Nuclear Data Experiments at LANSCE: Highlights 2009

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Cross Section Evaluation Working Group Meeting
US Nuclear Data Program Meeting
Brookhaven National Laboratory
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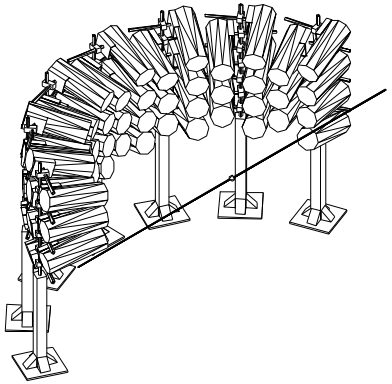
LA-UR-09-06991

Nuclear data measurements at LANSCE are made with several instruments

GEANIE (n,xγ)

FIGARO (n,xn+γ)



DANCE (n,γ)

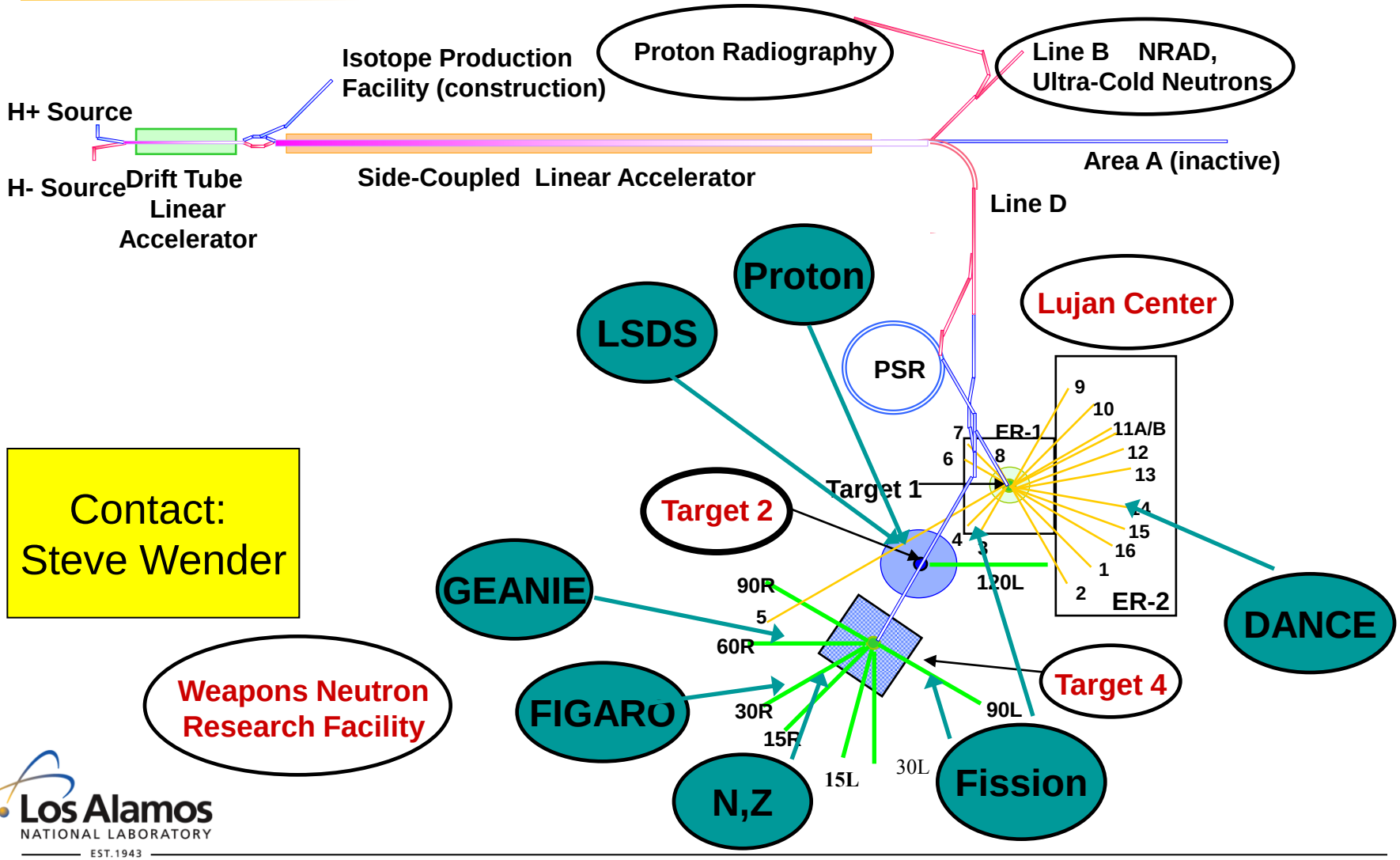
N,Z (n,charged particle)

Fission

LSDS

Double Frisch-grid fission chamber; also standard fission ion chamber; new detector station for fission and (n,alpha)

Nuclear data experiments at LANSCE use neutrons at the Lujan Center, Target 2 and Target 4



Contact:
Steve Wender

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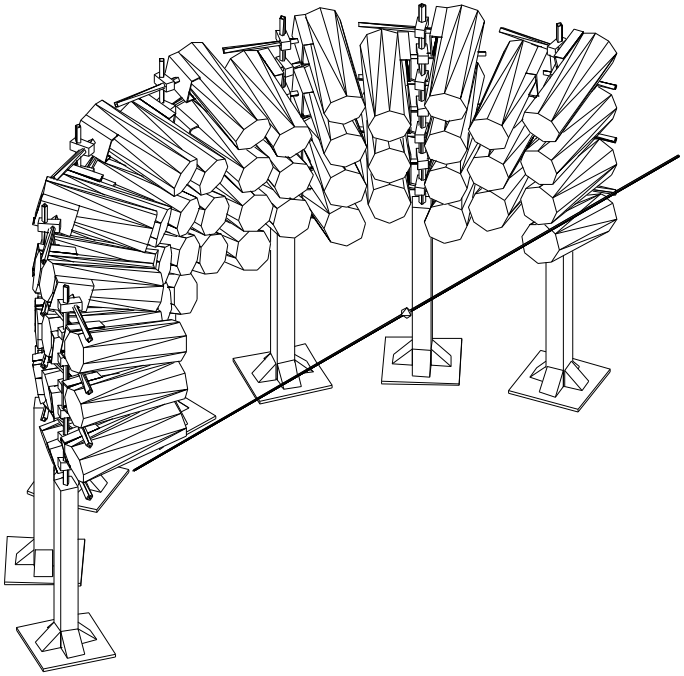
NNSA

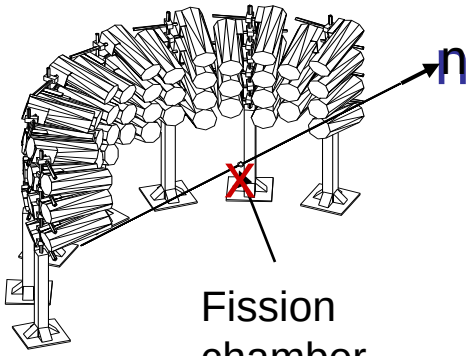
Chi-Nu (aka FIGARO) (n,xn+γ)



Contact:
Bob Haight
Ron Nelson
Matt Devlin

Chi-nu array of detectors for measuring neutron-emission spectra

FIGARO (n,xn+γ)



22.7 m from WNR source

- **20 liquid scintillator neutron detectors**
- **2 gamma-ray detectors**

Double time-of-flight experiment

Present experiments at Chi-Nu/WNR: neutron-emission spectra and ν-bar in fission

Fissionable isotopes: CEA fission chambers in beam

- ^{235}U, ^{239}Pu(n,f) – fission neutron spectra (1-8 MeV)
  - Analyzed new measurement for ^{239}Pu(n,f)
  - Improvements in fission detector, neutron detectors, DAQ
  - ^{232}Th fission neutron spectra (in progress)

Other materials: Gamma-ray trigger (HPGe, BaF_2, $LaBr_3$)

- ^{56}Fe,$^{\text{all-A}}$Mo, $^{\text{nat}}$Ba – to measure (n,xn) emission spectra

  1 MeV < E_n < 200 MeV
  (in progress)

Staples data look pretty good …

^{239}Pu(n,f) – fission neutrons

Solid curve is from Madland and Nix

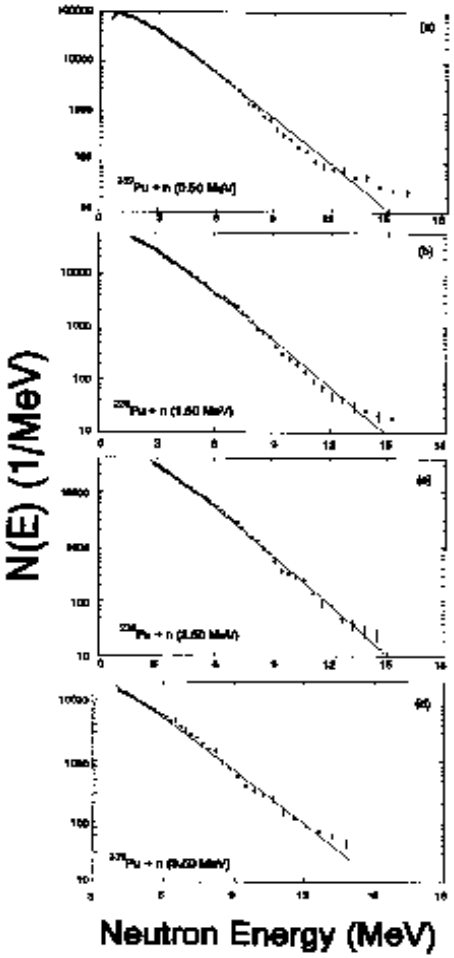


Fig. 7. The relative fission neutron yield for ^{239}Pu at the incident neutron energies of (a) 0.50, (b) 1.50, (c) 2.50 and (d) 3.50 MeV. The solid line is the calculation by Madland and Nix [3,6]

En - incident

0.5 MeV

1.5 MeV

2.5 MeV

3.5 MeV

For better visibility of the 4 orders of magnitude:

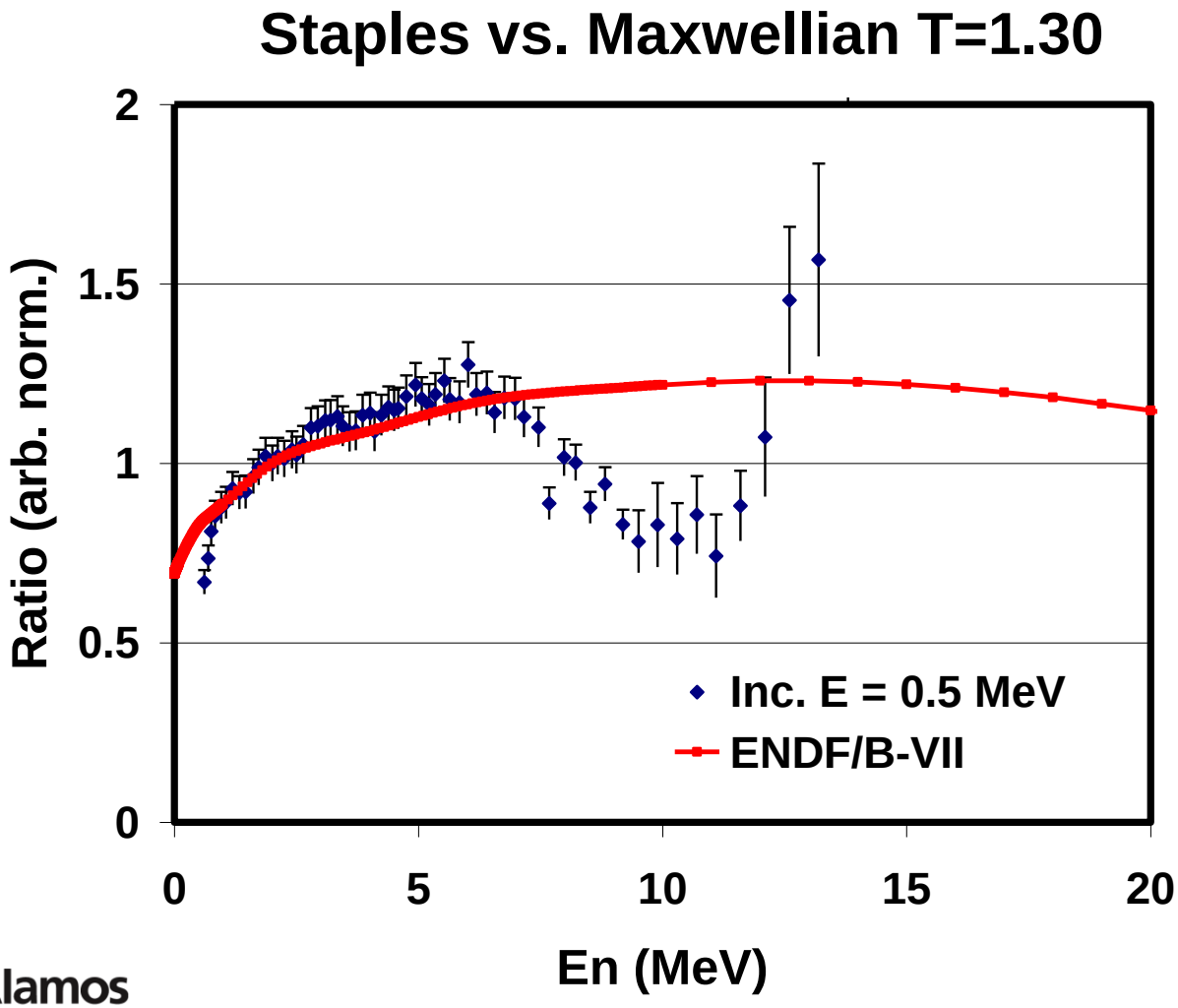
- **Take ratio of data to Maxwellian**

$$N(E) \sim \sqrt{E}\ \exp(-E/T)$$

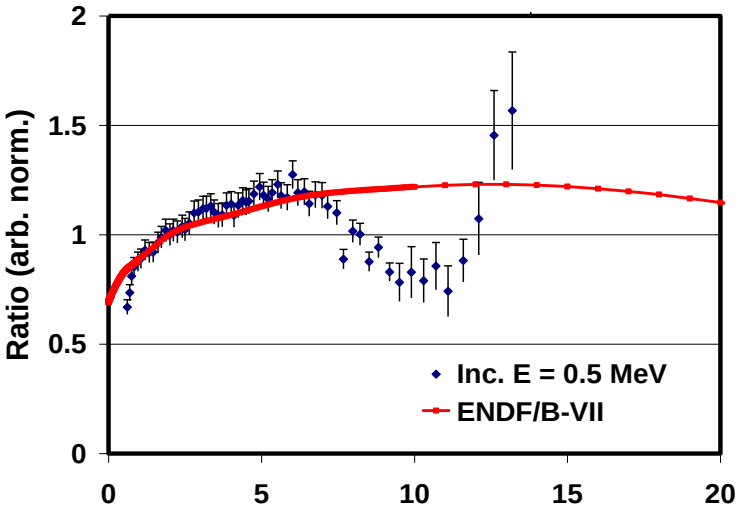
with T = 1.30 MeV

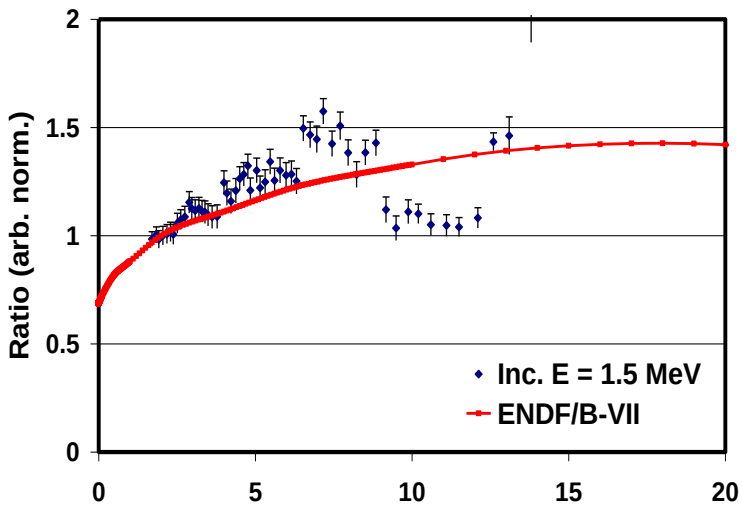
This form is taken for <u>convenience only</u>

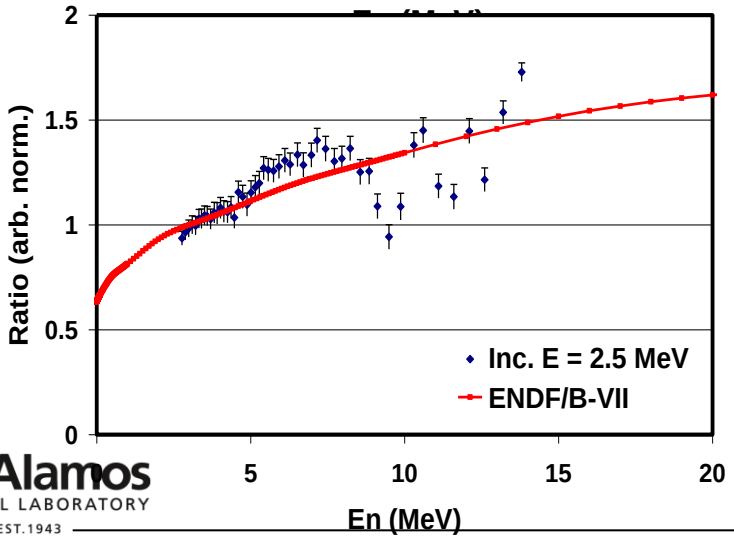
Staples @ 0.5 MeV incident neutron energy

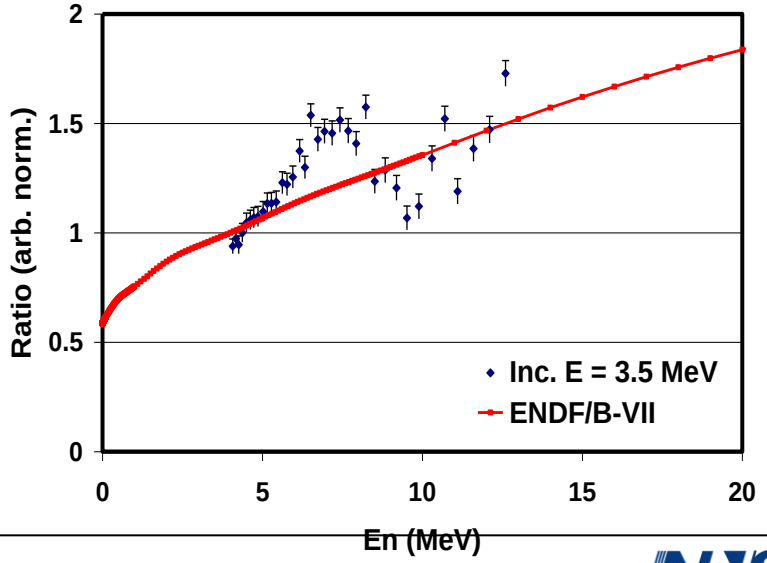


Reprise: Staples and ENDF/B-VII.0 vs. Maxwellian (1.30 MeV)



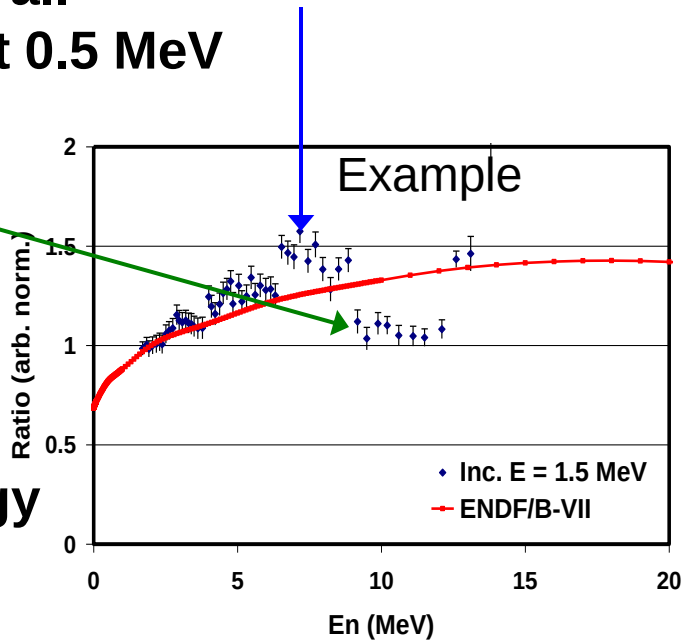






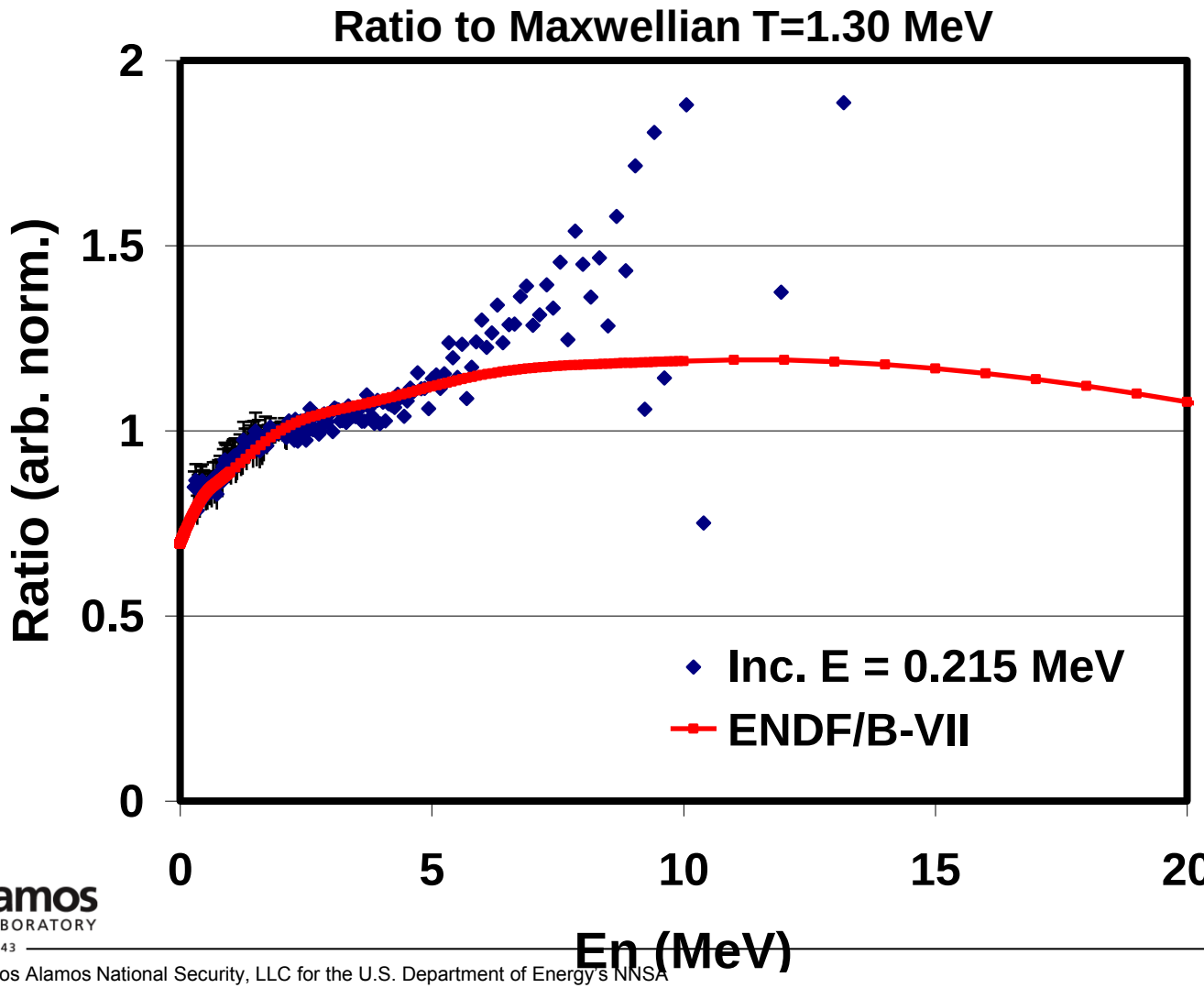
Observations on Staples' data

- Differ from ENDF/B-VII.0 in shape
  - Higher than ENDF in 5 – 8 MeV for all incident neutron energies except 0.5 MeV
  - Dive lower ~ 9 MeV
  - Go bananas above 12 MeV
    → background problem
- Statistical errors rather small (good!)
- No data below incident neutron energy



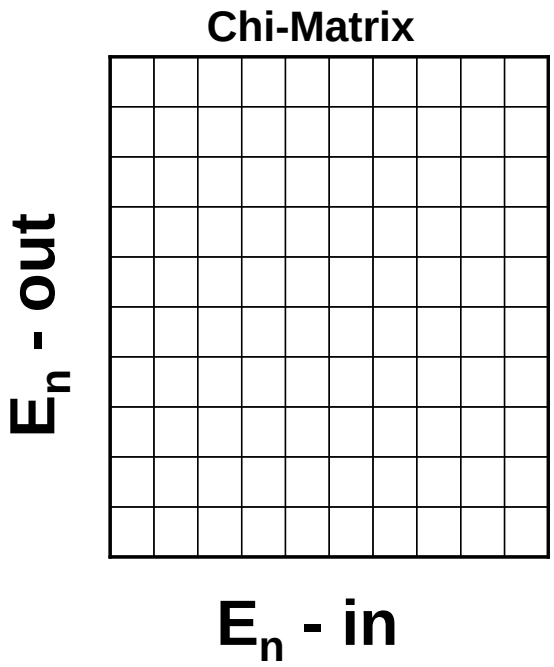
Data -- ratio to Maxwellian with T = 1.30 MeV

Knitter (1972) data; E_{inc} = 0.215 MeV



IRMM
Belgium

Chi-Matrix relates incident neutron energy to fission neutron output



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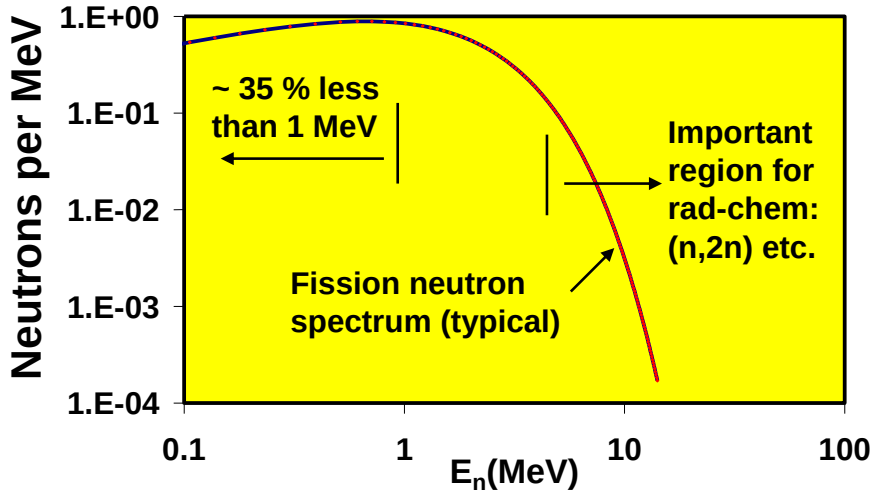
Fission neutron spectrum as a function of incident neutron energy

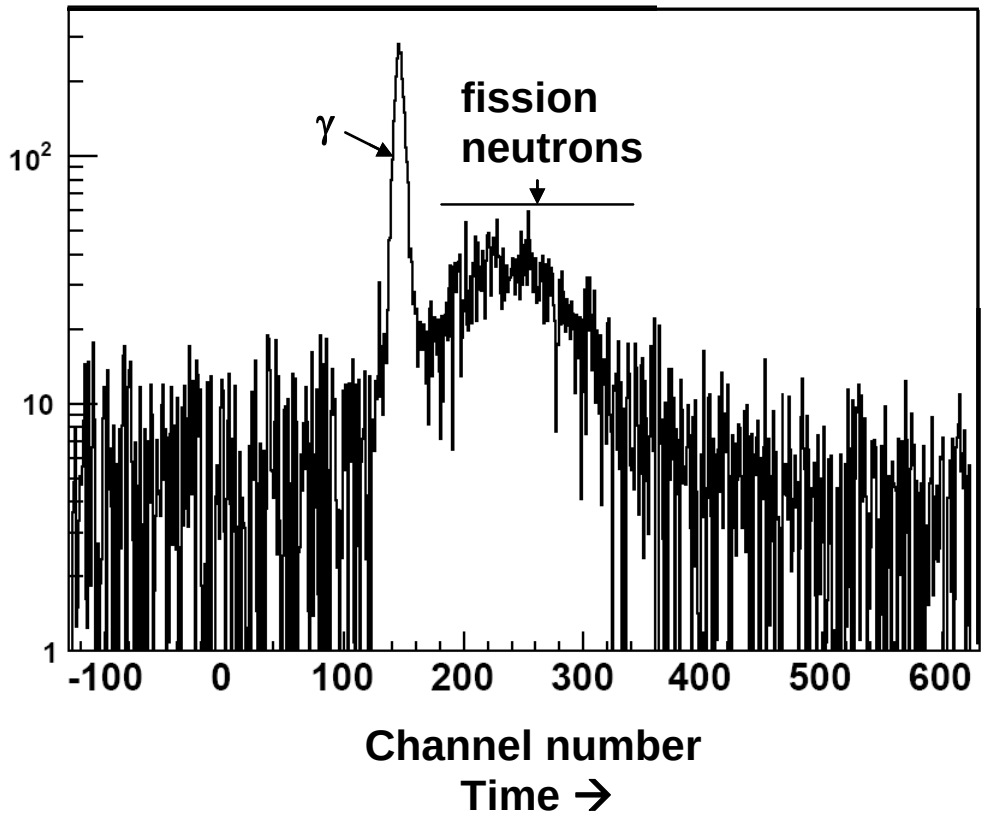


Experimental data base is very limited

Theory (Los Alamos model) is used to generate the chi matrix

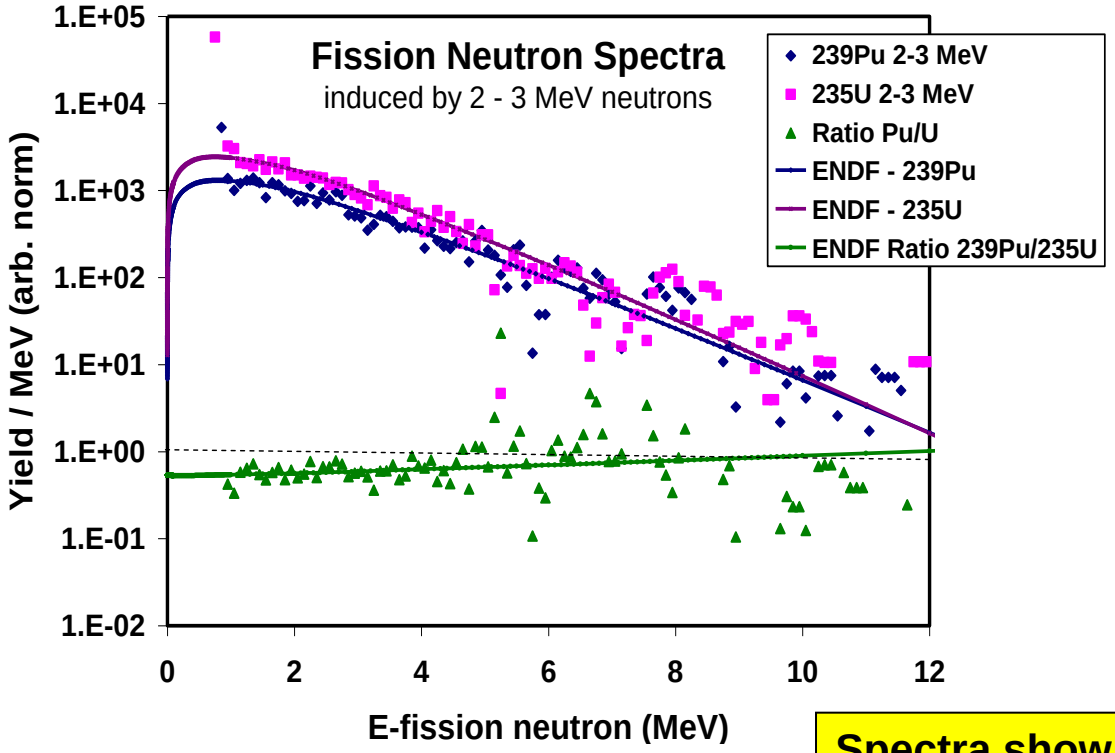
→ significant uncertainties in the chi matrix

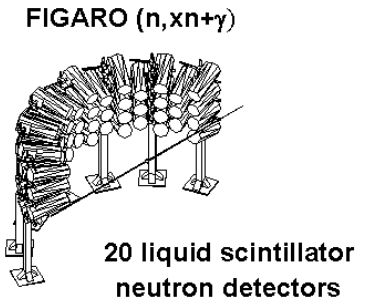
Time difference spectrum from fission shows neutron spectrum



We measure the shapes of fission neutron spectra and ratios of spectra

Incident E_n = 2 to 3 MeV





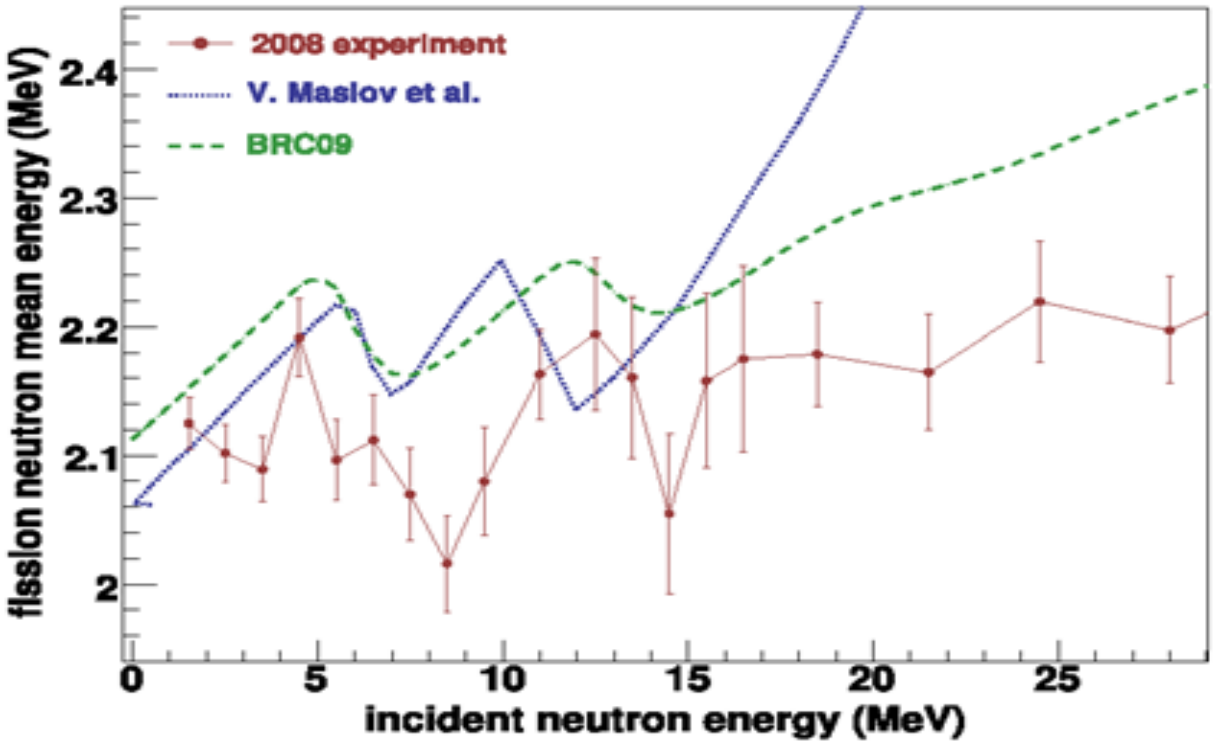
Spectra show no significant difference from ENDF in 1-7 MeV region

Recent progress on fission neutron spectra measurements

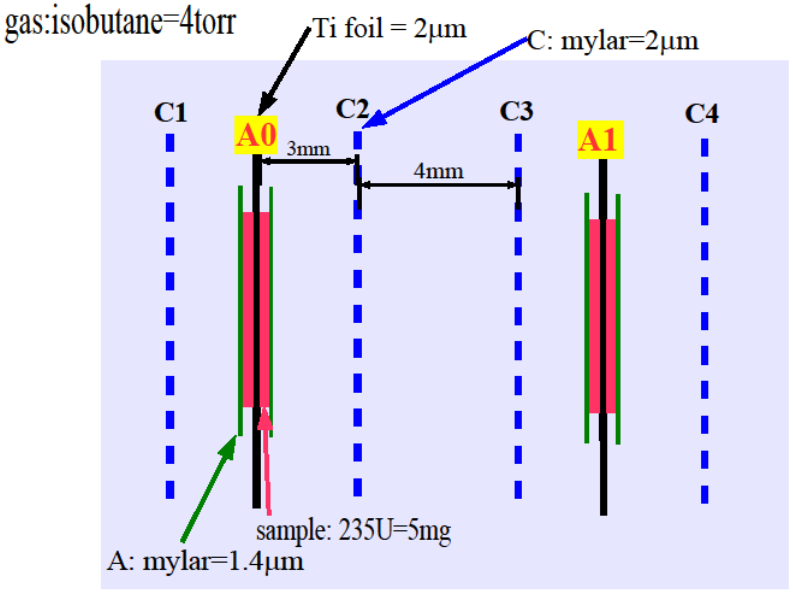
- New results on average fission neutron energy from analysis of ^{239}Pu(n,f) experiment
- LLNL Fission Chamber (Parallel-plate avalanche detector) – tested; much improved over previous fission chambers
- 6Li-glass prototype detector -- tested successfully for detection of fission neutrons with En < 1 MeV
- DAQ – Waveform digitizers assessed: timing vs. sample rate, number of bits, front-end capabilities

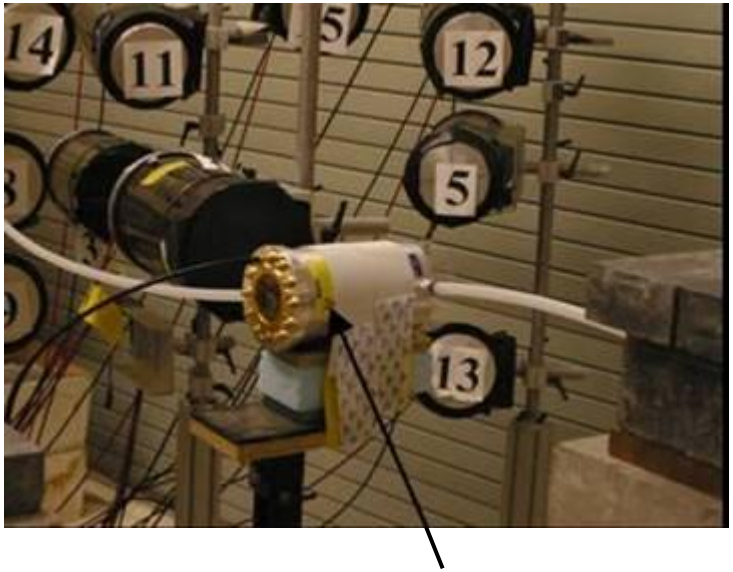
New data on average fission neutron energies

^{239}Pu(n,f)



LLNL fission chamber is a parallel-plate avalanche counter (PPAC)



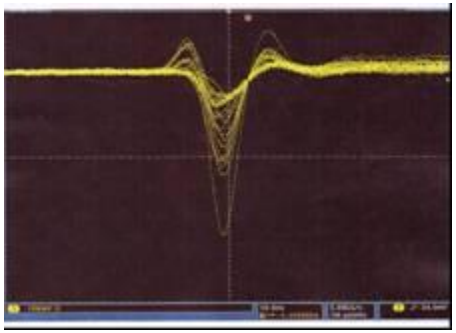


PPAC

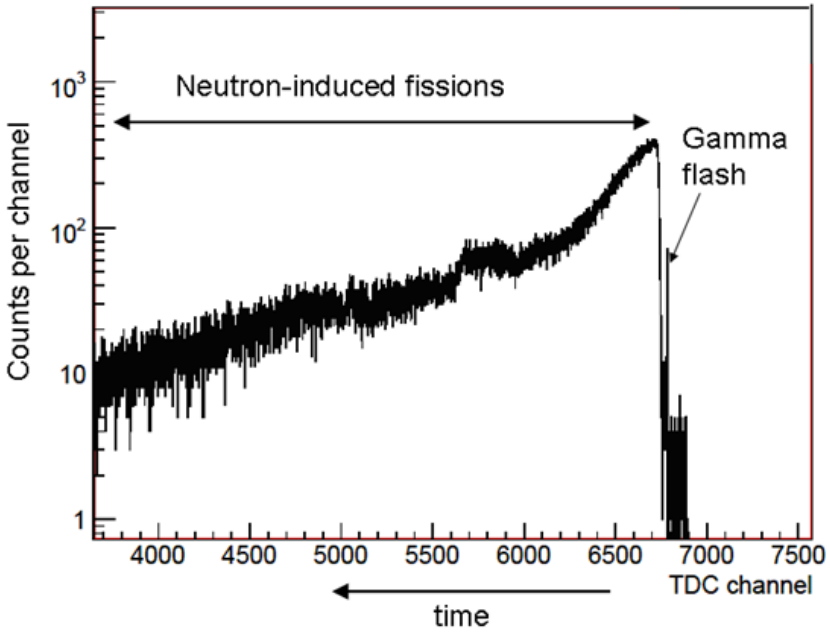
Features of PPAC

- Gas gain for larger signal
- Fast (~ 1ns)

PPAC demonstrated timing of < 1 ns



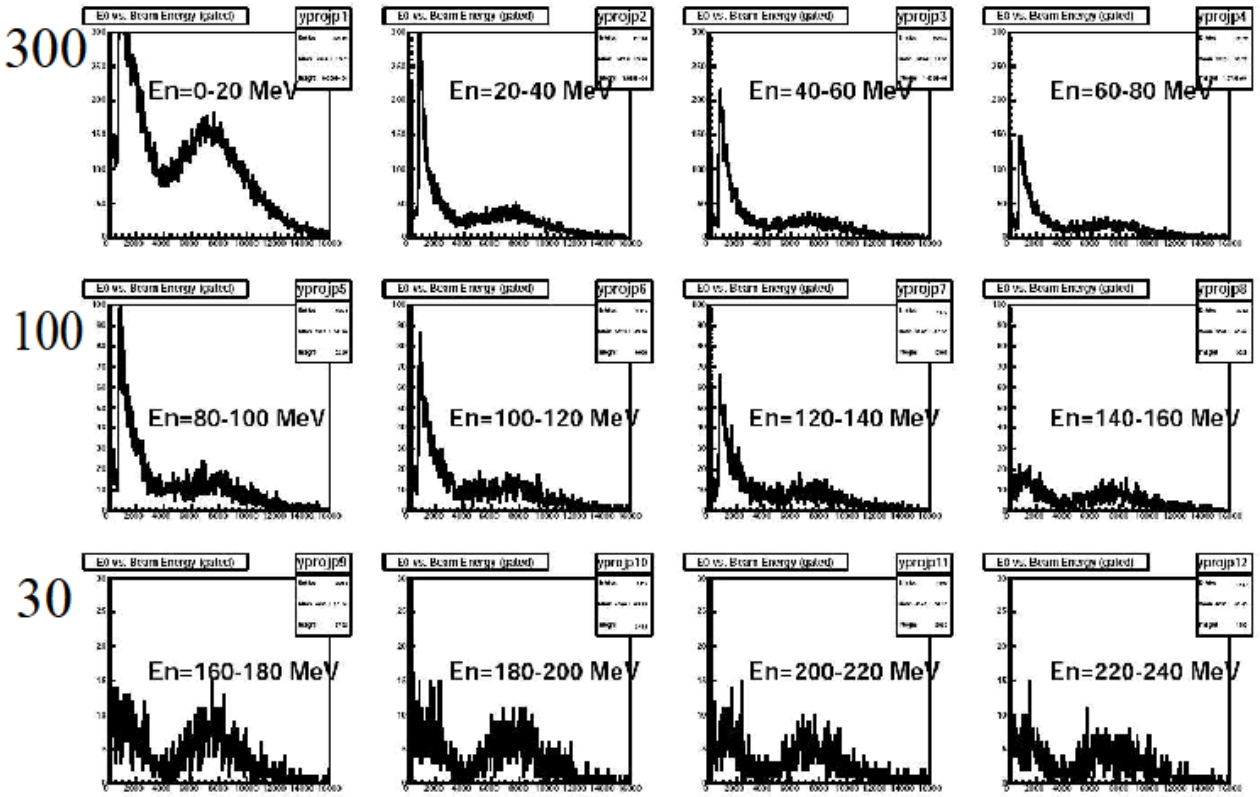
Fast signal
(10 ns/div)



Time resolution of gamma-flash is < 1 ns

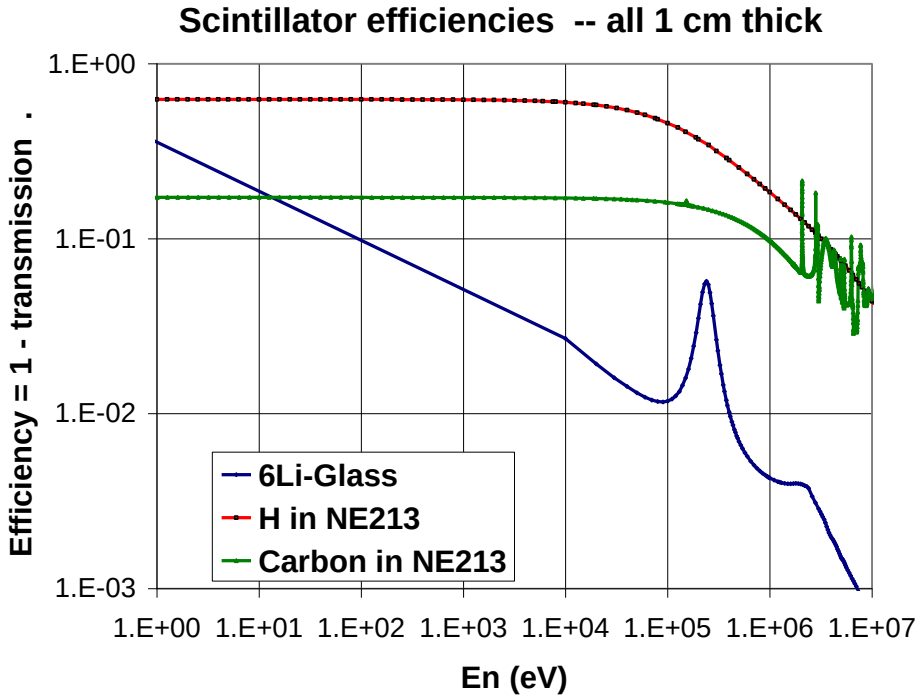
Pulse-height distributions from PPAC clearly show neutron-induced fissions

Run 8414-19 : with neutrons, each plot is gated on the same energy slice of 20 MeV, without any gate.



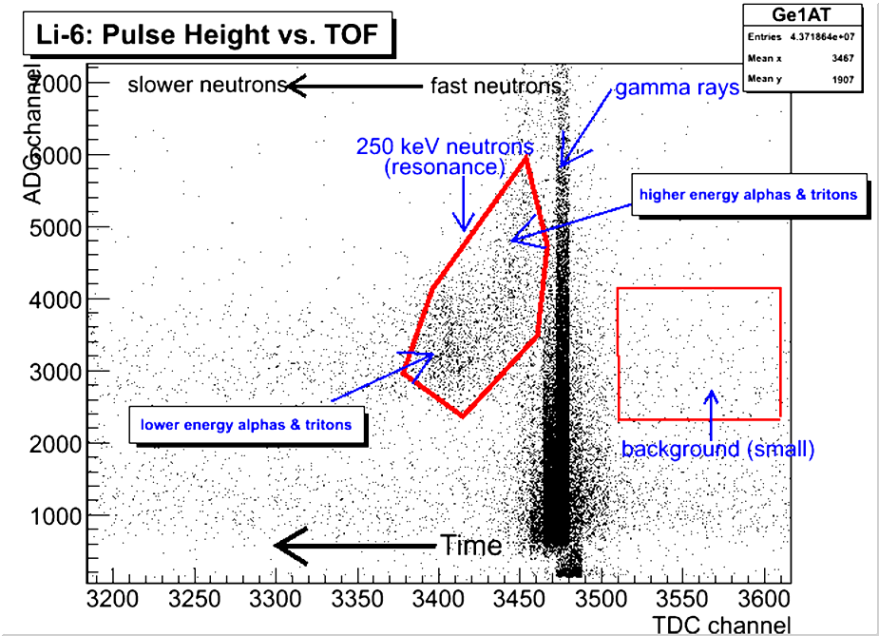
Prototype ^{6}Li-glass neutron detector was tested successfully

- Reaction: $^{6}Li(n,alpha)^{3}H$
- Q-value = 4.8 MeV
- Efficiency good at low En



^{6}Li-glass scintillator detects neutrons cleanly by pulse-height and time of flight

- **Experimental setup**
  - **^{252}Cf spontaneous fission neutron source**
  - **Event gated by gamma rays: BaF_2 scintillator**
  - **^{6}Li glass detector @ 50 cm**
    - **Record pulse height and time of flight relative to gamma rays**
- **Observe pulse height ~ (En + Q-value) and time of flight**



Summary

- We are measuring neutrons emitted in neutron-induced fission of actinides of importance to AFCI, Defense, basic physics
- CEA-LANL collaboration → LLNL now also
- The WNR/LANSCE spallation neutron source produces useful incident neutrons from 1 MeV to ~ 100 MeV
- Fission neutron results so far do not contradict ENDF/B-VII evaluations – (maybe a little at incident neutron energies)
- Program is continuing

Publications to date

- ^{238}U: T. Ethvignot, et al. Physics Letters B575 (2003), 221.
- ^{235}U and ^{238}U: T. Ethvignot, et al. Phys. Rev. Lett. 94, 052701 (2005).
- ^{237}Np and ^{238}U: J. Taieb et al., Int. Conf. on Nuclear Data for Science and Technology, Nice, France, April 23-27, 2007.
- ^{235}U and ^{239}Pu: R. C. Haight et al., LA-UR-08-2585, April 16, 2008.
- several conference proceedings

N,Z Reactions

Z = p, d, t, ^{3}He, α

Contact:
Bob Haight

Double differential (n,charged particle) cross section measurements

- Incident neutron energies from Time-of-flight (TOF)
- Beam flux monitored with a ^{235}U fission foil: resulting cross sections are relative to the ^{235}U fission cross section
- Targets this year (with Ohio University):
  - ^{56}Fe
  - $^{58,60}Ni$

GEANIE (n,xγ)

Contact:
Ron Nelson
Nik Fotiades
Matt Devlin

Recent Neutron-Induced Gamma-Ray Measurements with GEANIE at LANSCE/WNR

$$\sim 1\ \text{MeV} < E_n < 200\ \text{MeV}$$

- **^{191,193}Ir and ^{197}Au isomer production – accepted for publication - Physical Review C, all data to be submitted to NNDC - CSISRS**
- **^{150}Sm(n,n'γ),(n,2nγ) – cross sections & modeling paper submitted to Nuclear Inst. and Methods in Physics Research, B – NC State Univ., LLNL**
- **(n,xγ) for backgrounds in 0$\nu\beta\beta$ decay experiments**
  - **CdZnTe – data acquired 8/2009**
  - **^{nat}Cu – analysis in progress**
  - **^{76}Ge – analysis in progress**
  - **^{nat}Pb – published Phys. Rev. C 79, 054604, 2009**
  - **^{nat}Te -- Michelle Dolinski dissertation, UC Berkeley**
- **^{nat}Lu(n,xγ), – levels, isomers in ^{176}Lu – talk at APS DNP meeting 10/2009**
- **"Fast-neutron-induced gamma-ray reference cross sections"**
  - **^{nat}Ti, V, Nb, In, Au(n,xγ) – new data relative to ^{nat}Cr**
  - **Ti and V are most promising candidates for reference gamma cross sections**

DANCE (n,γ)

Contact:
John Ullmann
Aaron Couture

Analysis of DANCE neutron-capture data

^{89}Y, ^{157}Gd	(Andrii Chyzh, NCSU/Los Alamos: PhD Dissertation)
^{155,156,158}Gd, ^{94,95}Mo	(Bayarbadrakh Baramsai, NCSU/Los Alamos, PhD Dissertation)
^{97}Mo	(Carrie Walker, NCSU, PhD Dissertation)
^{63}Ni	(Aaron Couture, Los Alamos, Ethan Ubersedar, Notre Dame)
^{239}Pu,^{233,235}U	(Capture to fission: Los Alamos, Livermore)
^{191,193}Ir	(Todd Bredeweg, Los Alamos)
^{242m,243}Am	(Marian Jandel, Los Alamos)
^{238}U	(John Ullmann, Los Alamos)

Recent DANCE Publications

- Test of the Statistical Model in ^{96}Mo with the BaF_2 gamma calorimeter DANCE array. S.A. Sheets, et al., Phys. Rev. C 79, 024301 (2009).
  - Spin and Parity Assignment of Neutron Resonances using Gamma-ray Multiplicity. U. Agvaanluvsan, et al., Proceedings of the 1st International Conference on Nuclear Physics and Applications, AIP Conference Proceedings 1109, 11 (2009).
  - Study of Photon Strength Functions for Gadolinium Isotopes with the DANCE array. D. Dashdorj, et al., Proceedings of the 1st International Conference on Nuclear Physics and Applications, AIP Conference Proceedings 1109, 704 (2009).
  - Dancing with the Stars: Measuring Neutron Capture on Unstable Isotopes with DANCE. A. Couture, et al., Proceedings of the 20th International Conference on Applications of Accelerators in Research and Industry, AIP Conference Proceedings 1099, 715 (2009).
  - Neutron capture and neutron-induced fission experiments on americium isotopes with DANCE. M. Jandel, et al., 13th International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics, AIP Conference Proceedings 1090, 220 (2008).
  - Non-Statistical Effects in neutron capture. P.E. Koehler, et al., 13th International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics, AIP Conference Proceedings 1090, 424 (2008).

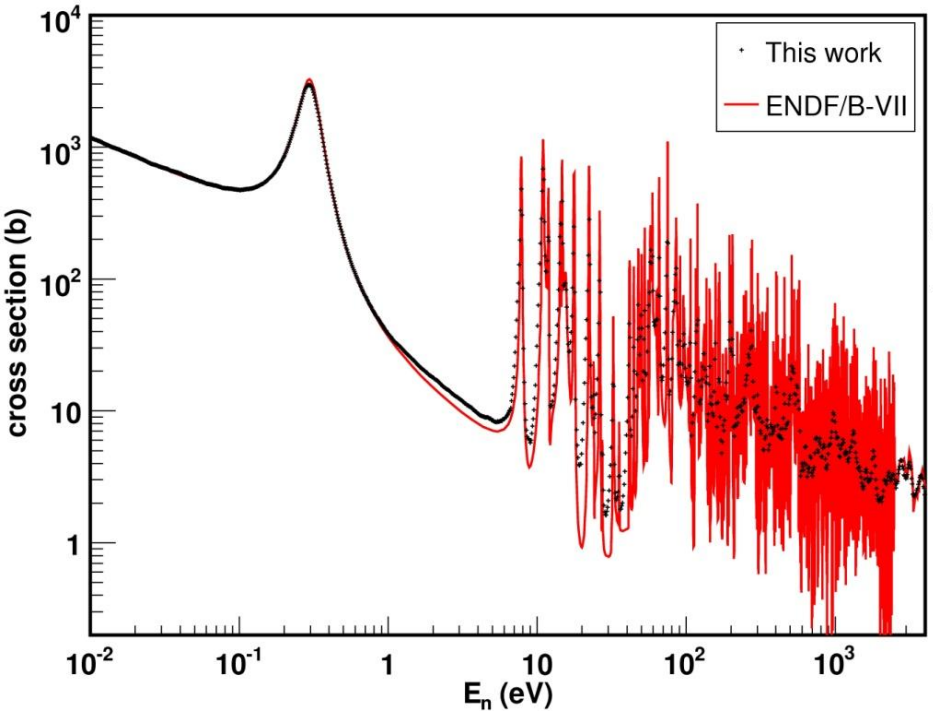
Fission Cross Sections

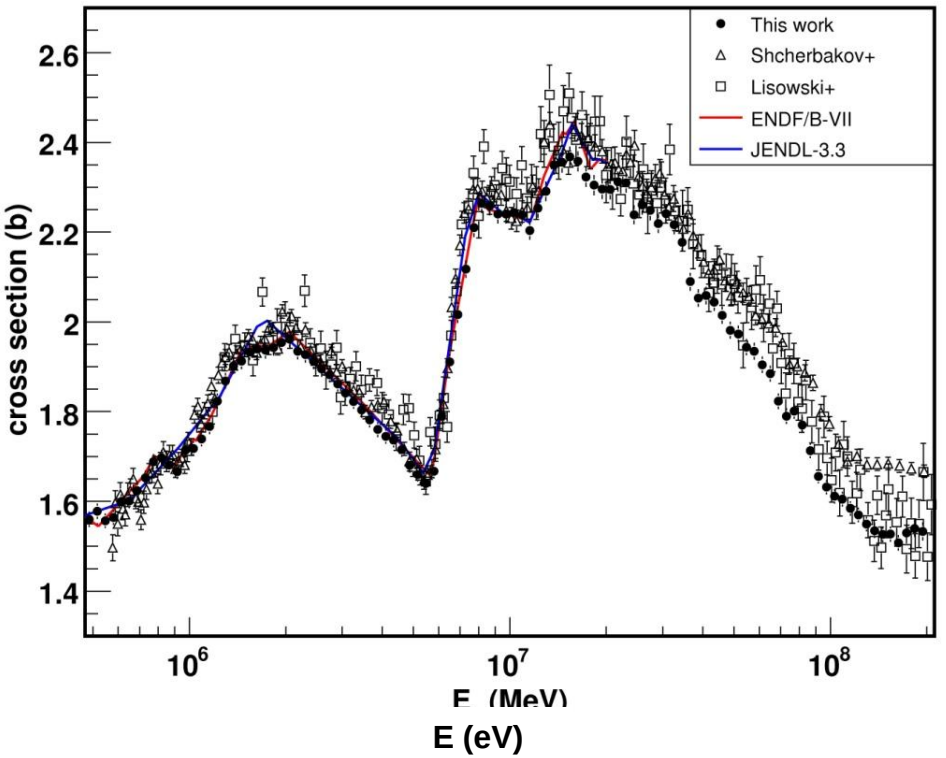
Contact:
Fredrik Tovesson
Alexander Laptev

Recent fission cross section activities at LANSCE

- **Pu-239(n,f) and Pu-241(n,f) cross section measurements completed. Accepted for publication in Nucl. Sci. Engineering.**
- **Am-243(n,f) data collected in the range (E=0.2 – 200 MeV). Analysis is ongoing.**
- **Ongoing development for the fission TPC. Will greatly improve accuracy of fission measurements.**
- **Plans to measure U-235(n,f) relative to H(n,n). First tests planned for later this year.**

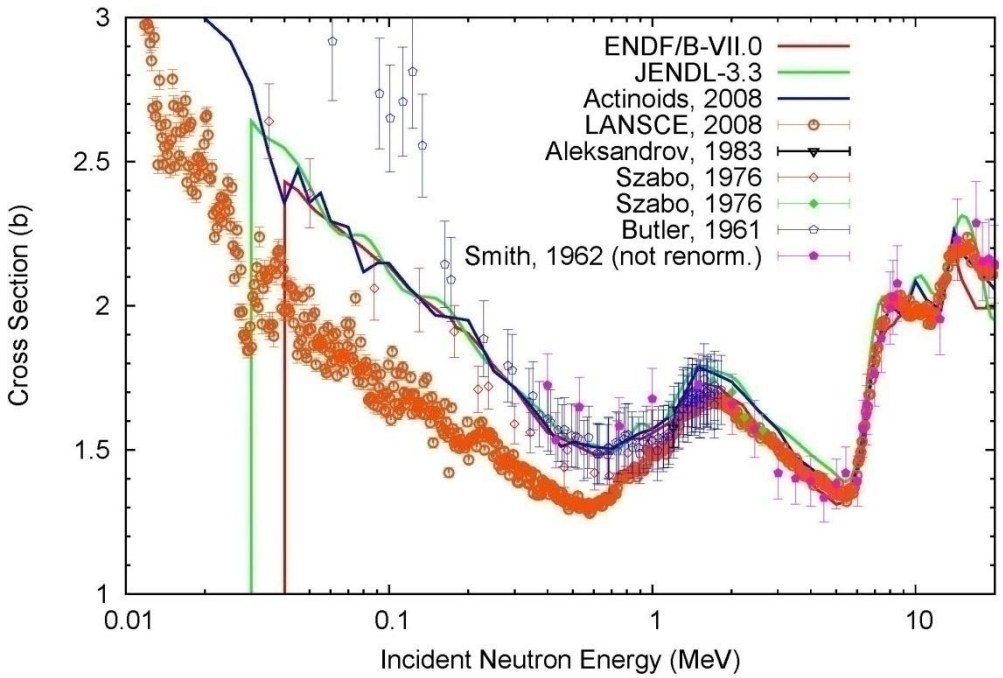
The Pu-239 fission cross section was recently measured at LANSCE





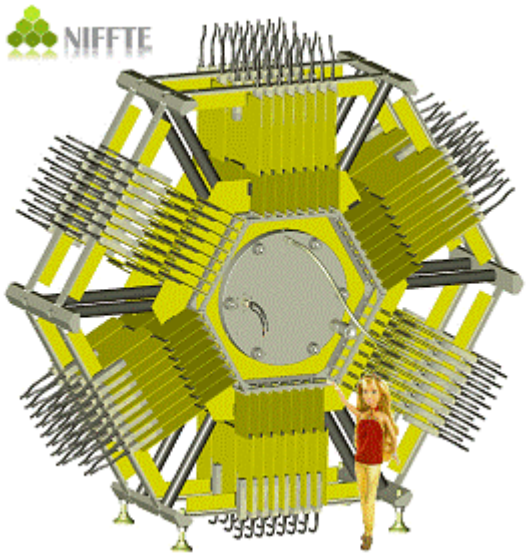
- Full energy range from thermal to 200 MeV covered
- The Pu-239 results are in good agreement with the measurement by Lisowski et al. in the early 90's
- Slight discrepancy with Shcherbakov *et al.* data at high energies

Pu-241 has the shortest half-life of the isotopes measured in the LANSCE fission program

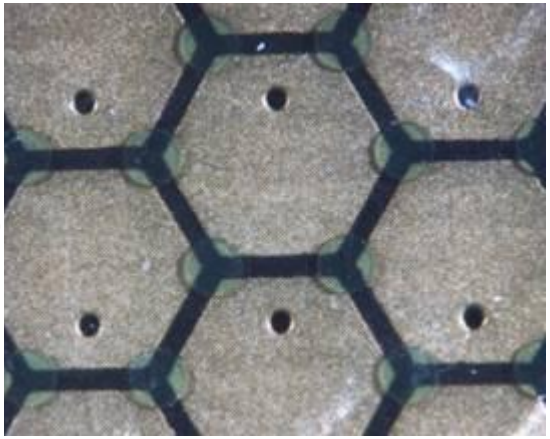


- **The measured cross section is significantly lower in the keV region than the evaluations. Few other data sets are available in EXFOR, and the existing data are relatively old.**
- **The LANSCE data set is the first to extend up to 200 MeV. Even if used only as a shape measurement, it clearly demonstrates the need for a re-evaluation.**

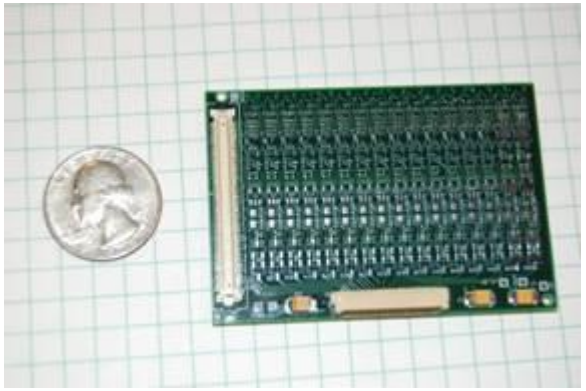
A Fission Time Projection Chamber (TPC) will provide cross section measurements with unprecedented accuracy



MICROMEGAS



Preamp card



Digital card

- **3D pictures of the particle tracks**
  - sample uniformity
  - beam uniformity
  - efficiency
  - erases decay / light charge particle background
- **“Absolute” fission cross sections**

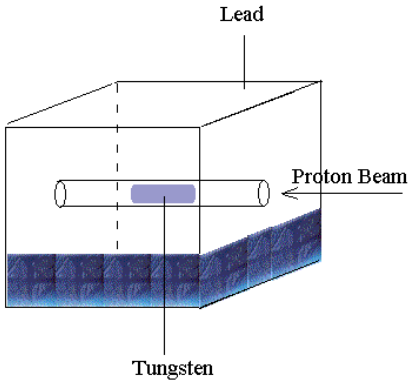
Fission studies

Fission and Other Cross Sections

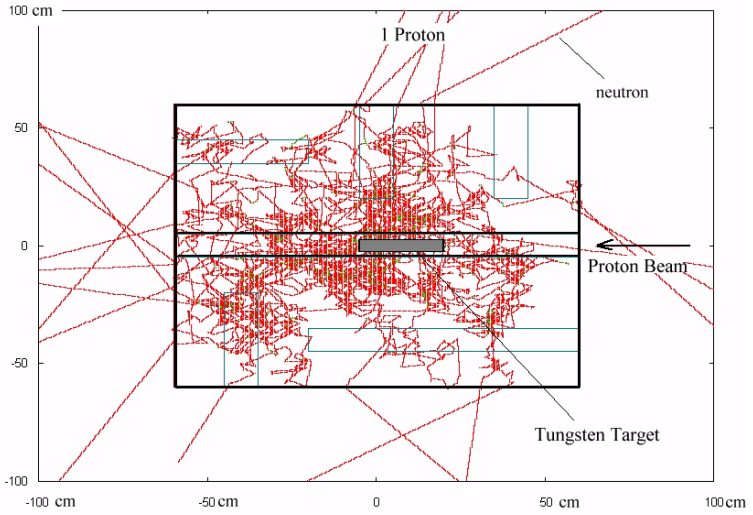
On Very Small Samples

Contact:
Bob Haight

A Lead Slowing-Down Spectrometer is under development, driven by 800 MeV protons from the PSR



Neutron trajectories following the interaction of 1 proton with the tungsten target in the lead cube

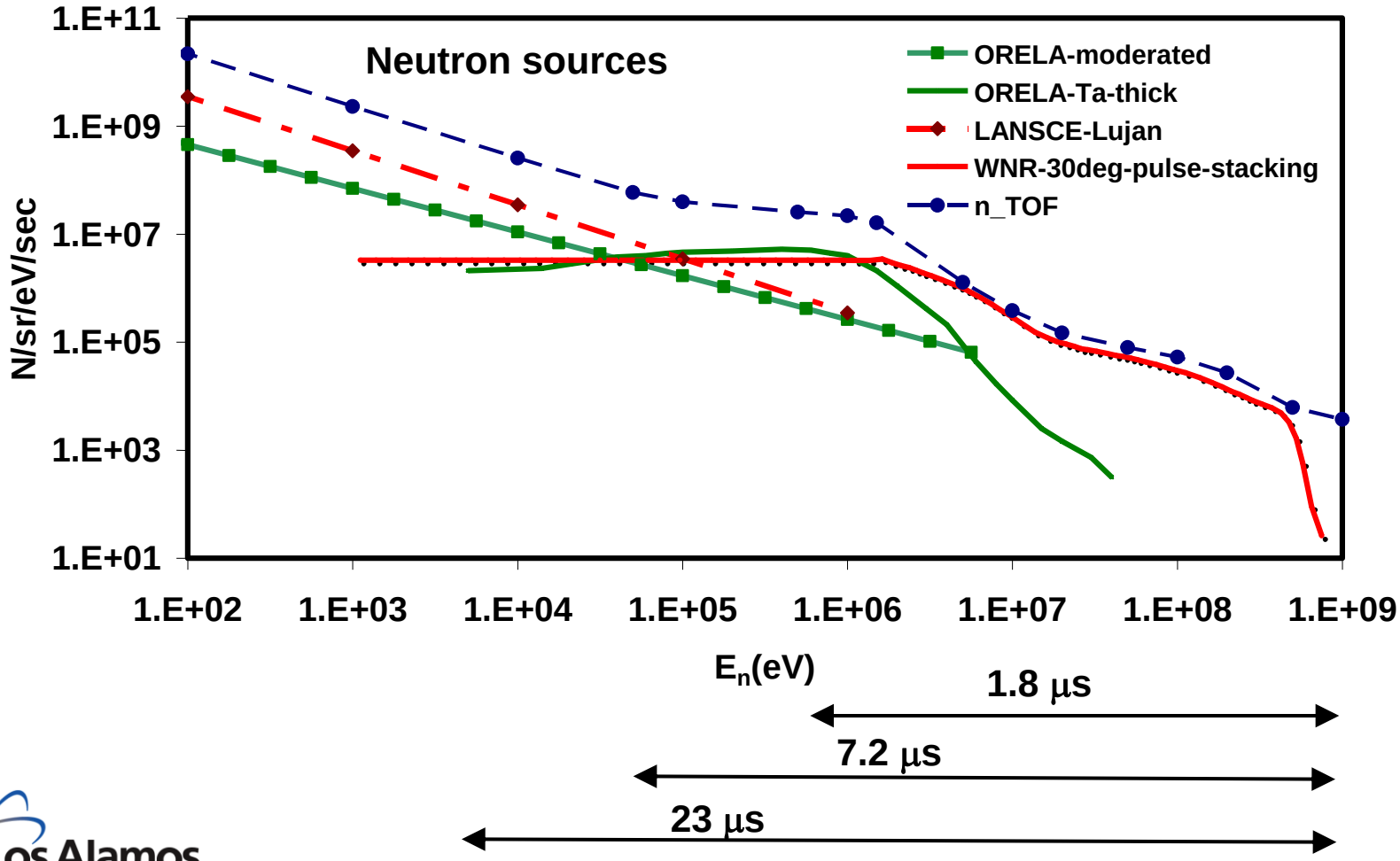


2009: in development for (n,p) and (n,alpha) measurements

Pulse stacking:

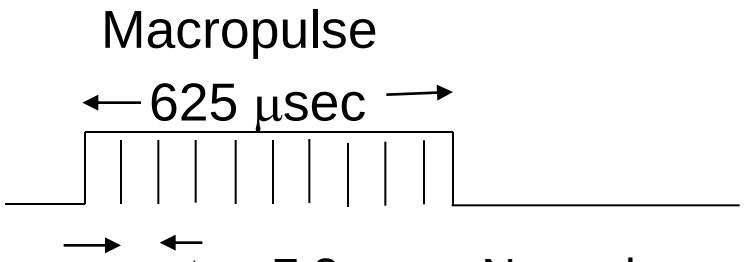
to increase usable flux of neutrons

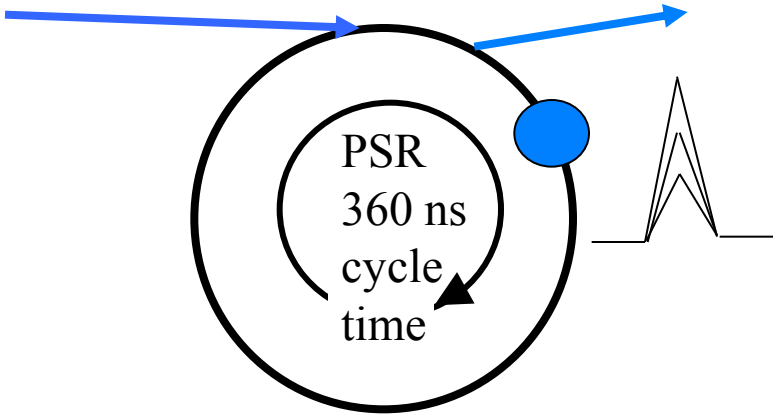
Pulse stacking will extend WNR source to lower usable neutron energies



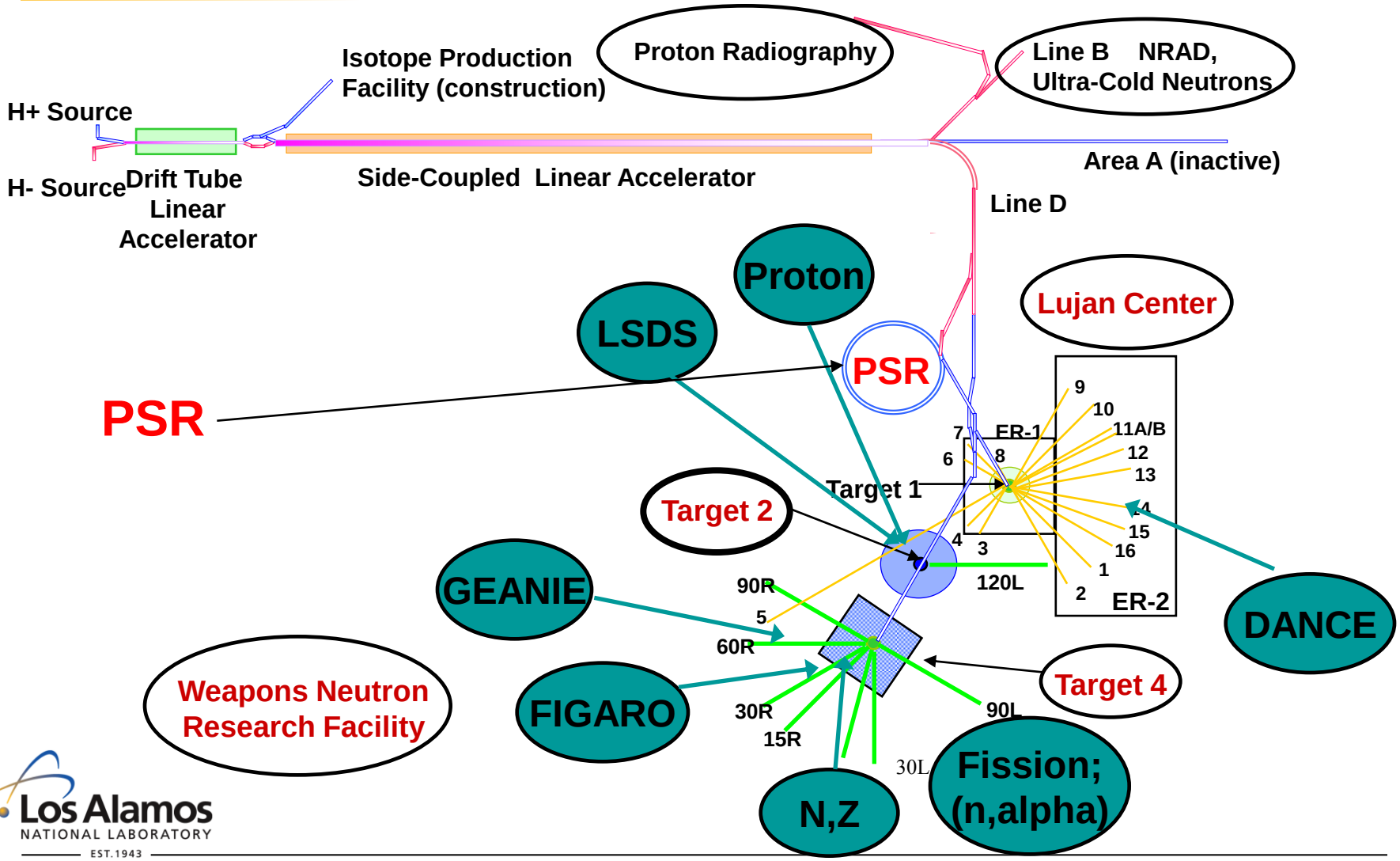
Stack single micropulses in PSR for entire macropulse (Full-fill mode)

- For 10 keV neutrons need pulse separation of 7.2 μsec (10 m)
- Separate micropulses by 360 ns in macropulse. Get x20 { 7.2 /.36 } increase in current / macropulse.
- Stack in pulses in PSR for duration of Macropulse (625 μs)
- Operate PSR at 60 Hz: 20 Hz to Lujan Center 40 Hz to Target-4
- 17 msec between pulses, x8 average beam (at 40 Hz) compared 7.2 μsec at Target-4 (at 100 Hz)
- It may be possible to store several pulses in the PSR

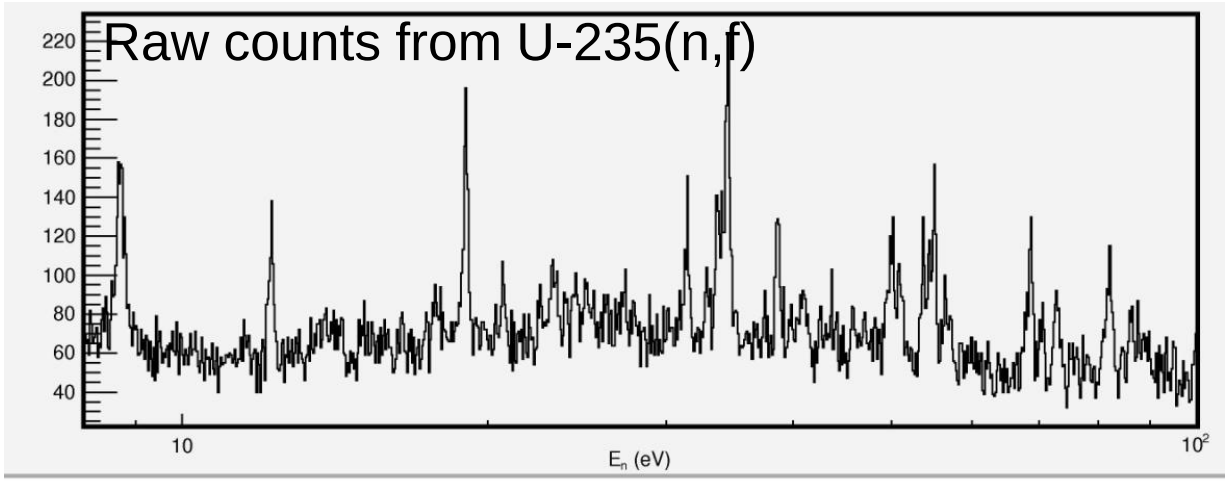




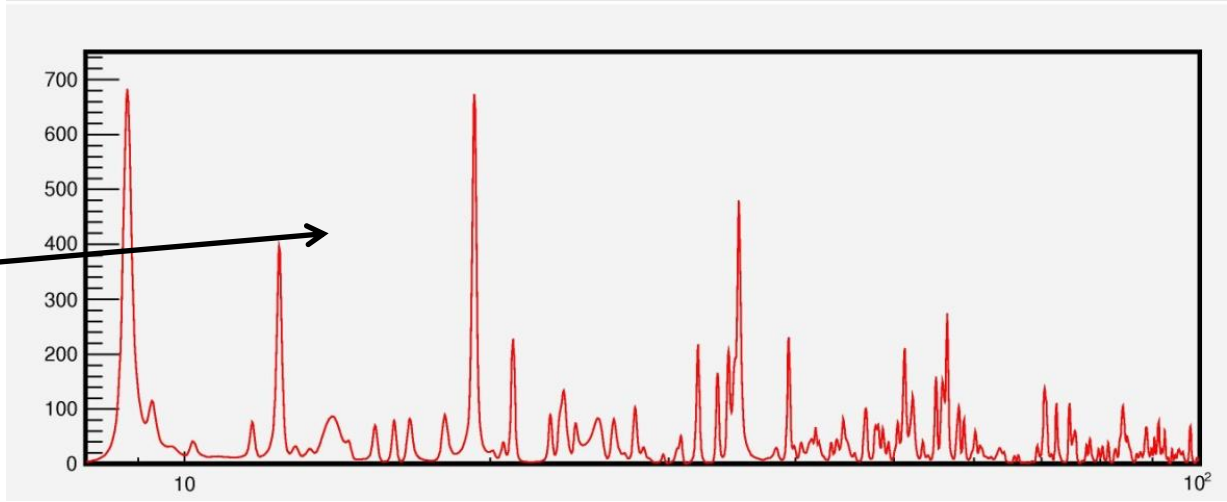
Proton storage ring serves to stack pulses



Fission cross section resonances observed down in eV region



ENDF



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Capabilities of the Recent Absolute Total *np* and *pp* Cross Section Determinations to Predict Experimental Observables

A.B. Laptev, R.C. Haight

Los Alamos National Laboratory, USA

R.A. Arndt, W.J. Briscoe, M.W. Paris,

I.I. Strakovsky, R.L. Workman

The George Washington University, USA

Ref: R. Arndt, W. Briscoe, A. Laptev, I. Strakovsky, R. Workman, Nucl Sci Eng 162, 312 (2009)

The SAID (Scattering Analysis Interactive Dial-in) NN History

- **Partial-Wave Analysis Facility SAID is based now at the GWU**
- **Publication history covers years from 1966 to 2009**
- **Access is available via URL**
  http://gwdac.phys.gwu.edu/
- **or via** ssh –C –X said@gwdac.phys.gwu.edu
  [no passwd]

GW SAID Fit of NN data

[R. Arndt, W. Briscoe, I. Strakovsky, R. Workman, Phys Rev C **76**, 025209 (2007)]

- Energy dependent SP07 and associated Single-Energy Solutions (SES)
- T_p = 0.3 – 3000 MeV T_n = 0.5 – 1300 MeV
- PWs = 17 [Isovector] + 19 [Isoscalar] [J < 8]
- Prms = 147 [I=0,1]
- 2-channel Chew-Mandelstam K-matrix parameterization

[included NΔ channel]

- GW PW… *model-independent* as poss…

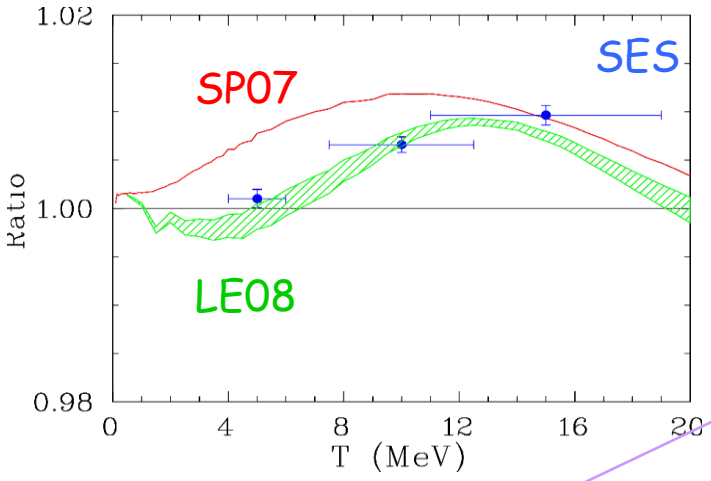
[no theoretical input]

Reaction	Data	χ^2
pp→pp	12,693	21,496
np→np	24,916	44,463
Total	37,609	65,559

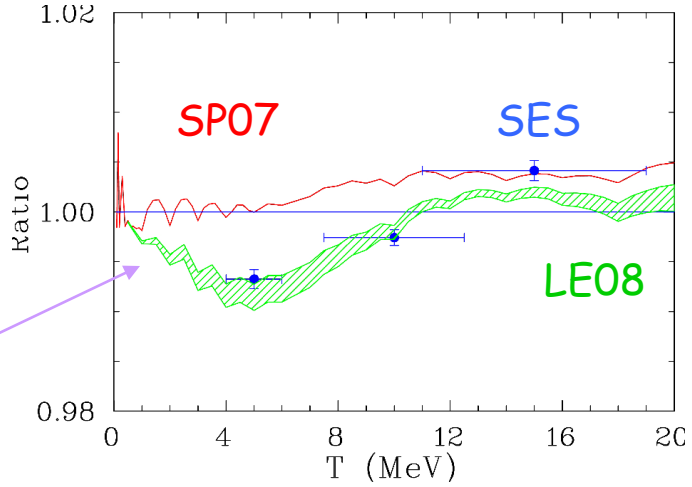
- Low-energy boundaries (beyond database issue)
  - for *pp*, there is the Coulomb
  - for *np*, there is the Schwinger (specifically for forward and pol measurements)

Low-Energy *np* Total Cross Section Ratio

- SP07, SES & LE08 to ENDF/B



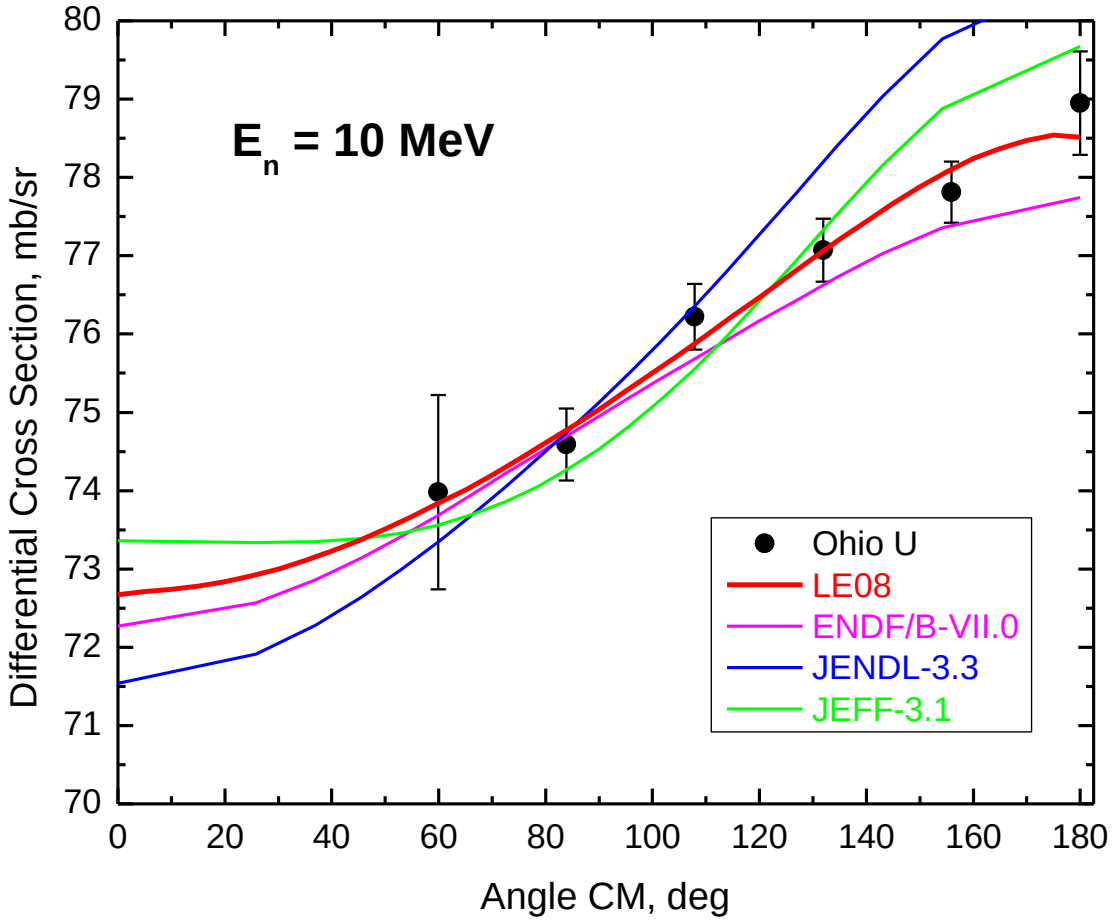
- SP07, SES & LE08 to JENDL



· **Slightly better agreement is found with JENDL than with ENDF/B**
· **Wiggles reflect a lack of smoothness in JENDL**
[SP07 and LE08 are smooth functions of Energy]

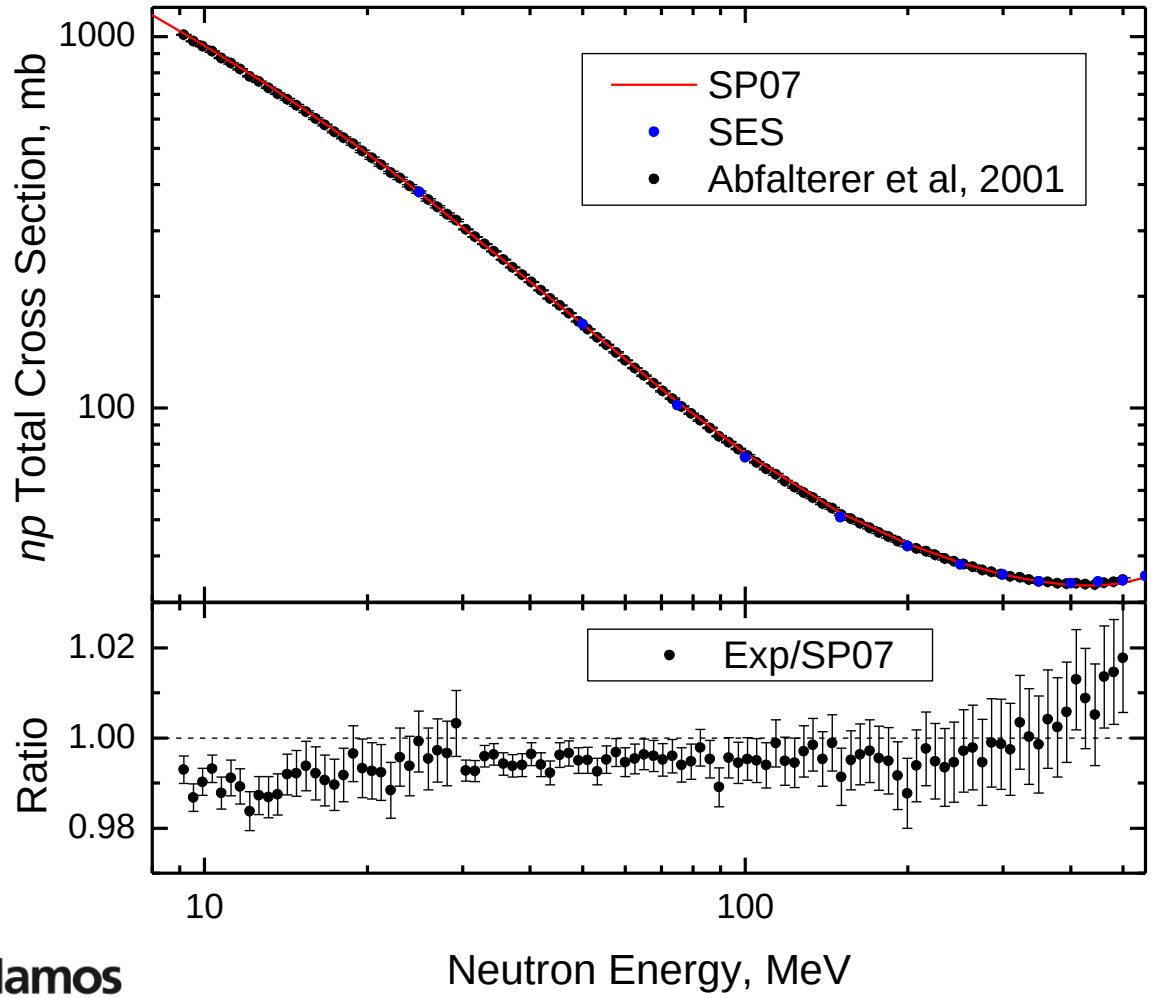
· **ENDF/B is systematically below SP07, LE08, and SES (~ 1 %)**
· **JENDL and SP07, LE08 & SES agreed at the level of < 1 %**

LE08 comparison with other libraries



- Angular distributions are more favorable for PWA

Predictions of SP07 and SES for *np* Total Cross Section

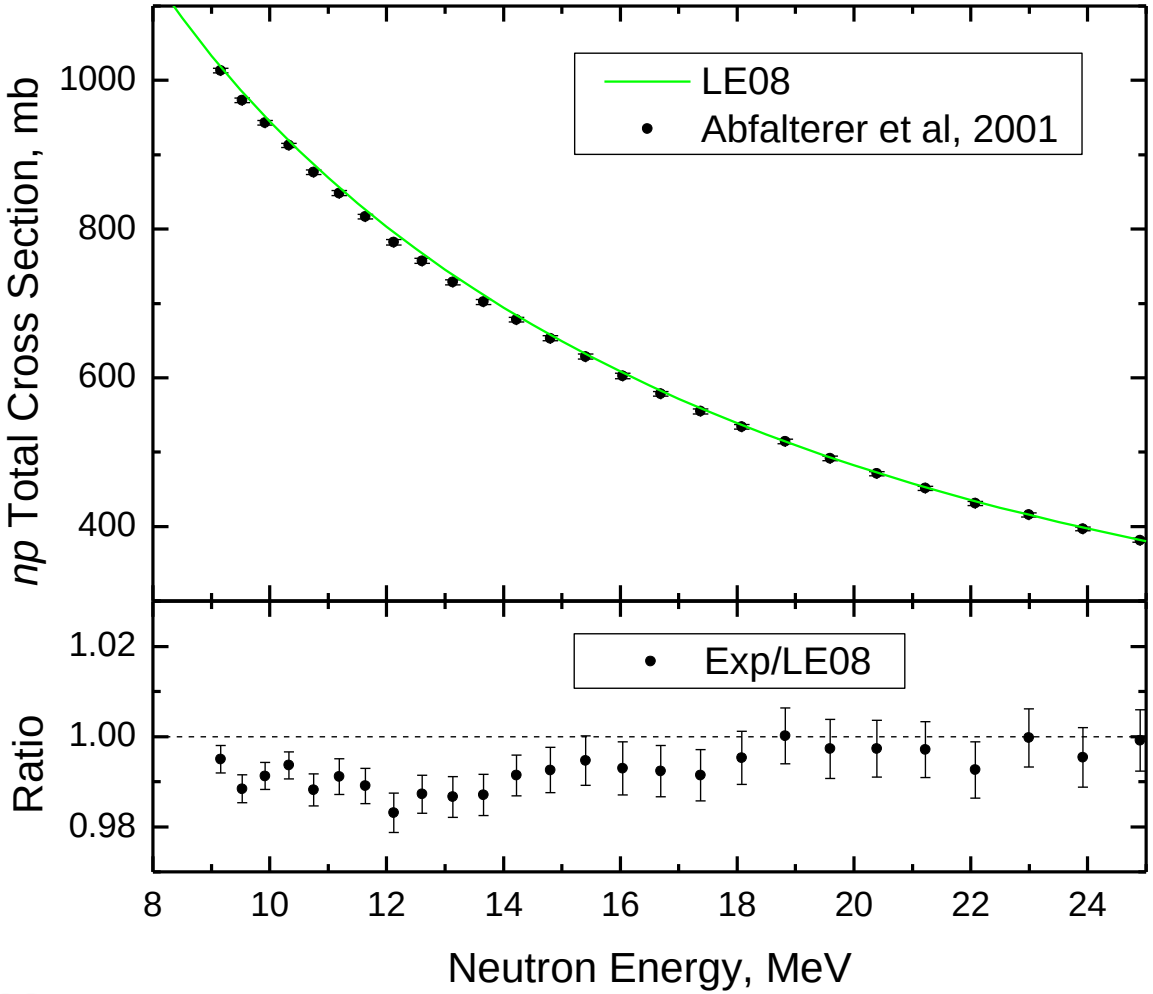


Data were not used in the PWA !

SP07
χ^2/data = 0.4

Predictions of LE08 for *np* Total Cross Section

[W. Abfalterer et al, Phys Rev C **63**, 044608 (2001)]



Data were not used in the PWA !

Fast neutron-induced fission of Pu-240, Am-243, and W-nat

A.B. Laptev, R.C. Haight

Los Alamos National Laboratory, USA

O.A. Shcherbakov, A.S. Vorobyev

Petersburg Nuclear Physics Institute, Russia

A.D. Carlson

National Institute of Standards and Technology, USA

Third Joint Meeting of the Nuclear Physics Divisions of the American Physical Society and the Physical Society of Japan

October 13-17, 2009

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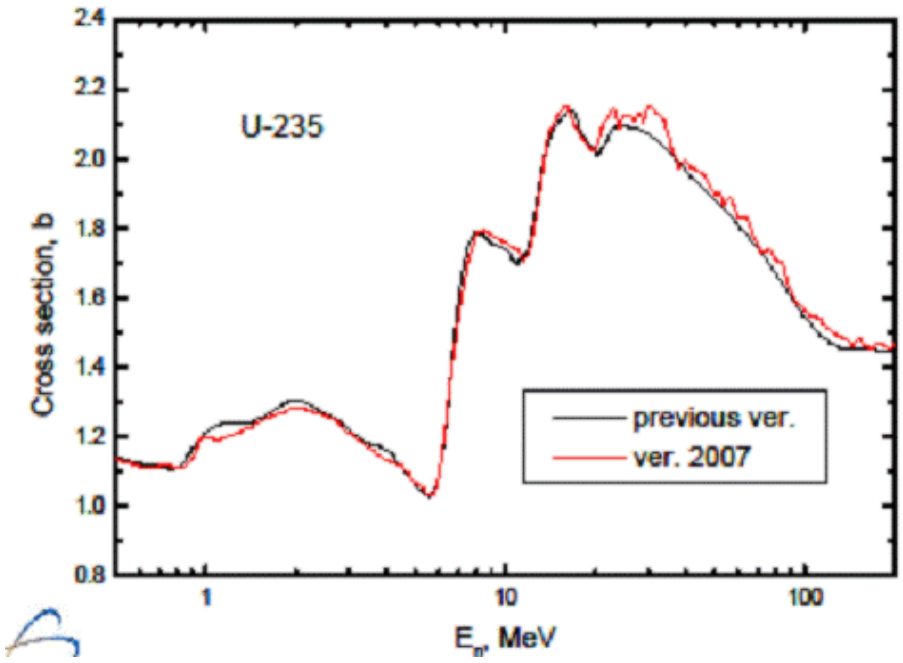
Motivation for Reanalysis

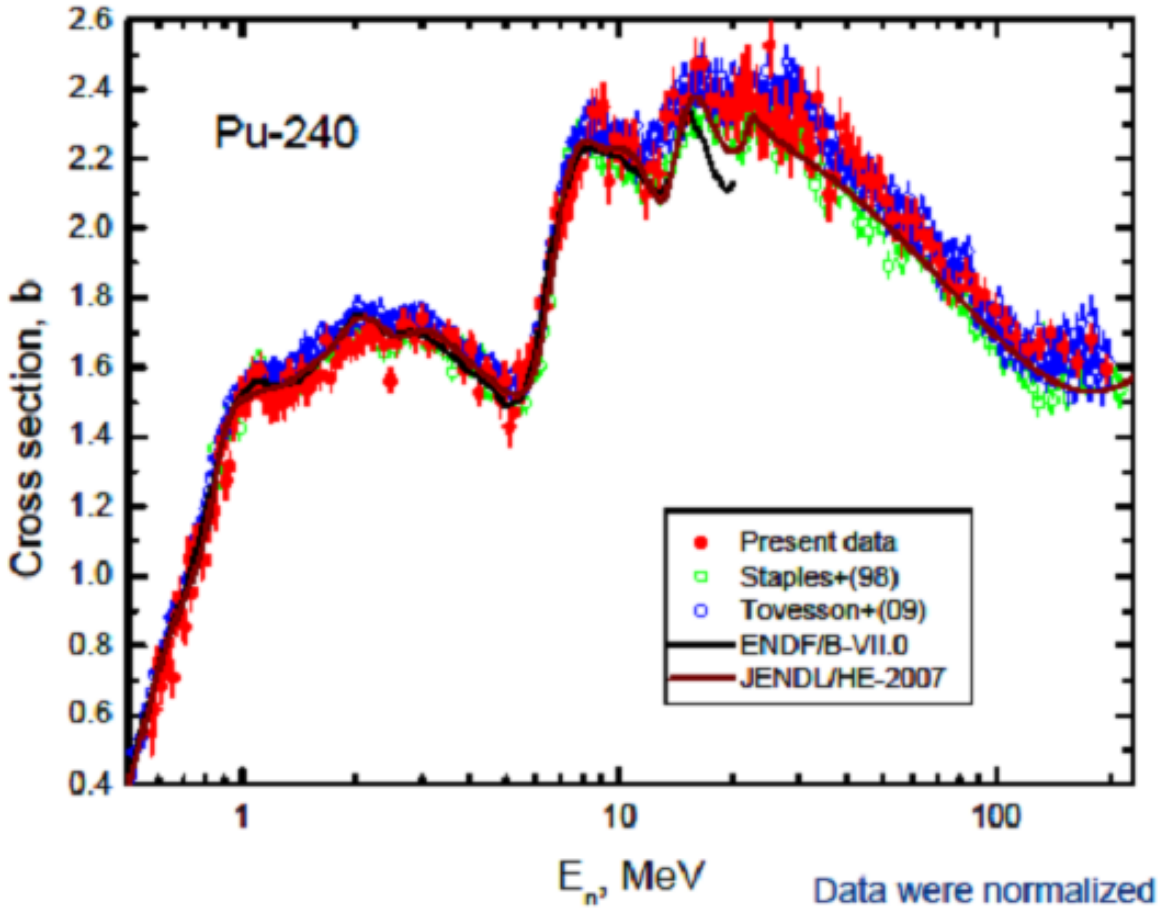
- New version of evaluated data file ENDF/B-VII.0:
  M.B. Chadwick et al., *Nuclear Data Sheets* **107**, 2931 (2006)
- The new evaluated fission cross section of ^{235}U:



"Old" is: JENDL-3.2 below 20 MeV, and the recommended data of A.Carlson et al., IAEA Report INDC(NDS)-368. Vienna, 1997 above 20 MeV.

"New" is: A.D. Carlson et al., "An international neutron cross section standards evaluation", *Proc. Int. Conf. Nucl. Data Sci. Tech.*, Nice, France, 2007, p.1233

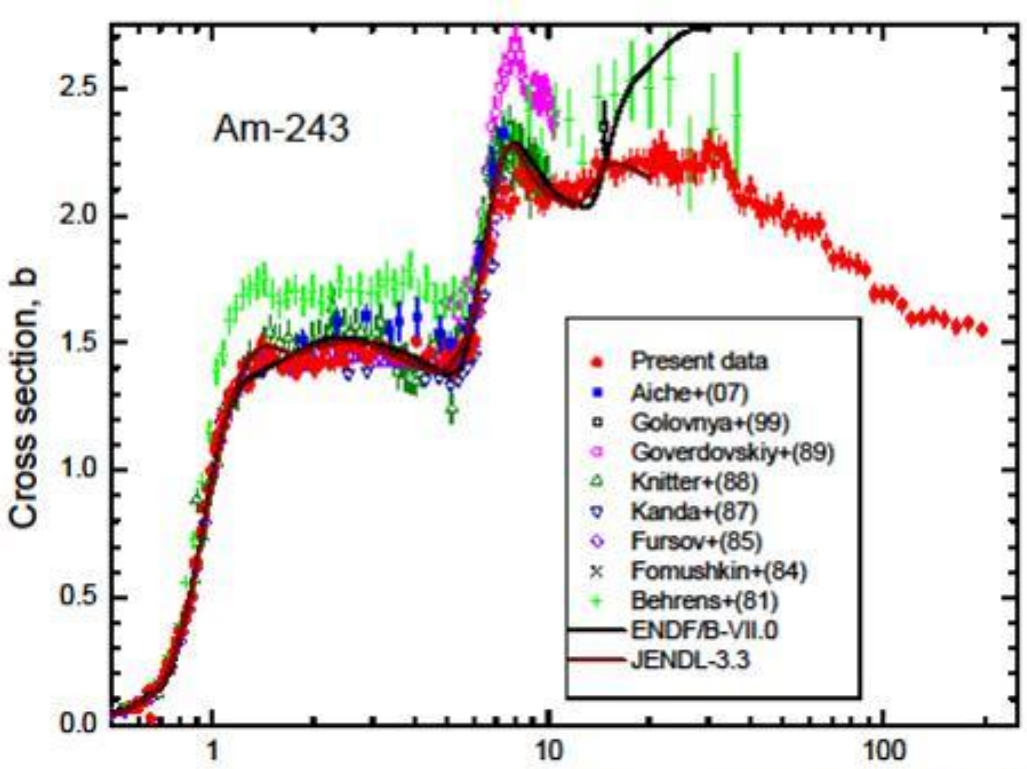
Measured fission cross section of ^{240}Pu compared with other data



EXFOR # 41487011

Data were normalized to the ENDF/B-VII.0 evaluation at 1, 5 and 10 MeV

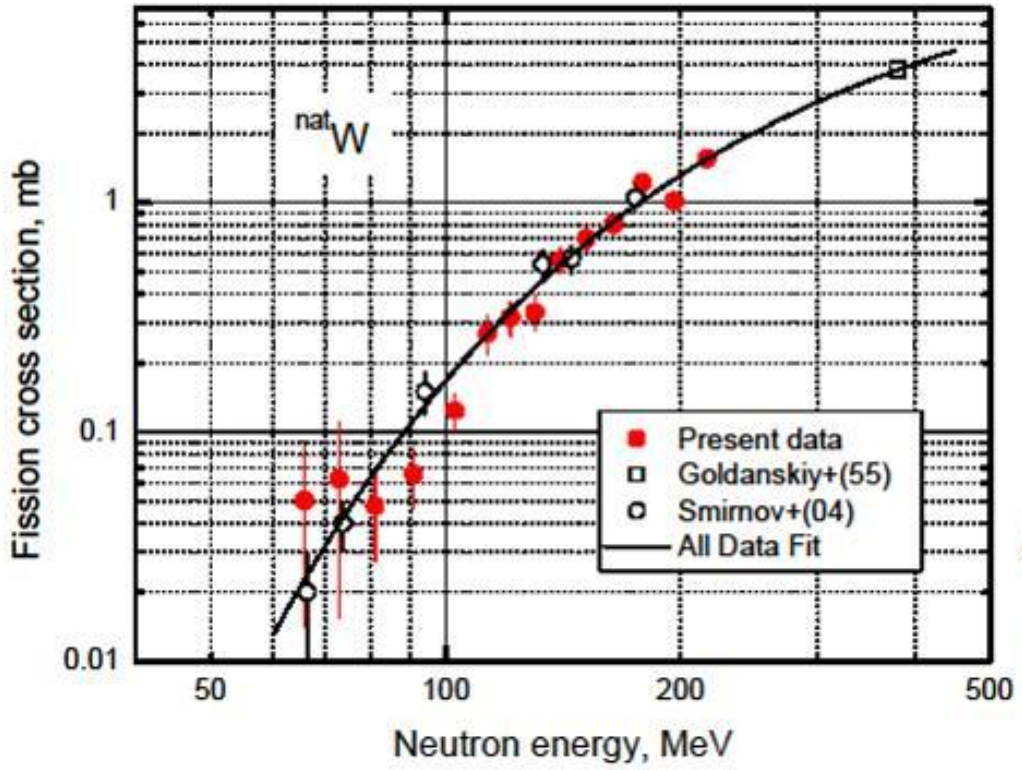
Measured fission cross section of ^{243}Am compared with other data



EXFOR
41487010

Data were normalized to the ENDF/B-VII.0 evaluation at 1, 5 and 10 MeV

Measured fission cross section of ^{nat}W compared with other data



EXFOR
41487013

Fitting formula

$$\sigma_f(E) = P_1 e^{-\left(\frac{P_2}{E}\right)^{P_3}}$$

P_1, P_2, and P_3 are fitting parameters

We address the needs of LANSCE sponsors

- Office of Science
  - Nuclear data and fundamental physics experiments
  - Support of SNS in understanding pulsed radiation effects on liquid mercury targets
- National Nuclear Security Administration
  - Program in radchem cross section measurements
    - Neutron capture cross sections on radioactive targets (DANCE)
    - Cross section measurements on high-order (n,2n), (n,xn) reactions (GEANIE)
  - Program in neutron-induced fission measurements
    - Fission cross sections
    - Fission product distributions (GEANIE), Gridded ion chamber
    - Energy output in fission: neutron and γ-ray spectra (FIGARO)
    - Nuclear properties of fission products and isomers (GEANIE and FIGARO)
- Office of Nuclear Energy
  - Measurements in support of the AFCI program include:
    - Capture and fission cross section on actinides
    - Gas production: (n,p), (n,α) reactions in structural materials
    - Advanced detector development
- National Resource
  - Nuclear science User Facility for defense, basic and applied research
  - Industrial testing of semiconductor devices in neutron beams
  - University research in nuclear science

The LANSCE program in nuclear data involves many laboratories

- GEANIE – LANL, LLNL, LBNL, INL, ORNL, Bruyères-le-Châtel, NC State
- Chi-Nu (formerly FIGARO) – LANL, Bruyères-le-Châtel, LLNL, Michigan, Kentucky
- N,Z – LANL, Ohio U
- DANCE – LANL, LLNL, ORNL, NC State, INL, Notre Dame, Colorado School of Mines, FZK Karlsruhe, GSI
- LSDS – LANL, LLNL, Bruyères-le-Châtel, RPI, UNLV
- Fission – LANL, IRMM, LLNL, INL, Bruyères-le-Châtel, RPI, NERI universities
- Others – MIT, Kentucky, Kyushu, Houghton, etc.