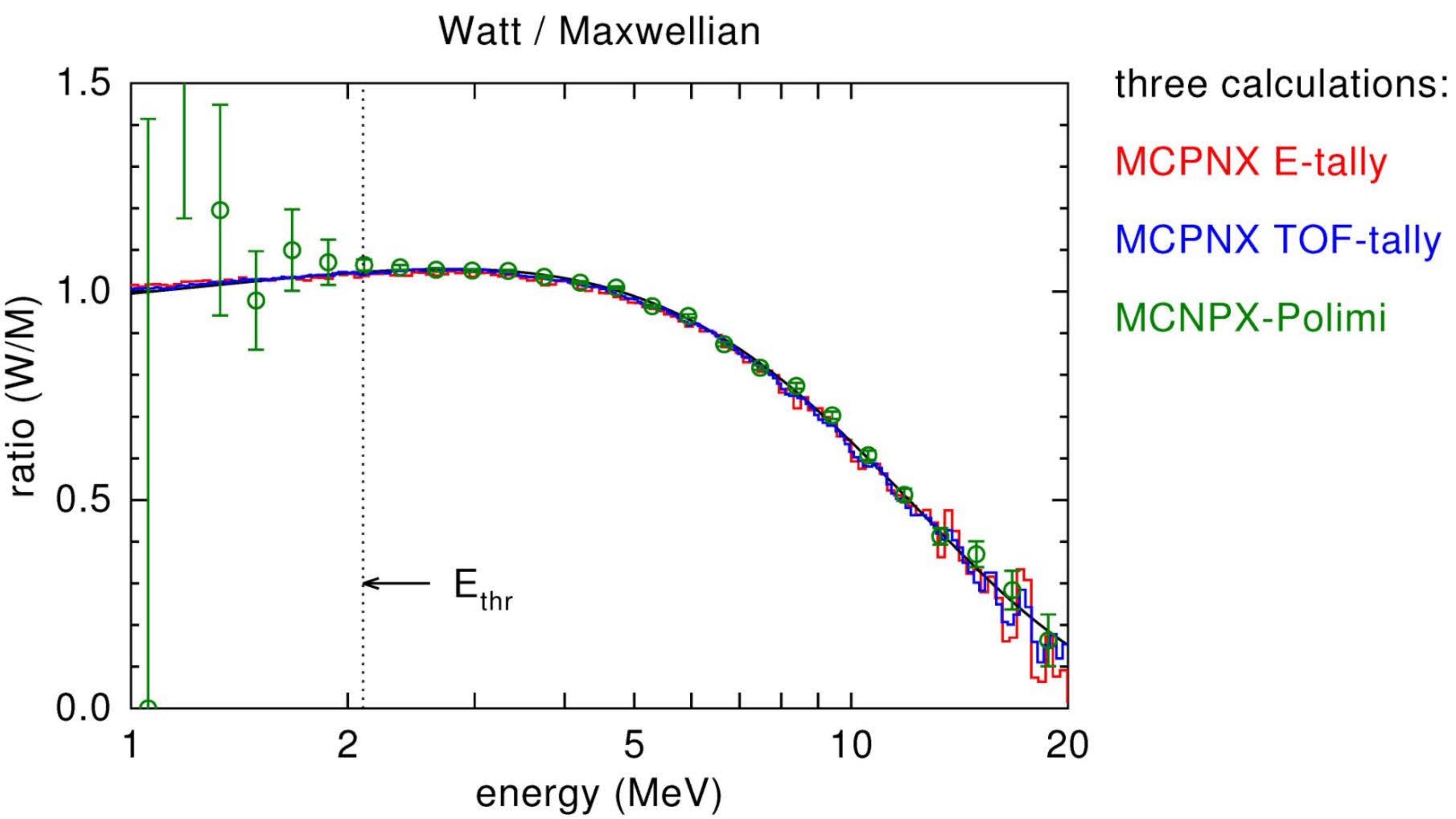


- 20-cm dia × 12-cm
- 1-cm Pb filter
- E_n > 2.1 MeV
- 5 ns Δt

(~580 keV_{ee})

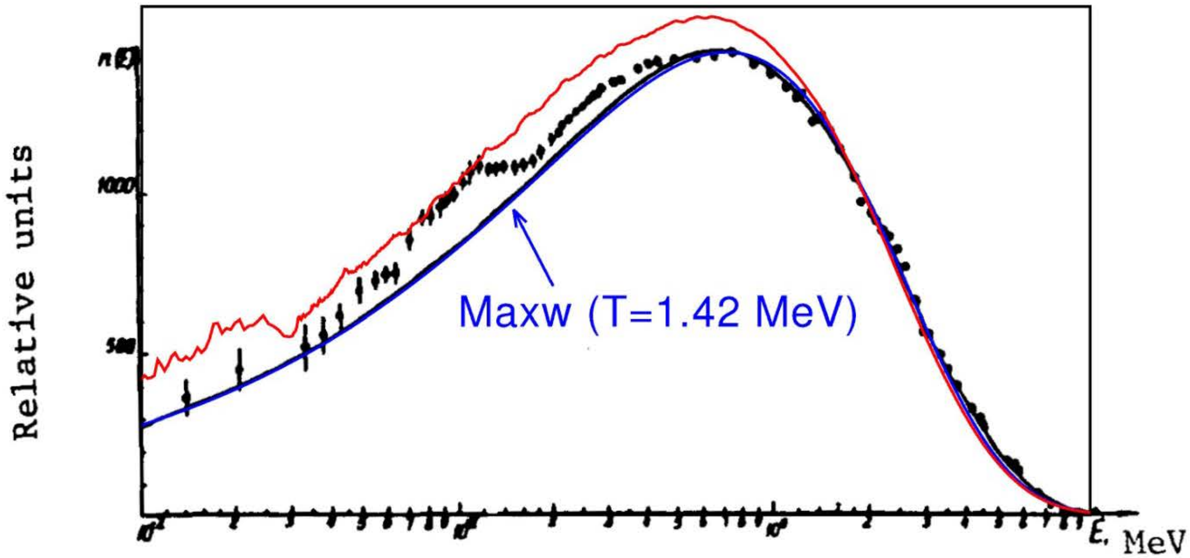
MIC = miniature ion chamber (2.5 g, 25 mm dia × 3 mm)

Spectral distortion in the 6.1-m measurements does not significantly affect the output versus input ratios



The averaged ^{252}Cf spectrum shows signs of undercorrection for multiple scattering

red = MCNP with IC at 21.4 cm



<u>Fig. 7.</u> Weighted averages for the ^{252}Cf fission neutron spectrum, based on all data.

Many measurements with different amounts of multiple scattering

Summary of analysis of Starostov data

Much of the MCNP modeling is based on best guesses.

Some tentative conclusions:

- Anthracene at 51 cm: not enough info to model
- Stilbene at 231.3 cm: not enough info to model
- plastic at 611 cm: ratio to ^{252}Cf probably ok
- GSDIC with compound shield:
  - huge multiple scattering
- IC with simple shield:
  - much less multiple scattering

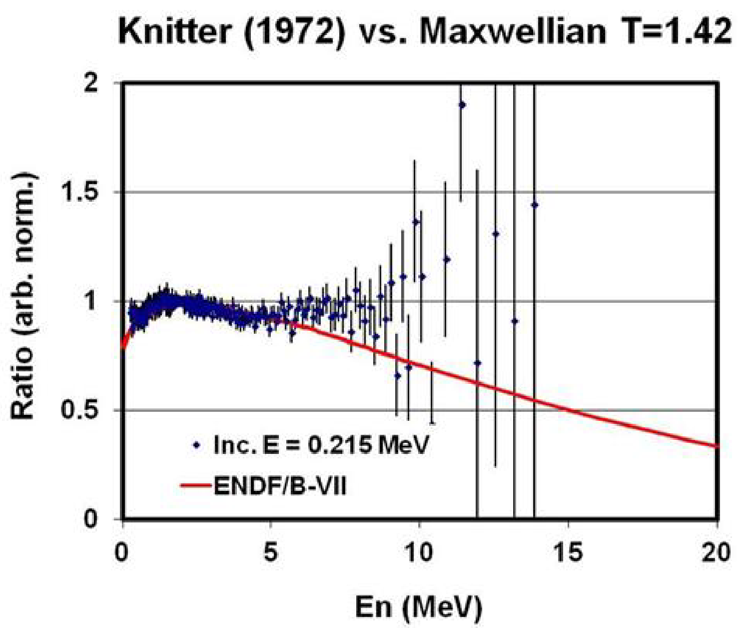
target + detector scattering estimated from multiple ^{252}Cf measurements

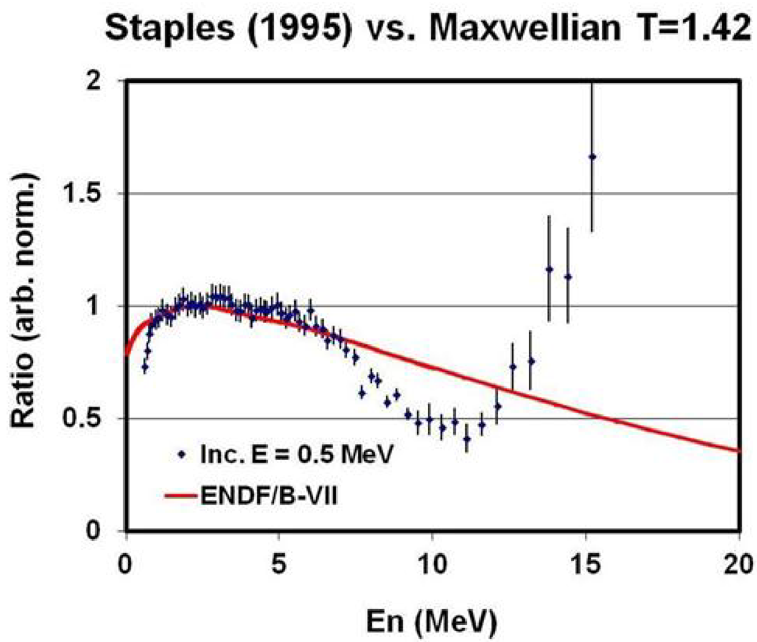
- ratios to ^{252}Cf *measured under the same conditions* are probably OK
- standalone ^{252}Cf spectrum appears to be undercorrected for multiple scattering

Fast neutron-induced fission - - monoenergetic incident neutrons

- Knitter Einc = 0.215 MeV
- Staples Einc = 0.5, 1.5, 2.5, 3.5 MeV

Discrepancy in monoenergetic data for high-energy end of PFNS





Data > ENDF for Eout > 7 MeV

Data < ENDF for Eout 7 to 12 MeV

Note: Staples also for Einc = 1.5, 2.5, 3.5 MeV

MCNP simulations have been used to investigate some previous measurements of the PFNS

Two standard papers for ^{239}Pu:

- P. Staples et al., Nucl. Phys. A591, 41 (1995)
- H.H. Knitter, Atomkernenergie 26, 76 (1975)

Some possible sources of systematic error:

- multiple scattering in the target
- multiple scattering in the collimation
- detector efficiency
- background subtraction
- Calibrations (TOF, PH, flight path, etc)

these are not necessarily decoupled

Experimental layout for the measurements by Staples et al.

P. Staples et al. / Nuclear Physics A 591 (1995) 41–60 45

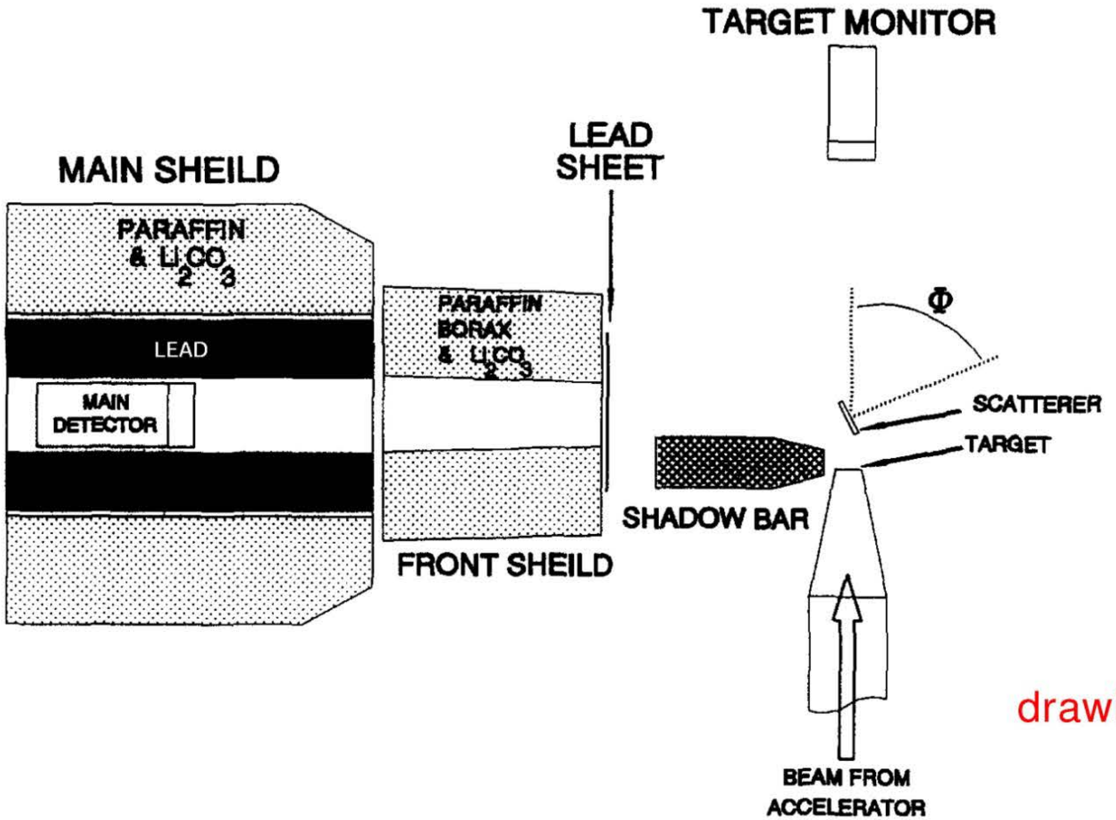


Fig. 1. Experimental arrangement in the target room.

drawing not to scale

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Experimental layout for the measurements by Knitter

M. Coppola and H.H. Knitter, Z. Physik 232, 286 (1970)

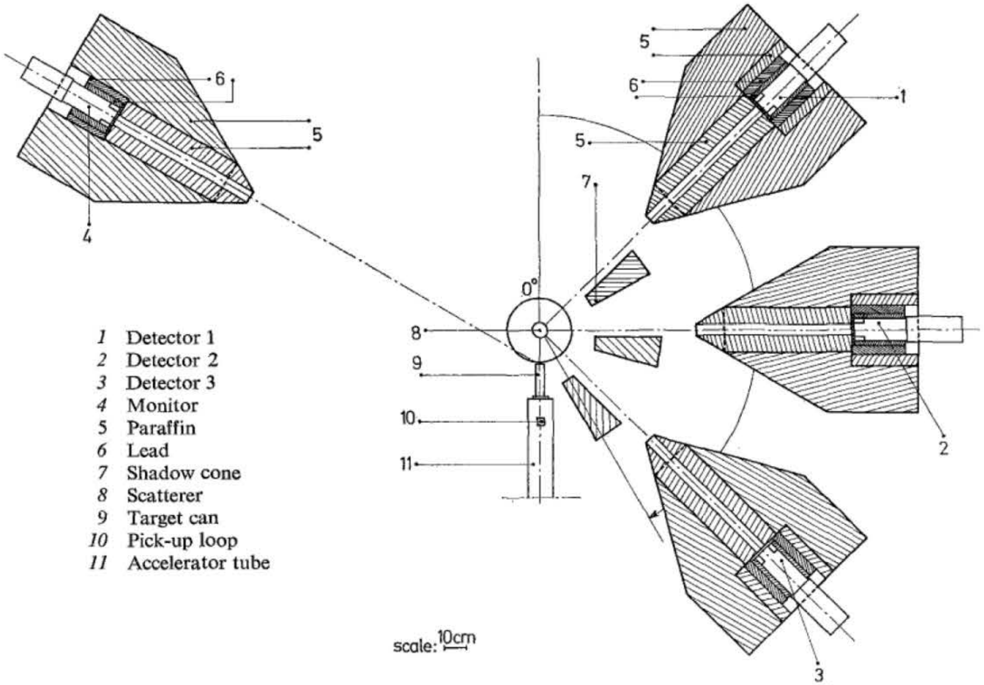
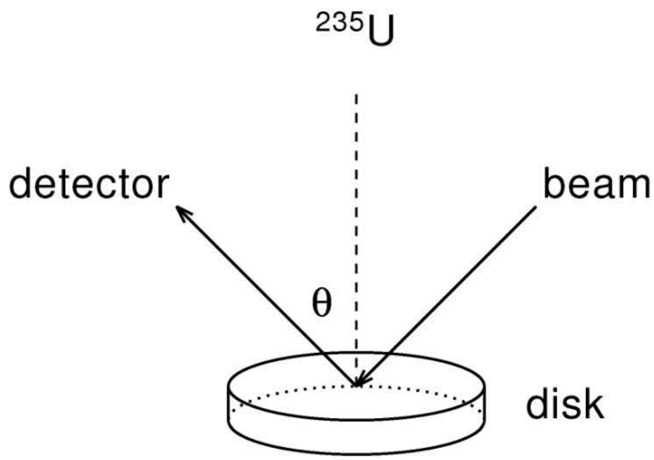
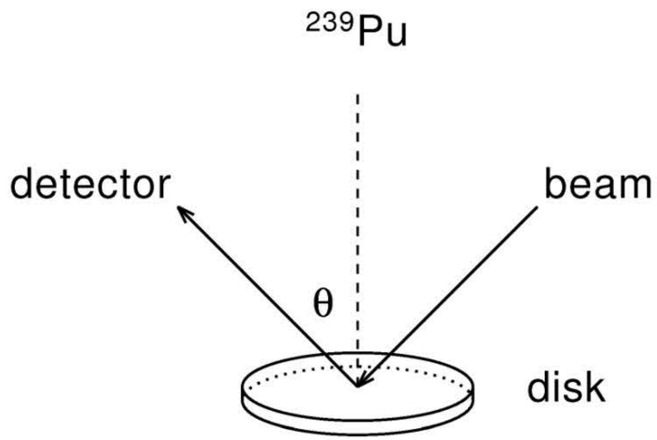


Fig. 1. Lay-out of the detecting system

typical for this facility (CBNM, Geel)

The target samples used by Staples *et al*. were thin disks



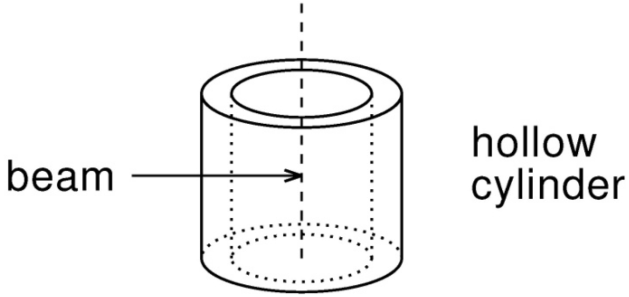


^{235}U	^{239}Pu
0.064-mm Al-foil cladding	0.064-mm Al-foil cladding
R = 1.92 cm	R = 1.73 cm
h = 5.1 mm	h = 2.1 mm
m_U = 107.5 g = 0.426 mole (U5)	m_{Pu} = 28.7 g = 0.12 mole
93.15% ^{235}U	99.1% ^{239}Pu

Cylindrical target samples were used by Islam and Knitter

Islam and Knitter

beam, detector ⊥ axis



0.2-mm Al can

R_o = 1.50 cm, R_i = 1.05 cm

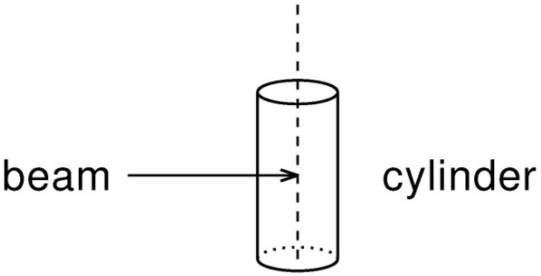
h = 2.46 cm

m_U = 161.3 g = 0.639 mole (U5)

3.15% ^{235}U

Knitter

beam, detector ⊥ axis



0.2-mm Zircalloy cladding

R = 0.6 cm

h = 2.5 cm

m_{Pu} = 54.8 g = 0.23 mole

98.91% ^{239}Pu

How did Knitter and Staples handle target corrections?

Staples:

"Multiple scattering corrections and neutron attenuation corrections have not been performed because the samples are so small that these effects can be neglected."

Knitter:

"The result of the fit gave an average fission neutron energy of

$$\langle E \rangle = 3/2T = 2.12 \pm 0.01 \text{ MeV}$$

This result contains a small calculable systematic error, since the fission neutrons produced in the sample can make secondary interactions with the sample material. Correction calculations were done in the manner described in a previous paper [1]."

[1] Kiefhaber,E., D. Thiem: Panel Proceedings Series, p127, IAEA Vienna (1972)

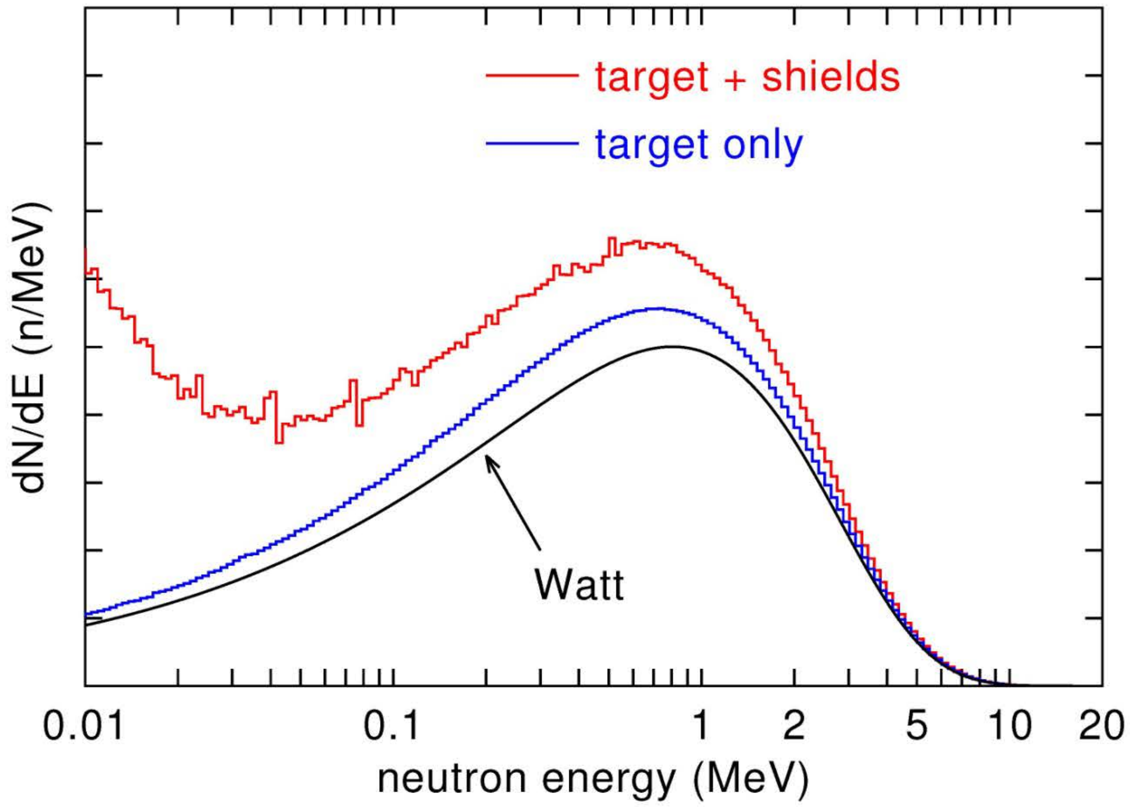
→ cf. Islam and Knitter, Nucl. Sci. Eng. 50, 108 (1973)

Sample specifications needed to be corrected for Staples experiment

Quantity	Nucl. Phys.	Revised (Prof. Egan)
235U Radius (cm)	3.84	1.92
Thickness (cm)	0.5	0.51
Mass (g)	62	107.5
Enrichment (%)	93	93.15
239Pu Radius (cm)	3.46	1.73
Thickness (cm)	0.2	0.21
Mass (g)	28.7	28.7
Enrichment (%)	98	99.1

Multiple scattering plays a significant role in the ^{239}Pu measurements of Staples *et al.*

MCNP flux at the detector position



two effects:

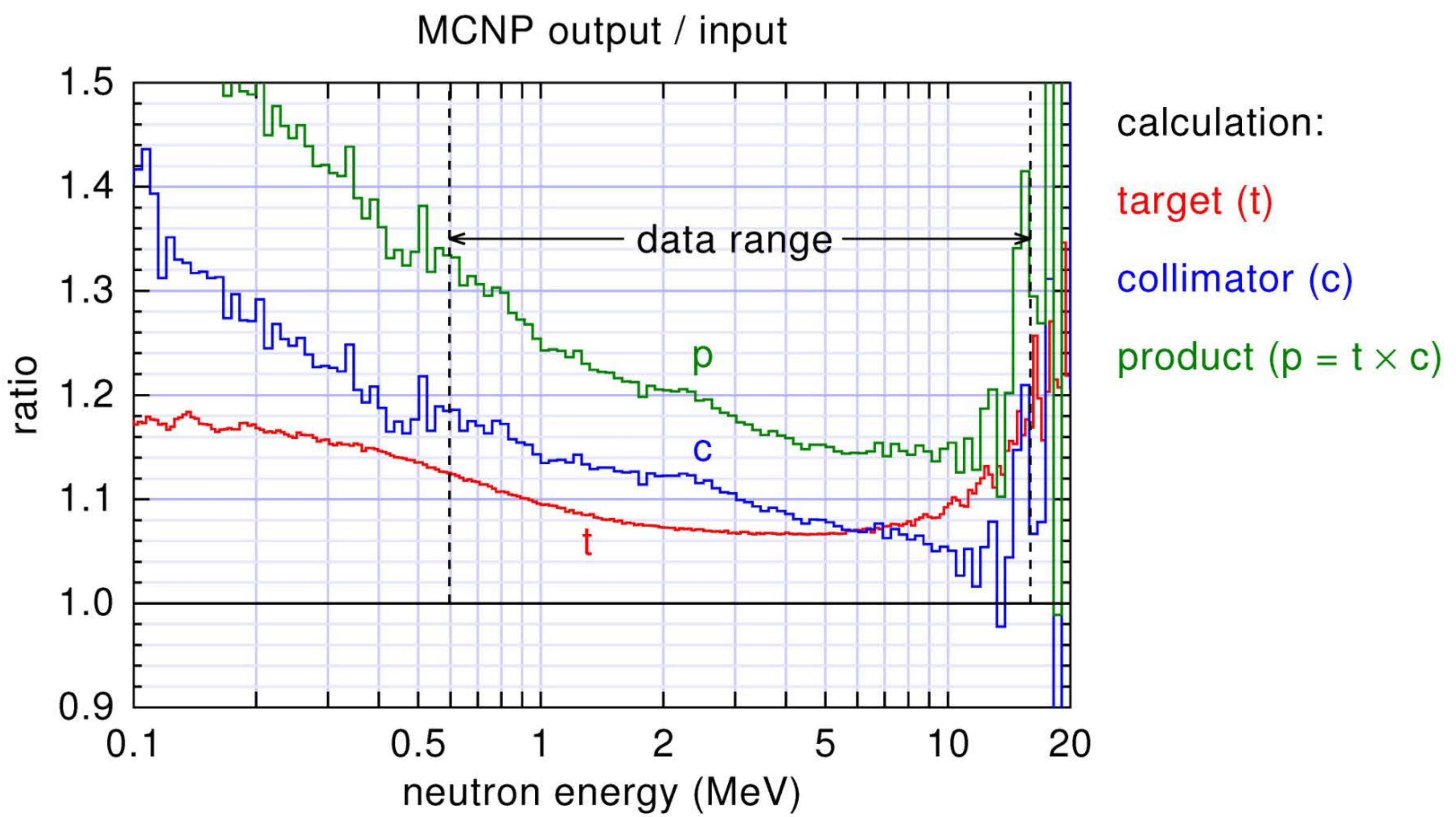
n-multiplication

in-scattering

calculations for

^{239}Pu target

Target and collimator effects in the ^{239}Pu data of Staples *et al.*



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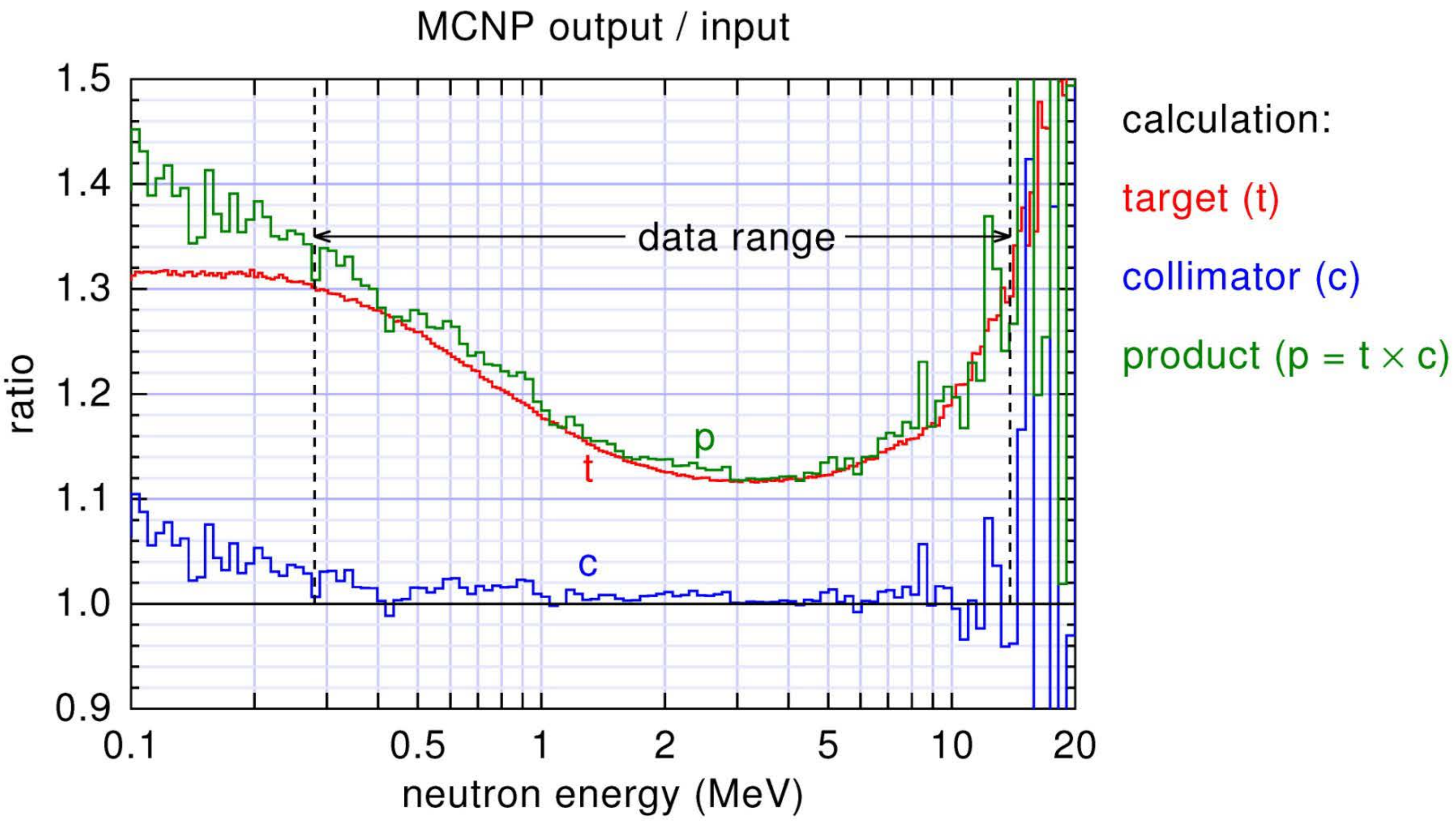
Target and collimator effects in the ^{239}Pu data of Knitter



Fast neutron-induced fission - - white source of incident neutrons

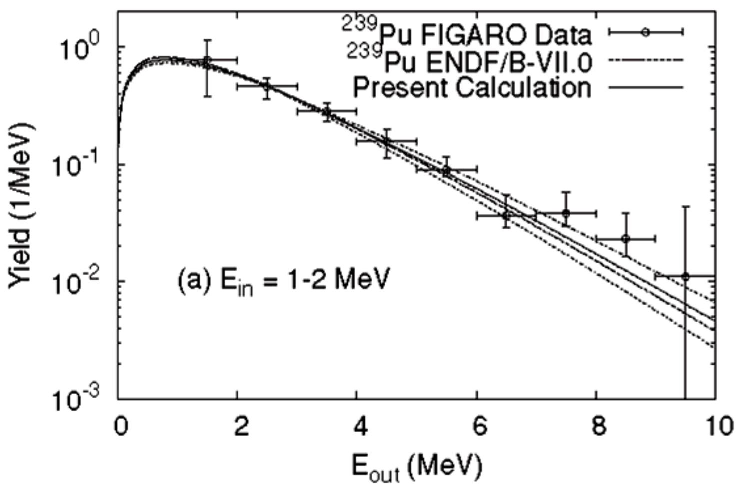
- Noda – Einc = 1 – 8 MeV
- Chatillon Einc = 1 - 200 MeV

Measurements made with “white” neutron source at LANSCE for ^{239}Pu(n,f): CEA-LANL collaboration

EST. 1943

S. Noda et al., Phys. Rev. C 83, 034604 (2011)

A. Chatillon et al., Phys. Rev. C 89, 014611 (2014)



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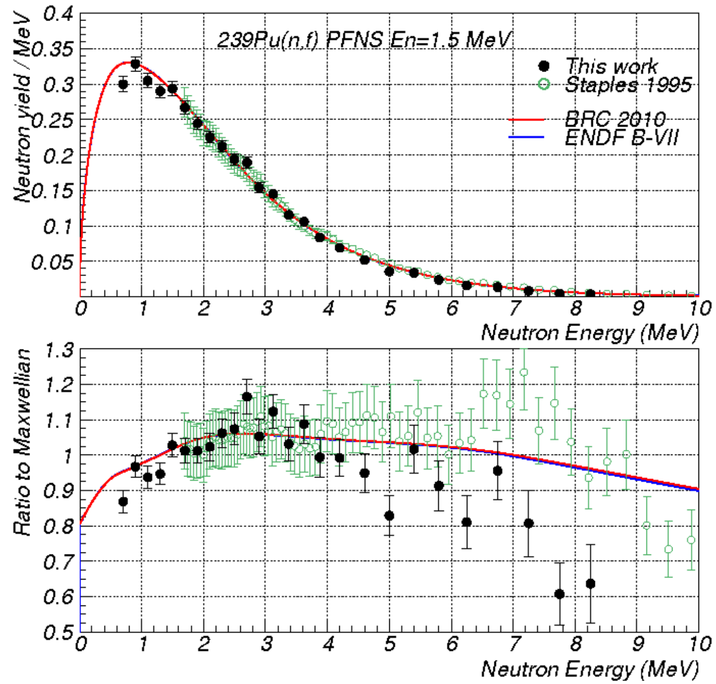
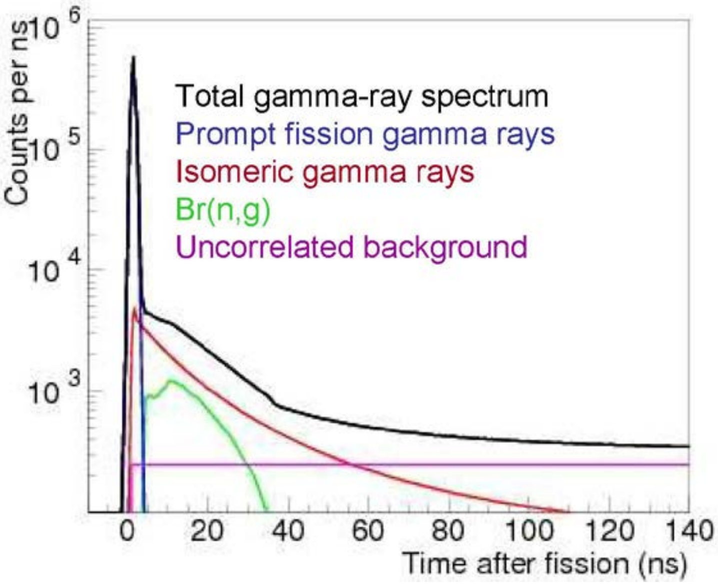


Data > ENDF for Eout > 7 MeV

Data < ENDF for Eout > 7 MeV

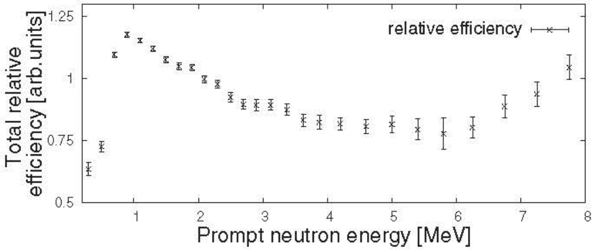
Note: Data for both also for Einc = 1.0 to > 20 MeV

Chatillon detector response was determined by ^{252}Cf source and gamma-ray trigger



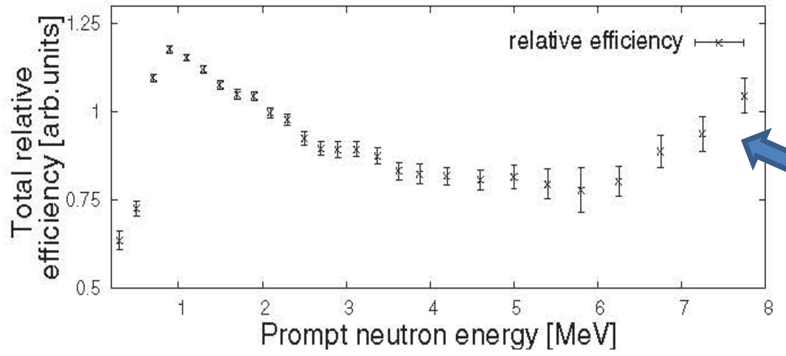
- Late trigger would make neutrons seem to have higher energy than they really do

Incorrect higher detector efficiency especially at the high energies

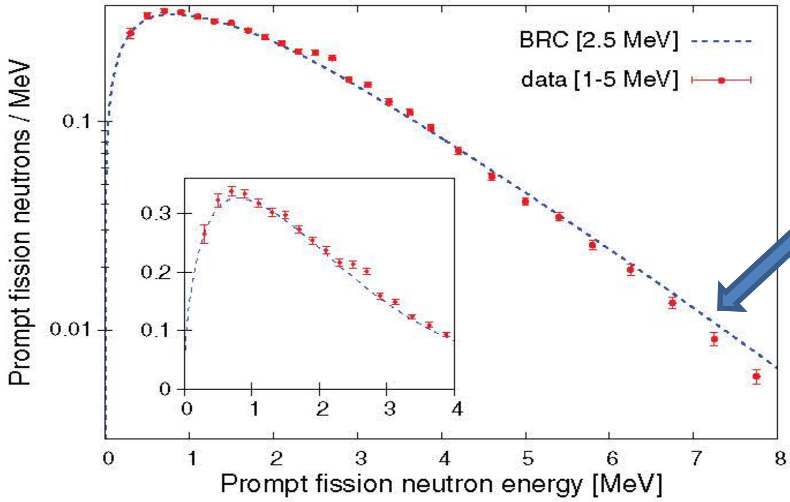


Incorrect lower neutron output especially at the high energies

Incorrect efficiency leads to incorrect (lower) PFNS at the higher output energies



Incorrect higher detector efficiency especially at the high energies



Incorrect lower neutron output especially at the high energies

And there will be some corrections to the Noda data, e.g. detector response, binning…

Reprise: Some issues in PFNS measurements

- Multiple scattering
  - In sample
  - In collimators
  - In detector
- Detector response
  - Including scattering
  - Light curves for scintillators
- Calibration problems

Colleagues in PFNS experiments at LANSCE

- LANL: H. Y. Lee, T. N. Taddeucci, J. M. O'Donnell, N. Fotiades, M. Devlin, J. L. Ullmann, T. Bredeweg, M. Jandel, R. O. Nelson, S. A. Wender, D. Neudecker, M. Rising, S. Mosby, S. Sjue, M. White; R. C. Haight
- LLNL: C.-Y. Wu, B. Bucher, R. Henderson
- CEA: T. Ethvignot, T. Granier, A. Chatillon, J. Taieb, B. Laurent

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  Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

- This work was supported by DOE-NNSA – Thank you!!

Backup Slides

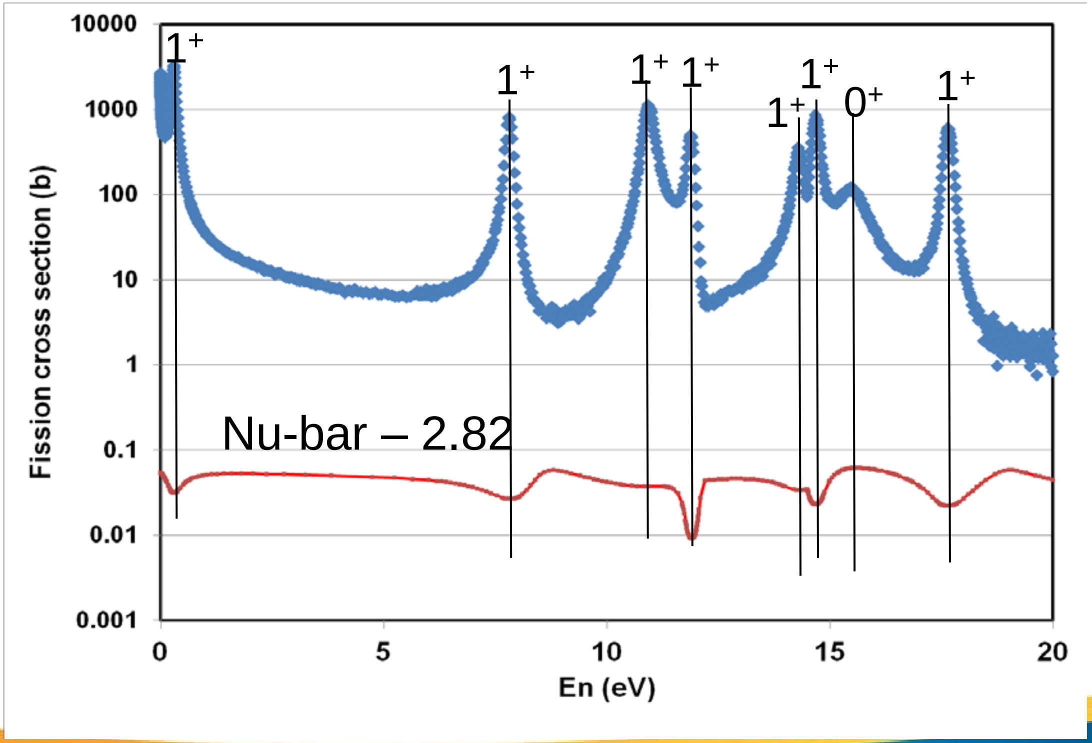
And now some speculation

$^{239}Pu(n_{th},f)$ – is it a good guide for PFNS in fast-neutron-induced fission?

- **Prompt fission neutron spectra have been measured at thermal for ^{235}U and ^{235}Pu. Reactions at thermal can be dominated by one or only a few resonances**
- **Do the data at thermal have any relevance to PFNS for fission induced by higher energy neutrons?**
- **Zero order analysis – look at average number of neutrons emitted in fission. If they vary with incident neutron energy, then there could well be a change in the spectra of emitted neutrons**

Correlate structure in nu-bar for $^{239}Pu(n,f)$ with fission cross section

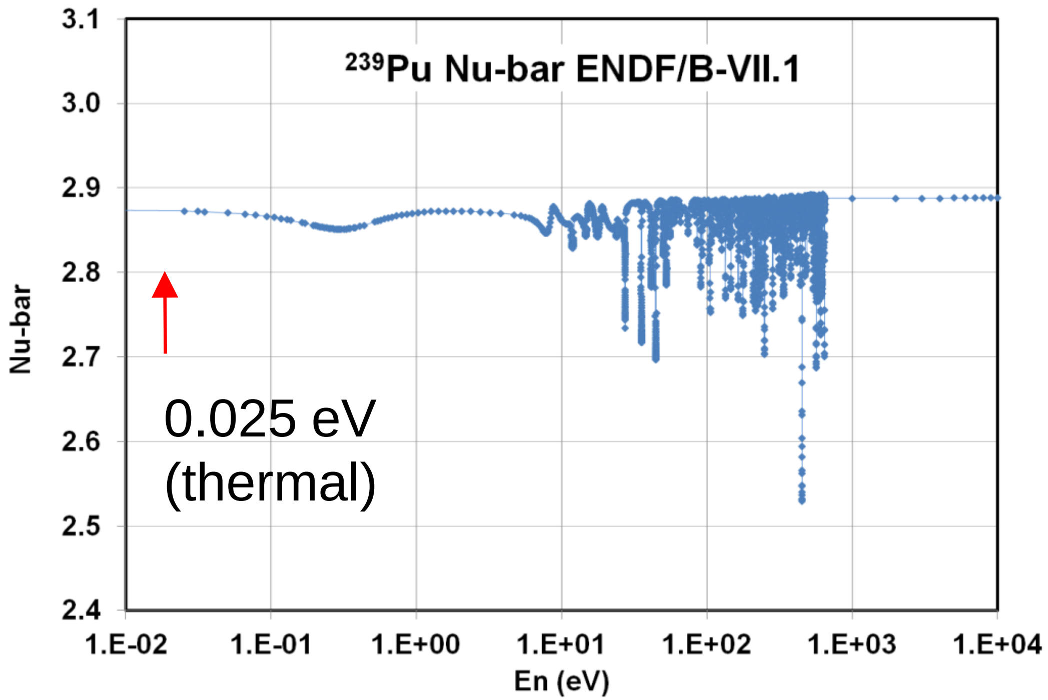
- Fission cross section from Weston [NSE 115,164 (1993)]
- Subtract a constant (2.82) from nu-bar for clarity of display
- Add spins and parities (all positive) from Mughabghab
  - 0+ resonance shows no effect in nu-bar
  - 1+ resonances show varying effects



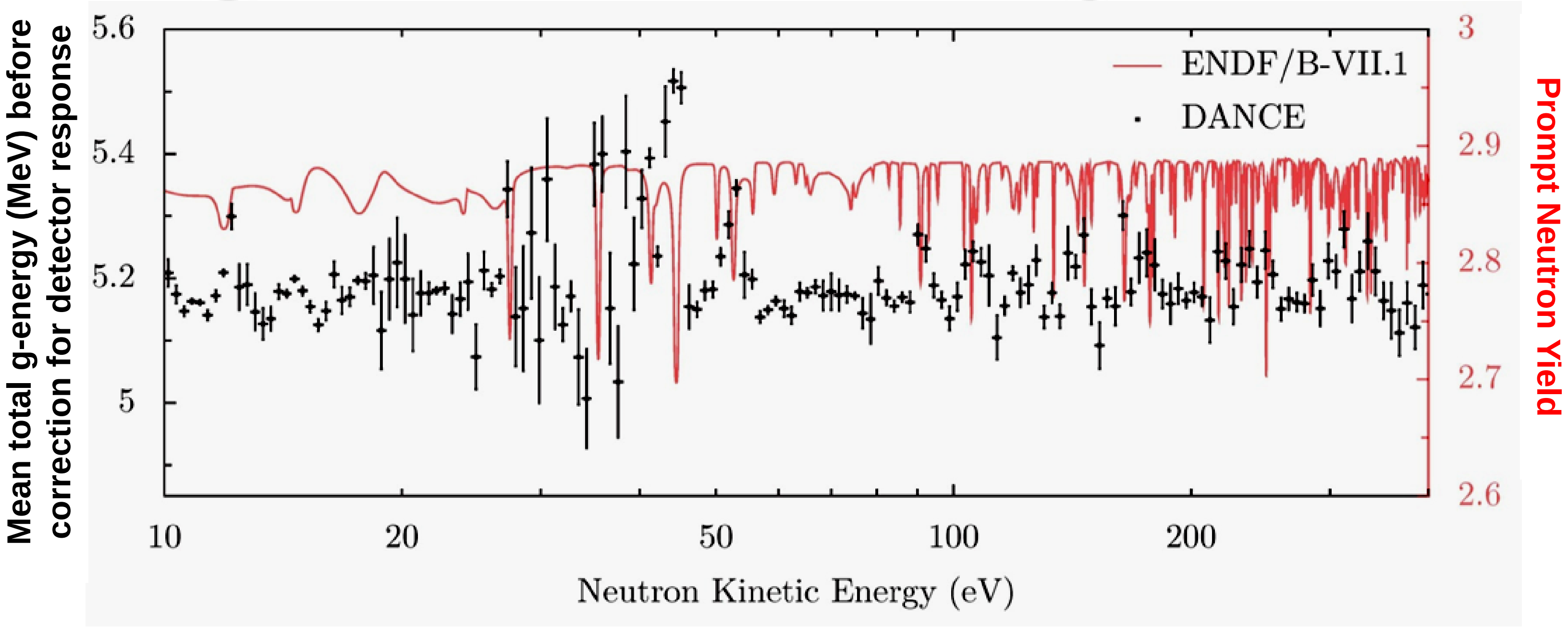
Probably (n,γ f) process

Now the good news (maybe)

- Nu-bar at thermal for ^{239}Pu(n,f) is almost the same as for 1-10 keV. Maybe the thermal neutron PFNS is relevant to higher energies
- Q: Is nu-bar at thermal dominated by the 1^{+} resonance at 0.3 eV ?



Fission total γ-ray energy vs. incident neutron energy for $^{239}Pu(n,f)$



- Fluctuations in prompt fission gamma energy anti-correlated with neutron emission
- More detailed information on $^{239}Pu(n,\gamma f)$ process (Lynn, 1965)
- Qualitative behavior reported by Shackleton in 1972

Necessary components for improving PFNS data

- **Experiments**
  - Neutron source – **intense, low background needed** -- **no new facilities for this type of measurement (?) :- (**
  - Detectors – **good neutron identification (psd or ?), good efficiency, "modelable" in MCNP** -- **nothing for greatly advanced capabilities :- (**
  - Data acquisition – implementation of new hardware, firmware, software – **good resolution, good timing, programmable, capable of handling high counting rates** -- **In progress :-)**
- **Modeling** neutron transport as corrections to literature data, and design and analysis of new experiments-- **NOW and continuing :-))**

Predictions for PFNS measurements

- ^{239}Pu(n,f) – for incident neutron energies > 0.5 MeV and to requested accuracy
  - Resolve discrepancies for PFNS > 0.5 MeV – probable in 2-3 years
  - Produce new data for PFNS in range 0.05 to 0.50 MeV -- maybe in 3-4 years
- ^{235}U(n,f) – for incident neutron energies > 0.5 MeV
  - Data for PFNS > 0.5 MeV – probable in 3-4 years
  - Produce new data for PFNS in range 0.05 to 0.50 MeV -- maybe in 4-5 years