ENDF Project Report to WPEC 2015

M. Herman for CSEWG

BROOKHAVEN NATIONAL LABORATORY
a passion for discovery
U.S. DEPARTMENT OF ENERGY | Office of Science

I will NOT talk about:

- CIELO (SG40)
  - H, ^{16}O, ^{56}Fe, $^{235,238}U$, ^{239}Pu
- Fission product yields (SG37)
- New data structure (SG38)
- Thermal scattering law data (SG42)

Summary and Outlook – Standards Work

- NN analysis progressing; more p-p elastic scattering data needed in the 30-50 MeV range. Low-energy parameters retain their earlier (correct) values. Need to extend analysis above 200 MeV.
- New data for n+^{6}Li fit in well with the existing data set, and cause no problems with the R-matrix fitting.
- n+^{12,13}C analyses in good shape below 2 MeV. Could produce a natural C standards file in this energy region now. More work is needed on both evaluations at higher energies, however.
- Problem with unrealistically small uncertainties on standards cross sections may be solved by using parameter confidence intervals.
- MBC: we await TPC precision data on 239Pu/235U and ratio to 1H.

M. B. Chadwick

Prompt Fission γ Rays Talou et al.

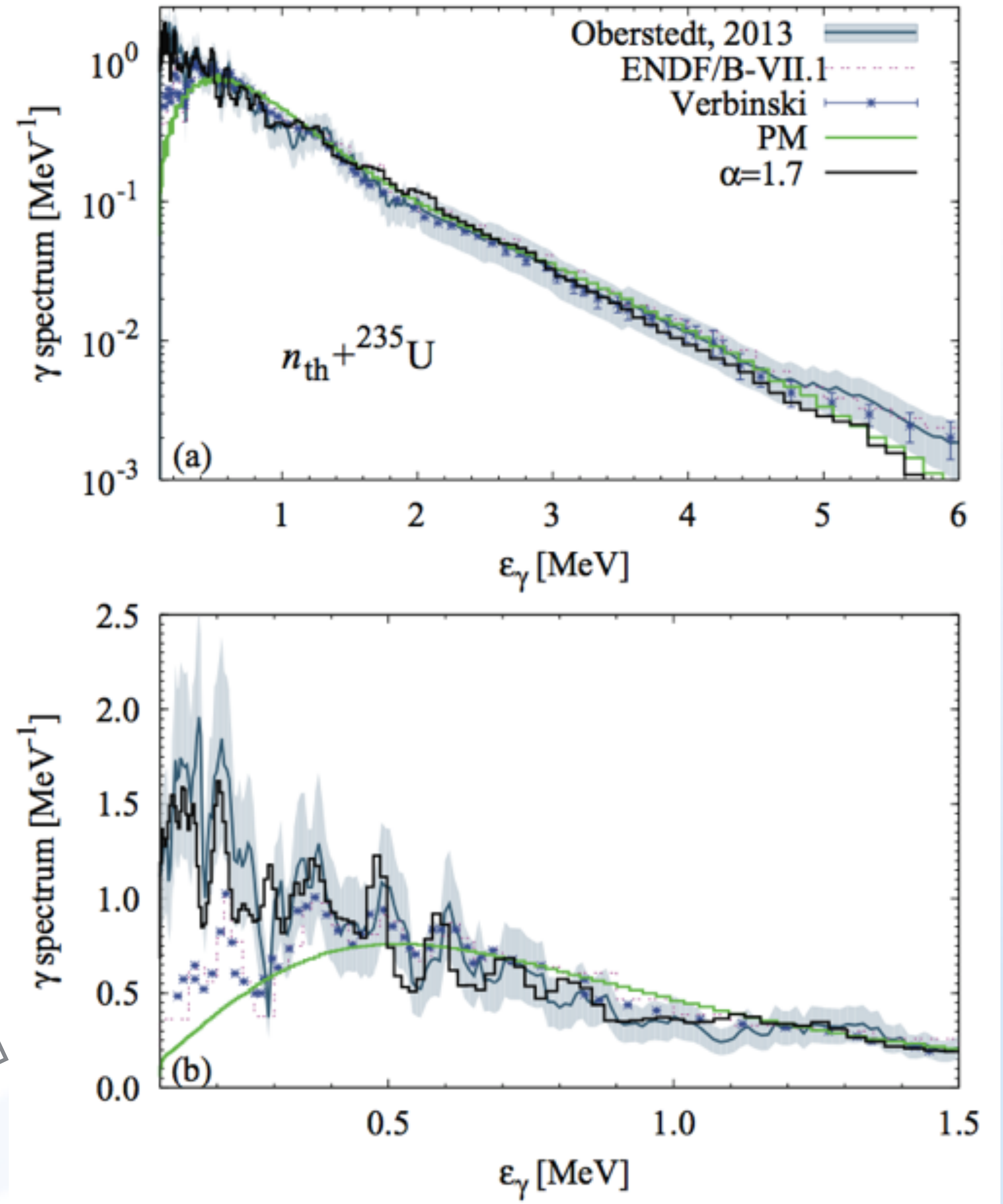
- Recent experimental efforts
  - IRMM, Geel, Belgium
    - R. Billnert et al., Phys. Rev. C 87, 024601 (2013); A. Oberstedt et al., Phys. Rev. C 87, 051602(R) (2013);
    - S. Oberstedt et al., Phys. Rev. C 90, 024618 (2014)
  - DANCE, LANL+LLNL
    - M. Jandel et al., references
    - J. Ullmann et al., Phys. Rev. C 87, 044607 (2013)
    - A. Chyzh et al., Phys. Rev. C 90, 014602 (2014), Phys. Rev. C 87, 034620 (2013)
- Recent model calculations
  - Monte Carlo simulations of the decay of fission fragments
    - I. Stetcu et al., Phys. Rev. C 90, 024617 (2014)
    - R. Vogt and J. Randrup, Phys. Rev. C 87, 044602 (2013)
    - O. Litaize and O. Serot, Phys. Rev. C 82, 054616 (2010)
- New evaluations in the works

M. B. Chadwick

Results for $n_{th}+^{235}U$

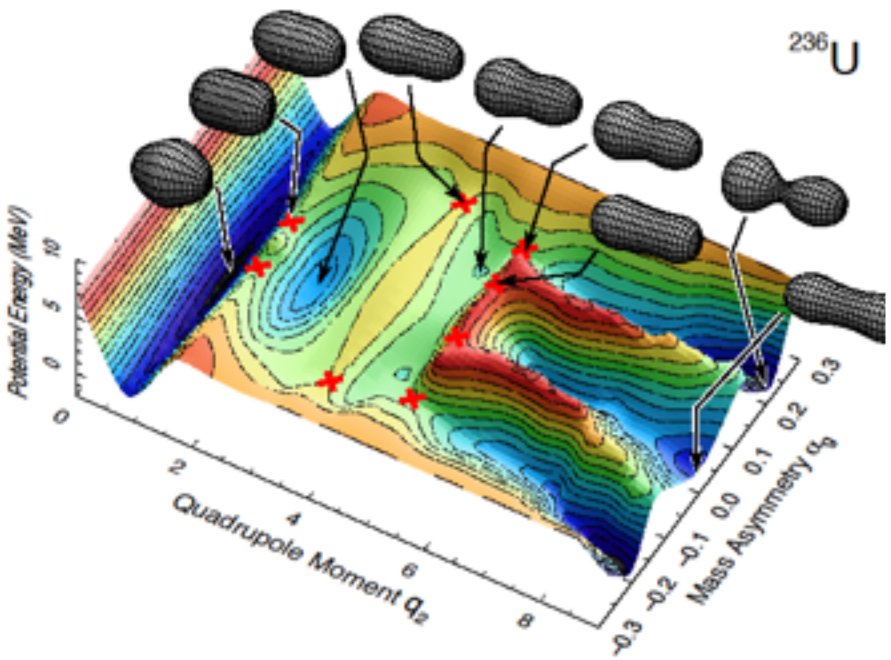
- Strong fluctuations of PFGS below 1 MeV, due to γ transitions in fission fragments
- Seen in IRMM experiments with LaBr detectors, but not at DANCE due to poor energy resolution
- Well reproduced by Monte Carlo simulations

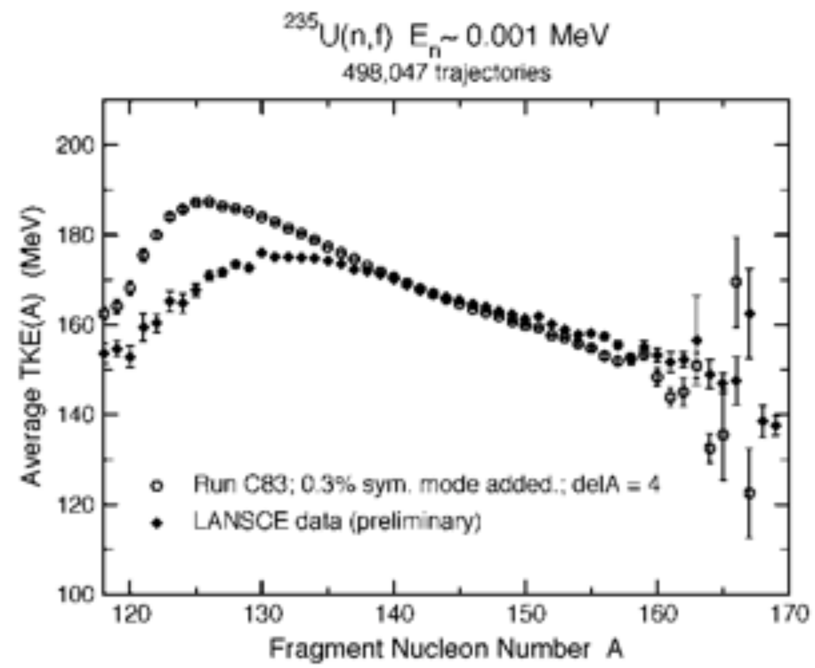
M. B. Chadwick

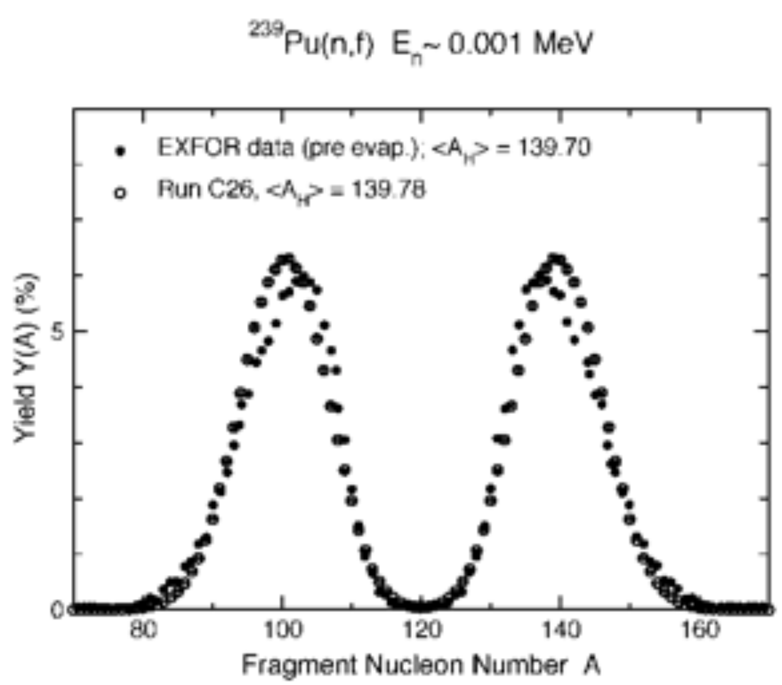


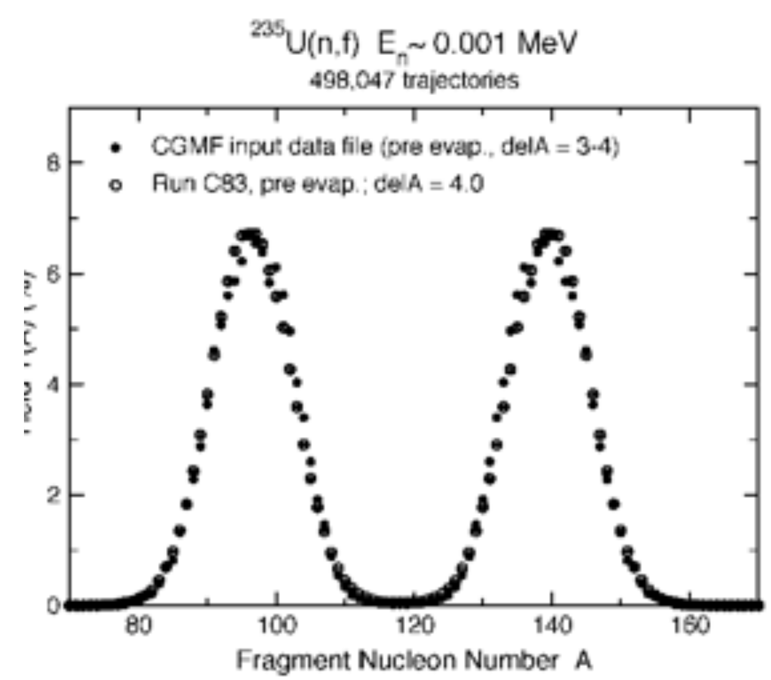
Theoretical calculations of fission fragment properties

A.Sierk LANL









- Macroscopic-microscopic description of fission successfully models potential energy of nuclei
- New advanced calculations of nuclei advancing through the potential predict mass, charge and kinetic energy of fission fragments
- Theory will provide nuclear data for isotopes that are challenging to measure
- Measurements of fission correlation helps constrain theoretical models

Work in resolved resonance range

- Resolved resonance evaluations were done for ^{182}W, ^{183}W, ^{184}W, ^{186}W, ^{63}Cu and ^{65}Cu
- Thermal data, coherent and incoherent data were used in the evaluation
- Resonance parameter covariance generated
- Resonance ranges extended with the help of high-resolution differential data
- RML Format (LRF=7) were used
- Blatt and Biedenharn methodology used for angular data representation

L. Leal

Resolved Resonance Region (RRR) Cross Section Evaluations

No.	Nucleus (I^π)	$E_{\min} - E_{\max}^{ORNL}(E_{\max}^{existing})$	Method	No. Levels(*)	s-wave	p-wave	Evaluator
1 ✓	^{182}W (0^+)	10^{-5} eV–10 (5.0) keV	RM	306	171	135	L. C. Leal
2 ✓	^{183}W ($1/2^-$)	10^{-5} eV–5 (2.2) keV	RM	387	346	21	M. T. Pigni
3 ✓	^{184}W (0^+)	10^{-5} eV–10 (4.0) keV	RM	178	94	84	L. C. Leal
4 ✓	^{186}W (0^+)	10^{-5} eV–10 (8.3) keV	RM	169	95	74	L. C. Leal
5 ✓	^{63}Cu ($3/2^-$)	10^{-5} eV-300 (100) keV	RM	527	323	204	V. Sobes
6 ✓	^{65}Cu ($3/2^-$)	10^{-5} eV-300 (100) keV	RM	762	525	237	V. Sobes

RM – Reich-Moore Approximation (*) bound and external levels not included

L. Leal

W cross section evaluation

		σ_t	σ_γ	σ_s	R'	b_{coh}	b_{inc}
^{182}W	ORNL	28.18±0.40	20.31±0.64	8.87±0.28	7.6	7.11	-
	ATLAS	-	19.90±0.30	8.84±0.30	8.1	7.04	-
^{183}W	ORNL	15.56±0.50	9.87±0.53	5.69±0.11	7.9	6.47	-0.43
	ATLAS	-	10.40±0.20	2.40±0.60	8.1	6.59	-
^{184}W	ORNL	8.98±0.40	1.63±0.13	7.35±0.10	7.6	7.41	-
	ATLAS	-	1.70±0.10	7.35±0.10	8.0	7.55	-
^{186}W	ORNL	37.97±0.40	37.88±0.59	0.09±0.02	7.7	-0.76	-
	ATLAS	-	38.10±0.50	0.09±0.01	7.6	-0.73	-

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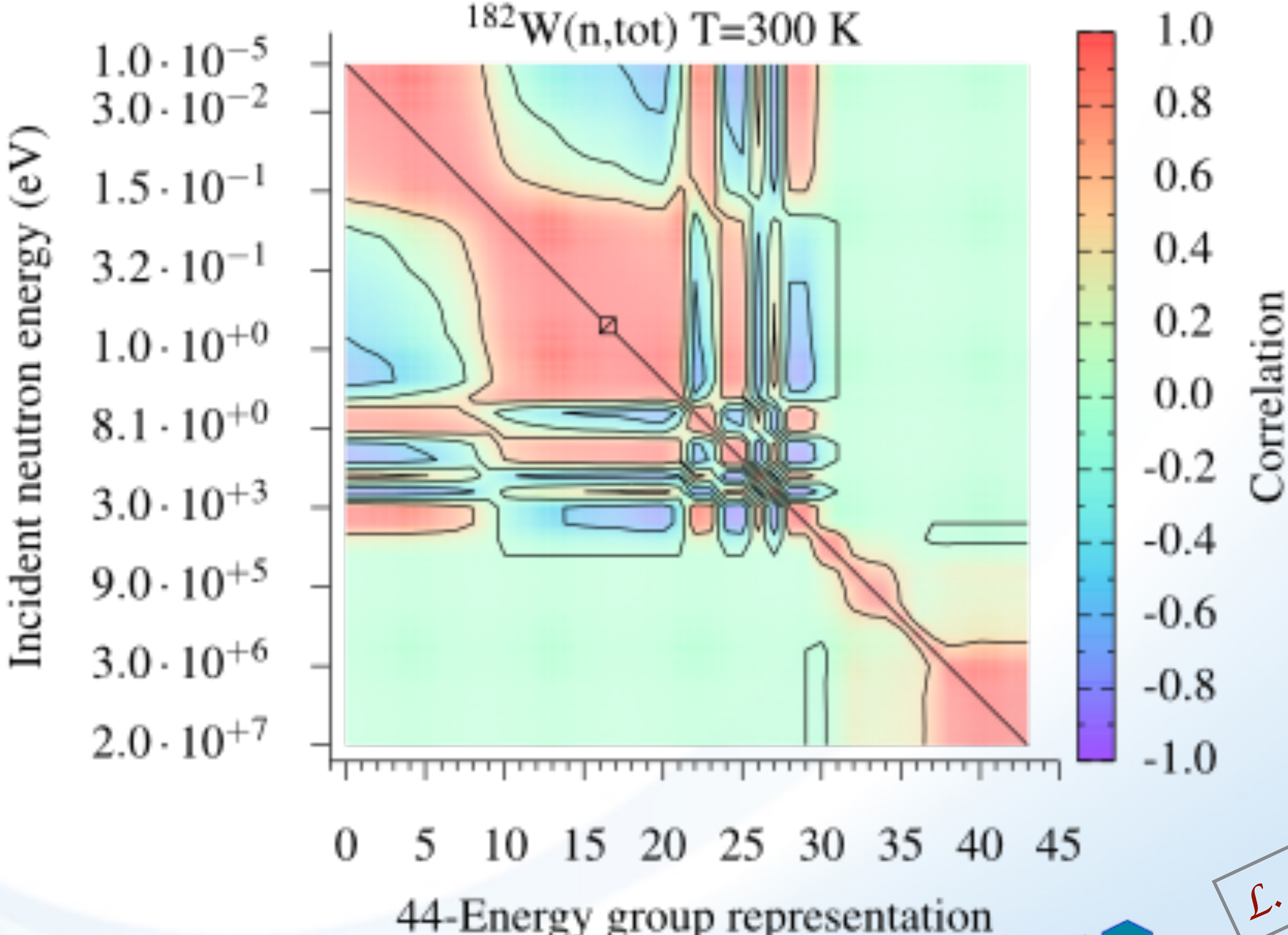
Covariance Evaluations (Total)



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… and Calculated Eigenvalues

- Compare calculated eigenvalues for E71 versus the new ORNL $^{182,183,184,186}W$ evaluations

S. Kahler

Benchmark	E71 k_{calc}	E71 EALF	E71 + revised ^{iso}W (GForge, v633-v636)
HMF3.8	1.00211(7)	638 keV	1.00141(9)
HMF3.9	1.00223(7)	579 keV	1.00180(9)
HMF3.10	1.00505(7)	531 keV	1.00558(9)
HMF3.11	1.00881(6)	514 keV	1.01089(9)
HMF49.1	0.99799(6)	803 keV	0.99781(9)
HMF49.2	0.99974(6)	765 keV	0.99946(9)
HMF49.3	0.99869(6)	726 keV	0.99849(9)
HMF50	0.99810(6)	647 keV	0.99793(9)
HMM17	0.99540(8)	176 eV	0.99654(12)
PMF5	1.00112(6)	1.008 MeV	1.00063(9)
UMF4.1	0.99866(6)	985 keV	0.99857(9)
UMF4.2	0.99559(6)	893 keV	0.99528(9)

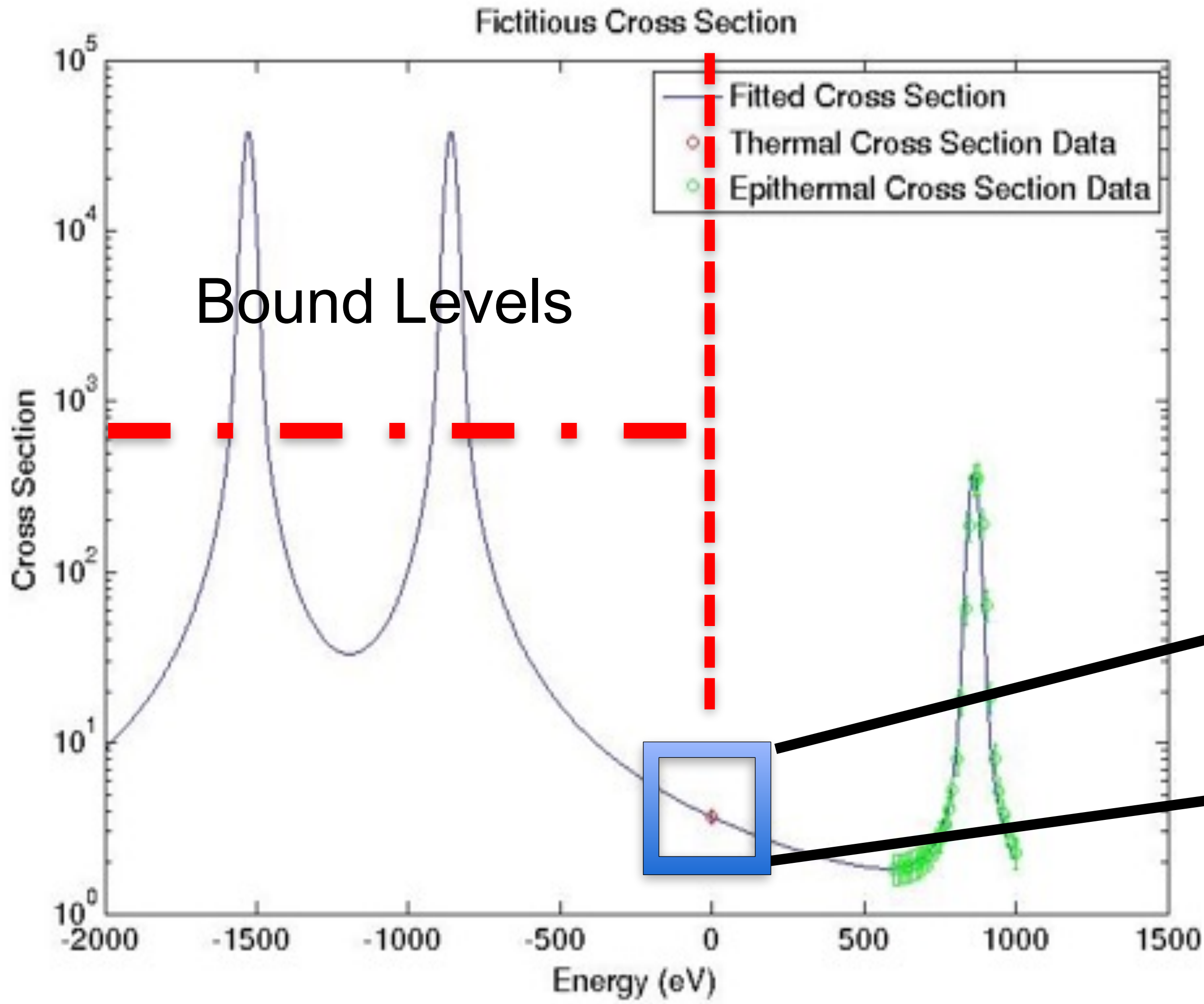
Cu evaluations at thermal (Sobes)

Motivation

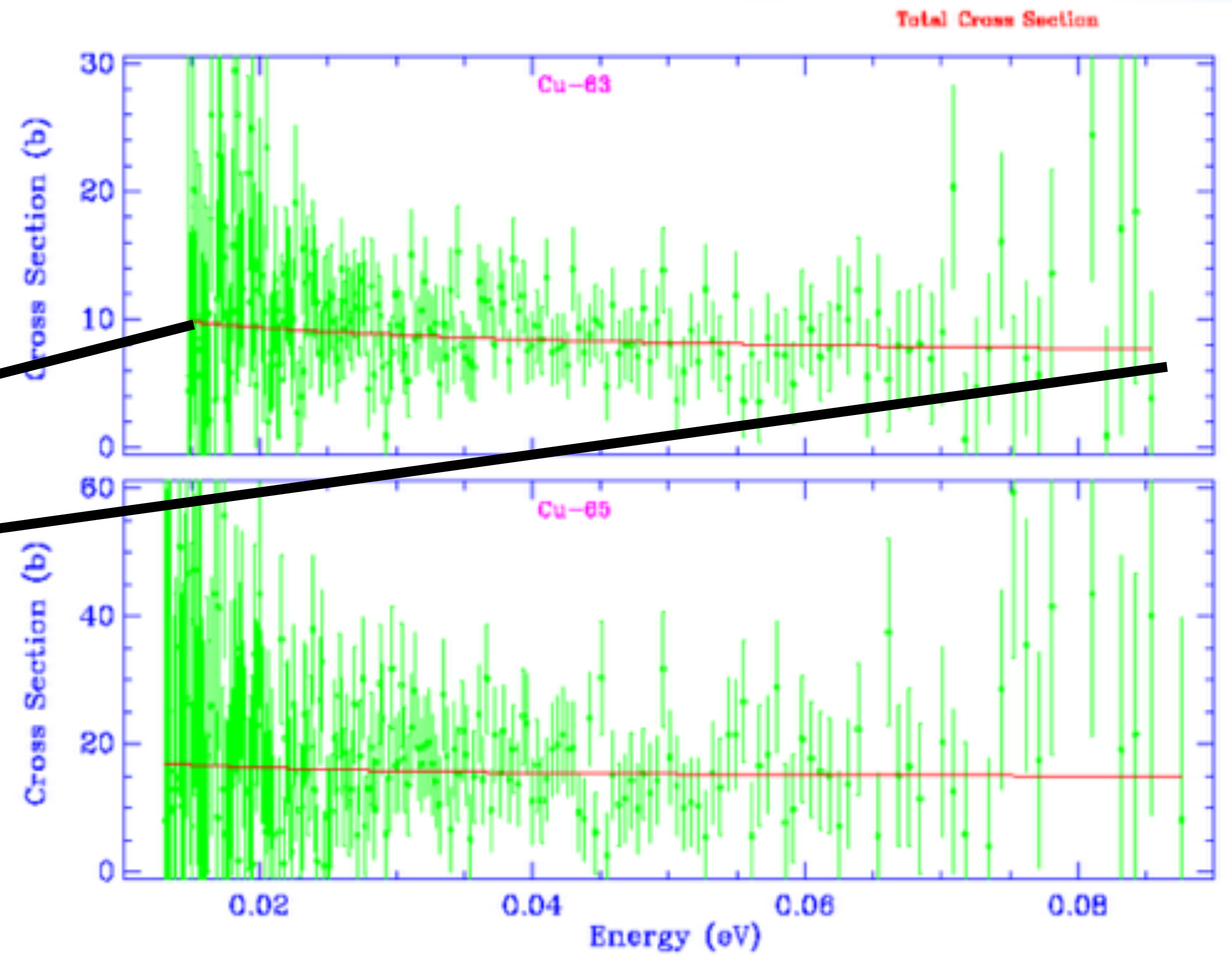
- Nuclear Data Advisory Group (NDAG) identified 63Cu and 65Cu important for criticality safety applications
- Measurements made at the Oak Ridge Electron Linear Accelerator (ORELA) by M. S. Pandey, J. B. Garg, and J. A. Harvey (1977)
  - Three major improvements of consequence to the Zeus benchmarks:
    - Resolved resonance region expanded three-fold
    - Capture cross section evaluated based on experimental measurements
    - Detailed angular distributions generated for elastic scattering

L. Leal

Cu evaluations at thermal



Measurements Performed
at the MIT Nuclear Reactor (MITR-II)



- A better definition of the negative external levels if we fit a differential cross section
- A better definition of the uncertainty and correlations at the thermal energy

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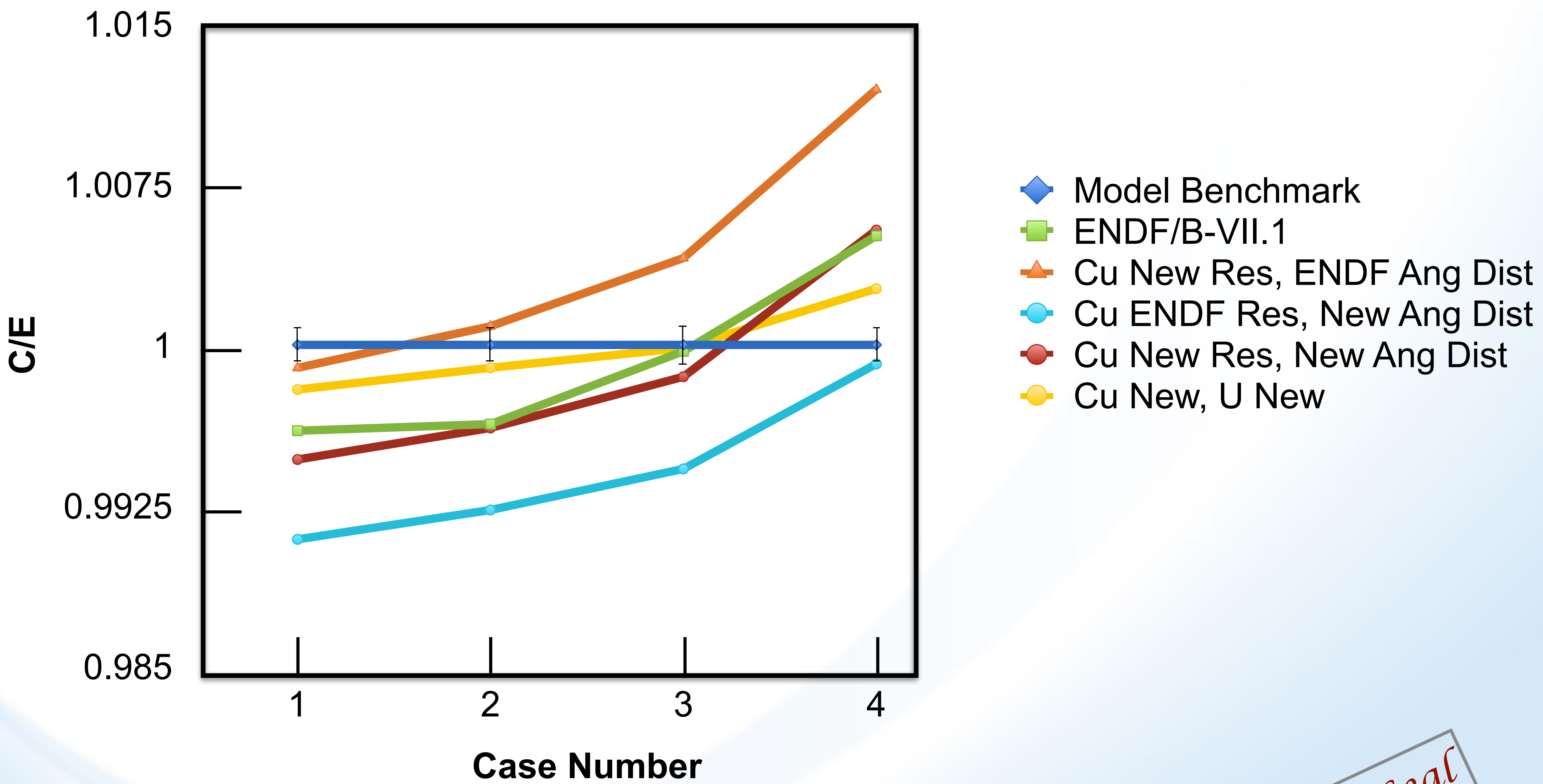
Benchmark Results



L. Leal

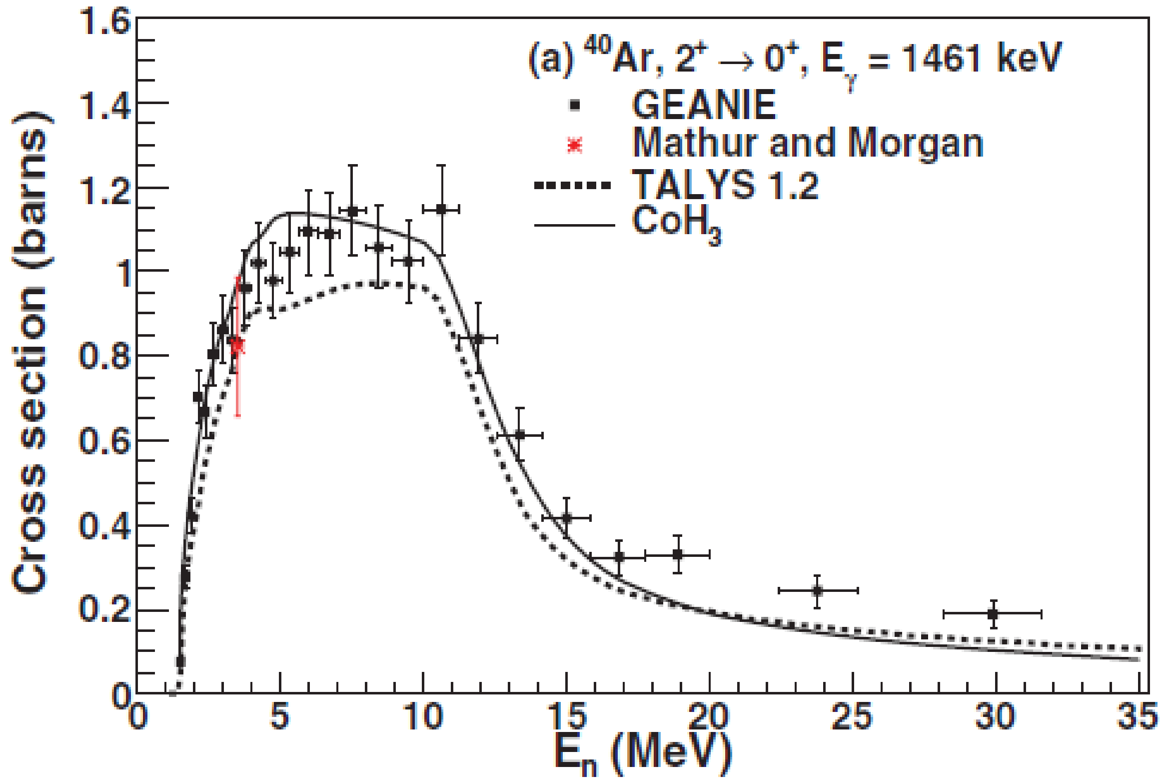
New Cross Section Evaluation Outlook in Fast Neutron Region

- **Ar-40**
  - new evaluation above resonances, based on GEANIE data
- **Ni-58, 59, 60, 61, 62, 64**
  - new evaluations above resonance regions with CoH3
  - angular distribution for Ni-58 and 60 from the ORNL resonance parameters (WPEC SG35)
- **Cu-63, 65**
  - new evaluation above resonance regions with CoH3
  - see benchmark results by Kahler
- **As-73**
  - LANL local evaluation, to be added to the repository
- **Np-236m**
  - New isotope, new evaluation
    - 60 keV level, half-life of 22.5h
- **K-38 photo-induced reaction**
  - funded by isotope production, ENDF-6 file not yet produced

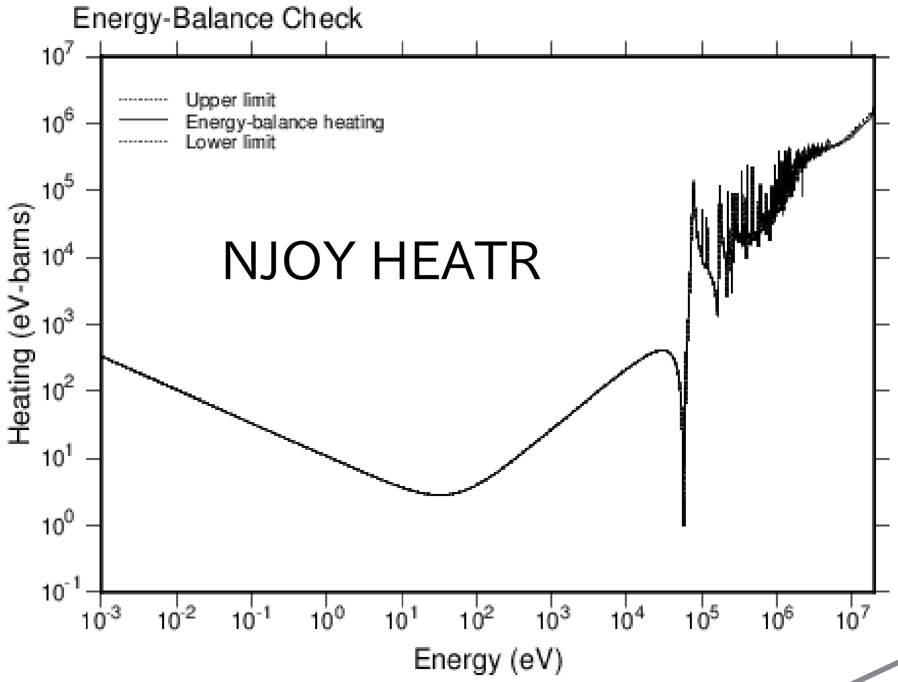
T. Kawano

Ar-40 Evaluation

- **ENDF/B-VII.1 Ar40 = JENDL-3.2 evaluated in 1994**
  - New GEANIE data available [S. MacMullien et al. PRC85,064612 (2012)]
  - TUNL new (n,p) data
  - Issue of EPMAX > Q-values; particle energy spectra given in MF=5



- **New evaluation with the CoH3 code**
  - Resonance (JENDL-3.2) up to 1.5MeV
  - Cross sections were fitted to available experimental data
  - Angular and energy distributions were re-calculated for better energy conservation



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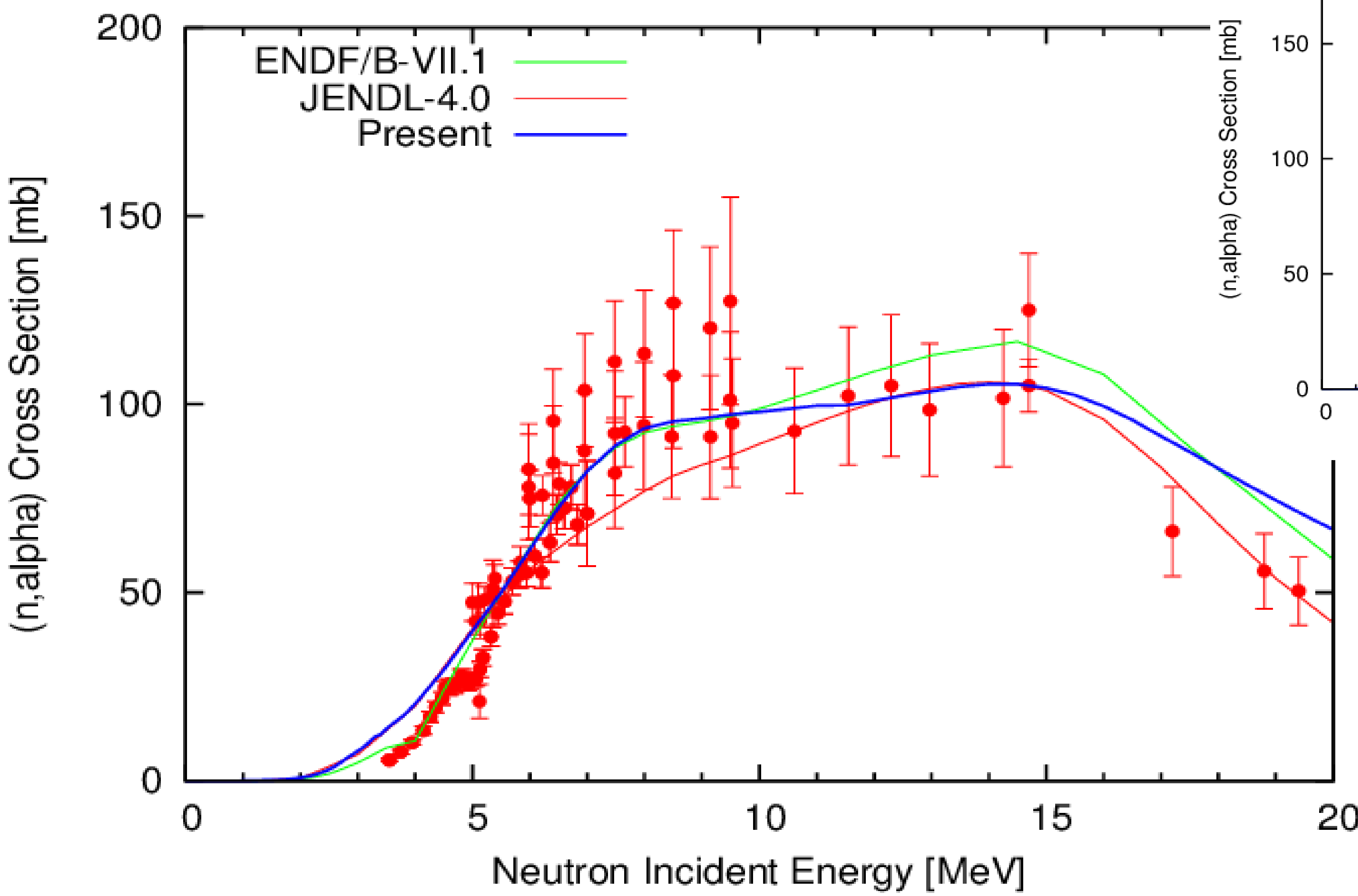
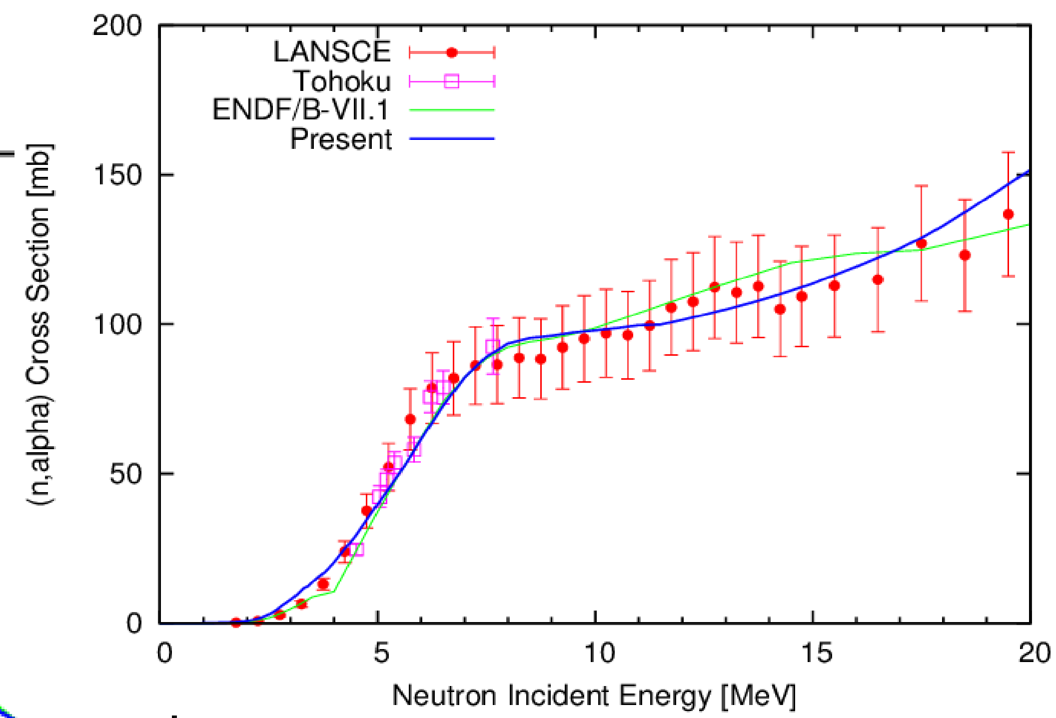
Ni-58(n,alpha) Reaction Cross Section





alpha-production above 20 MeV same as Kunieda's evaluation

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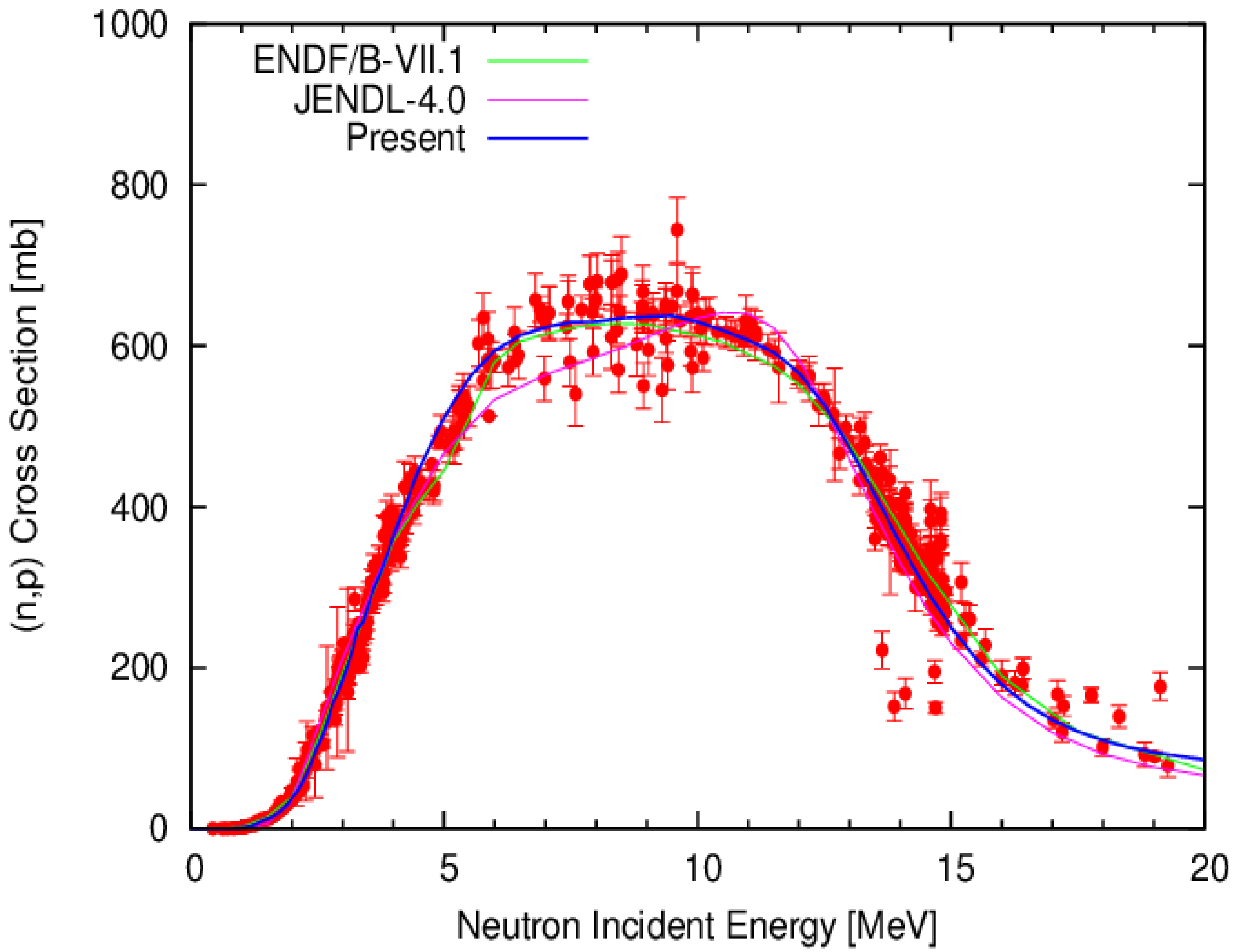
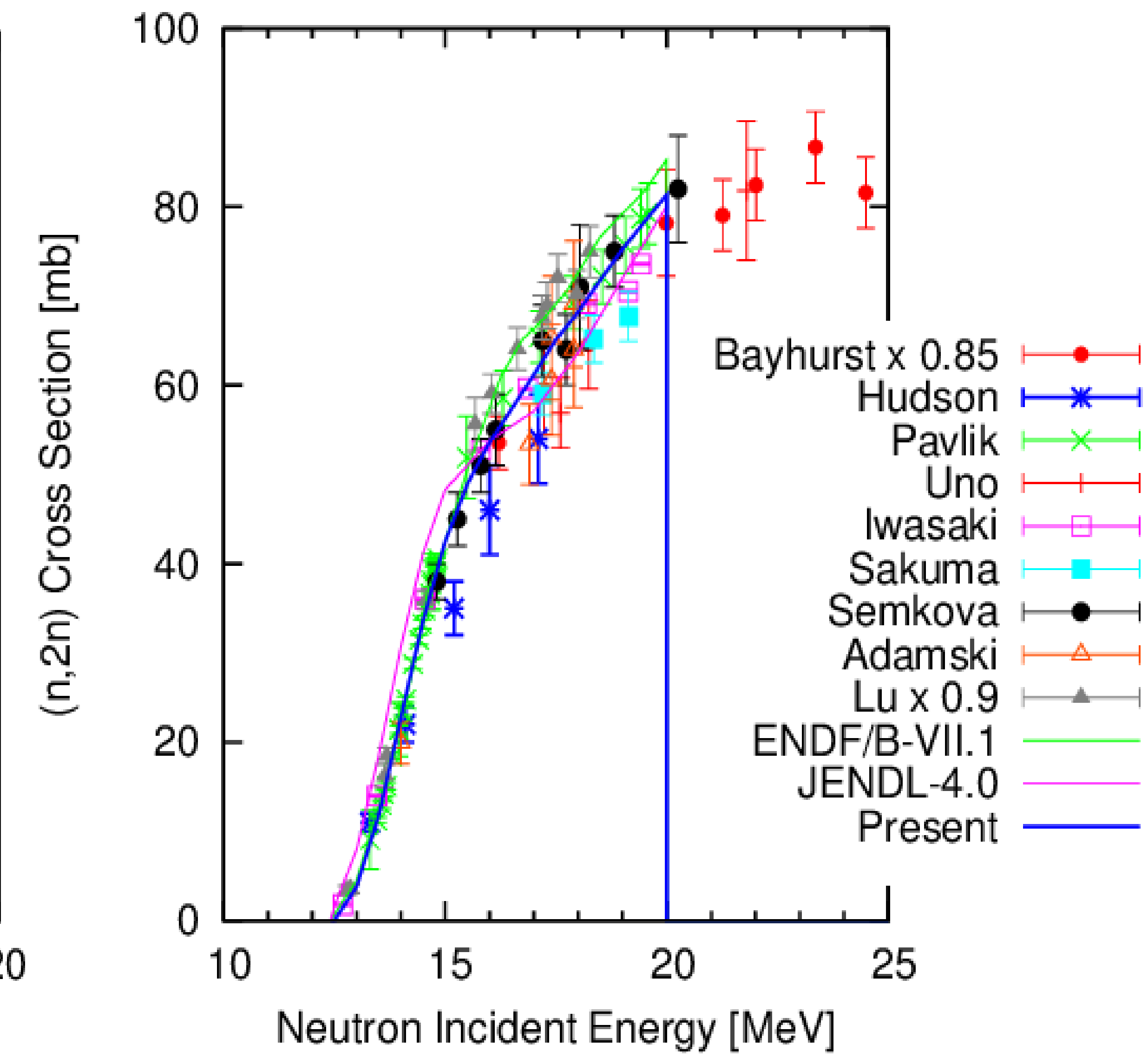
Ni-58(n,p) and (n,2n) Reaction Cross Sections

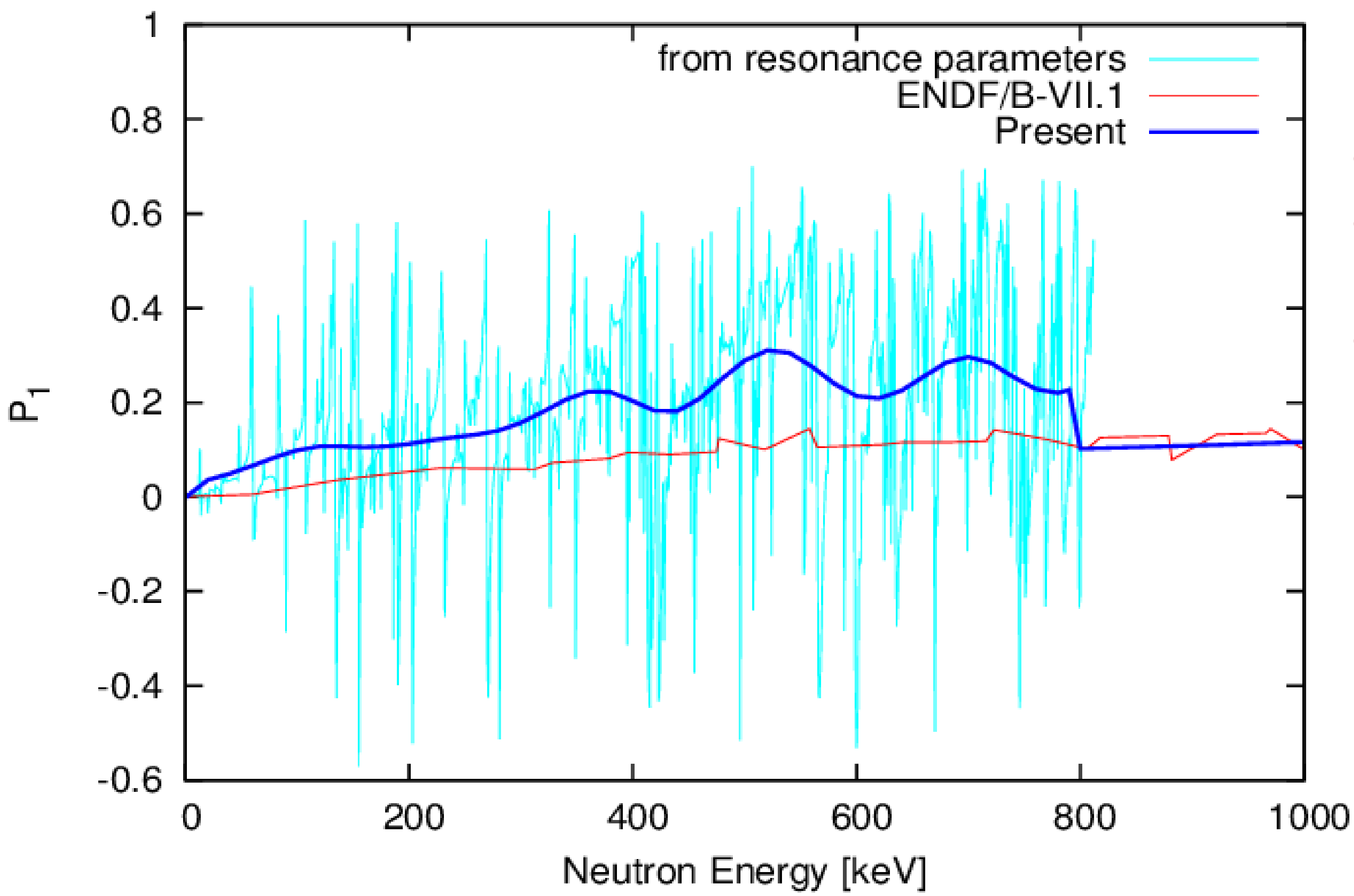




IRDF2002 is the same as ENDF/B-VII (VI)

T. Kawano

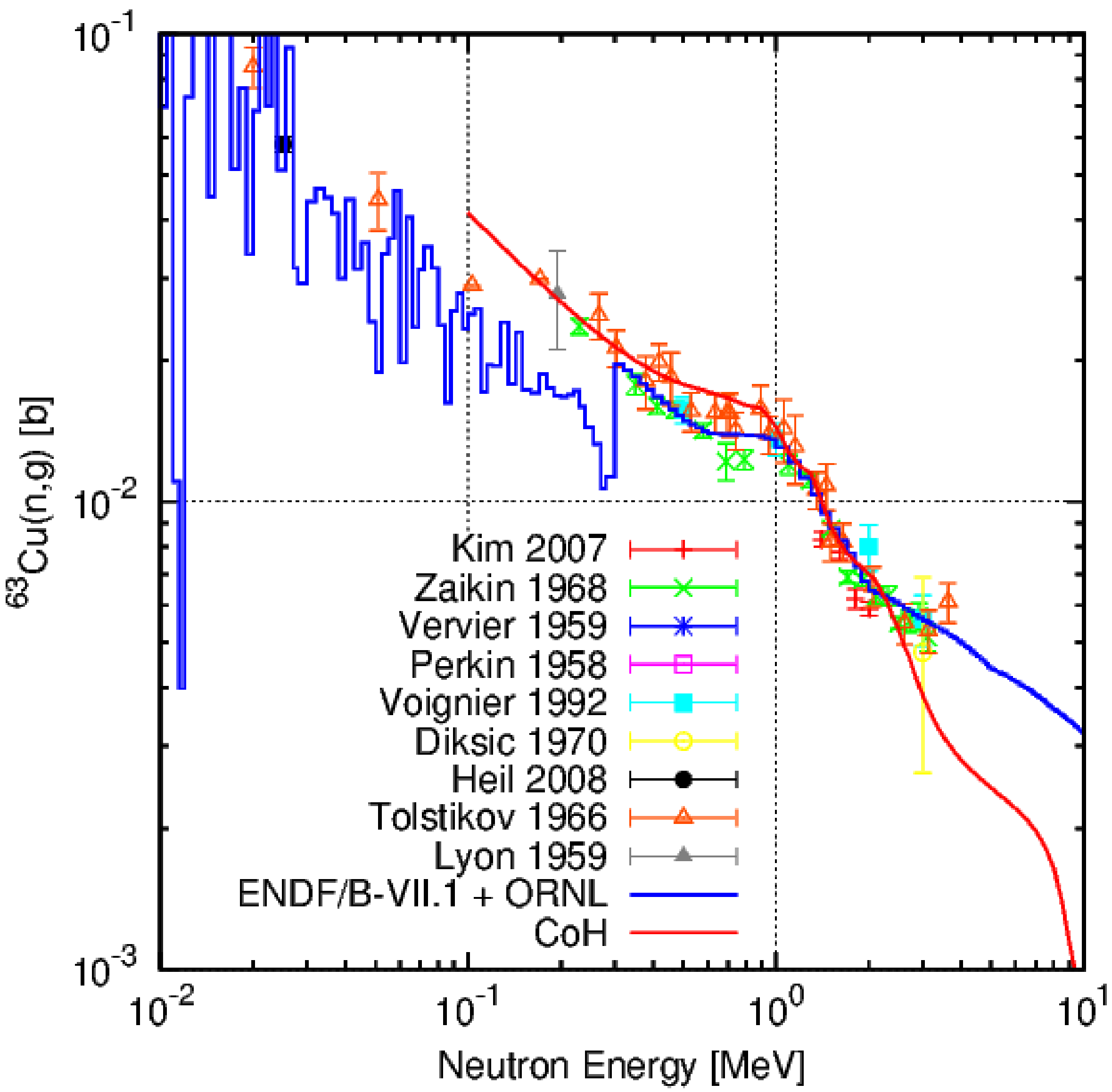
Elastic Scattering Angular Distribution

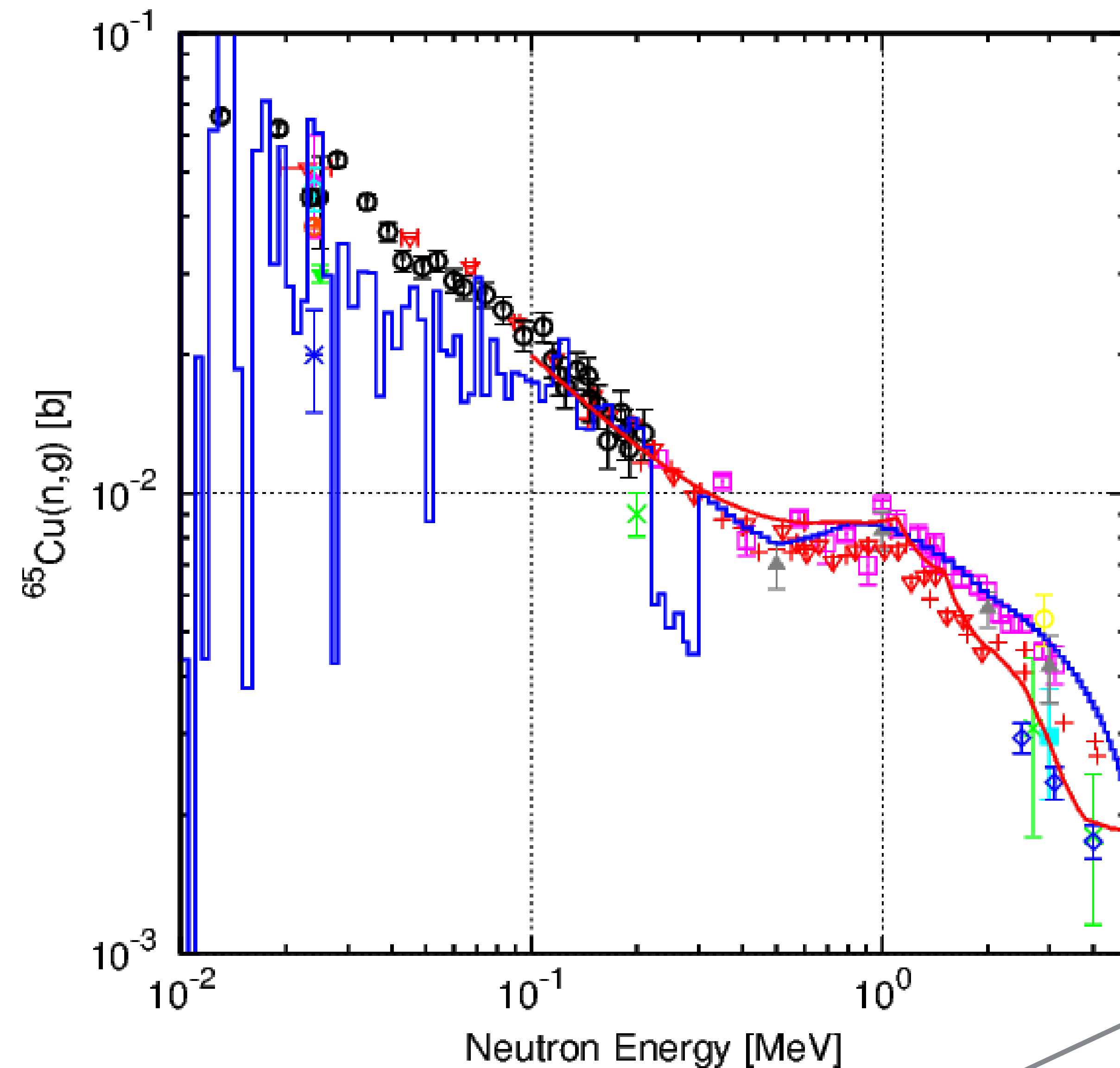


- **Elastic scattering angular distributions at low energies**
  - Reconstructed from R-M resolved resonance parameters using BB formula, and smoothed
  - Ni58 and 60 only
  - Produced more forward-peaked scattering ang. dist.
  - Method developed under WPEC/SG35 enables us to go beyond RRR

T. Kawano

Cu-63, 65 Capture Cross Section

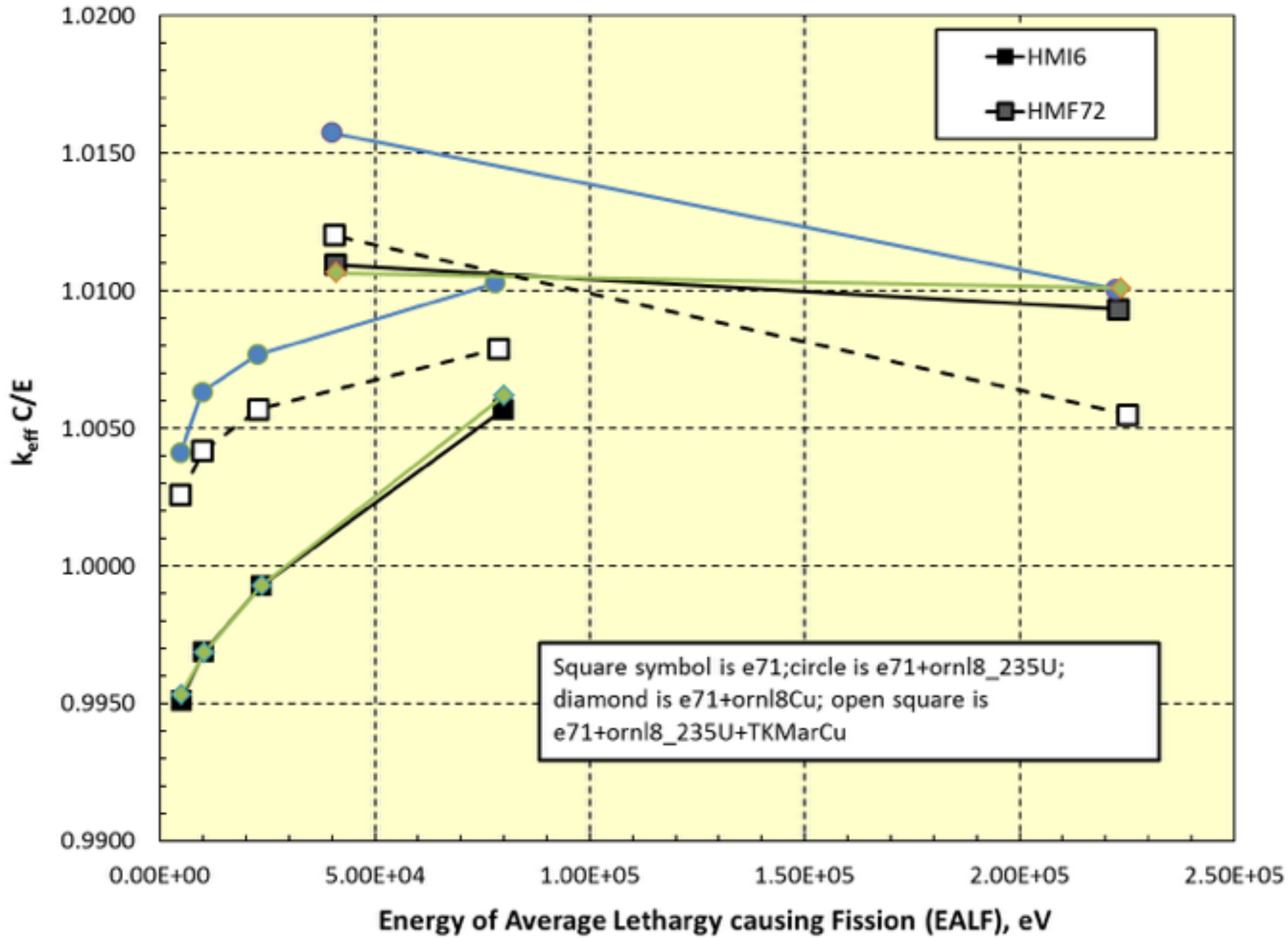




T. Kawano

ZEUS Benchmarks (HMF72, HMI6)

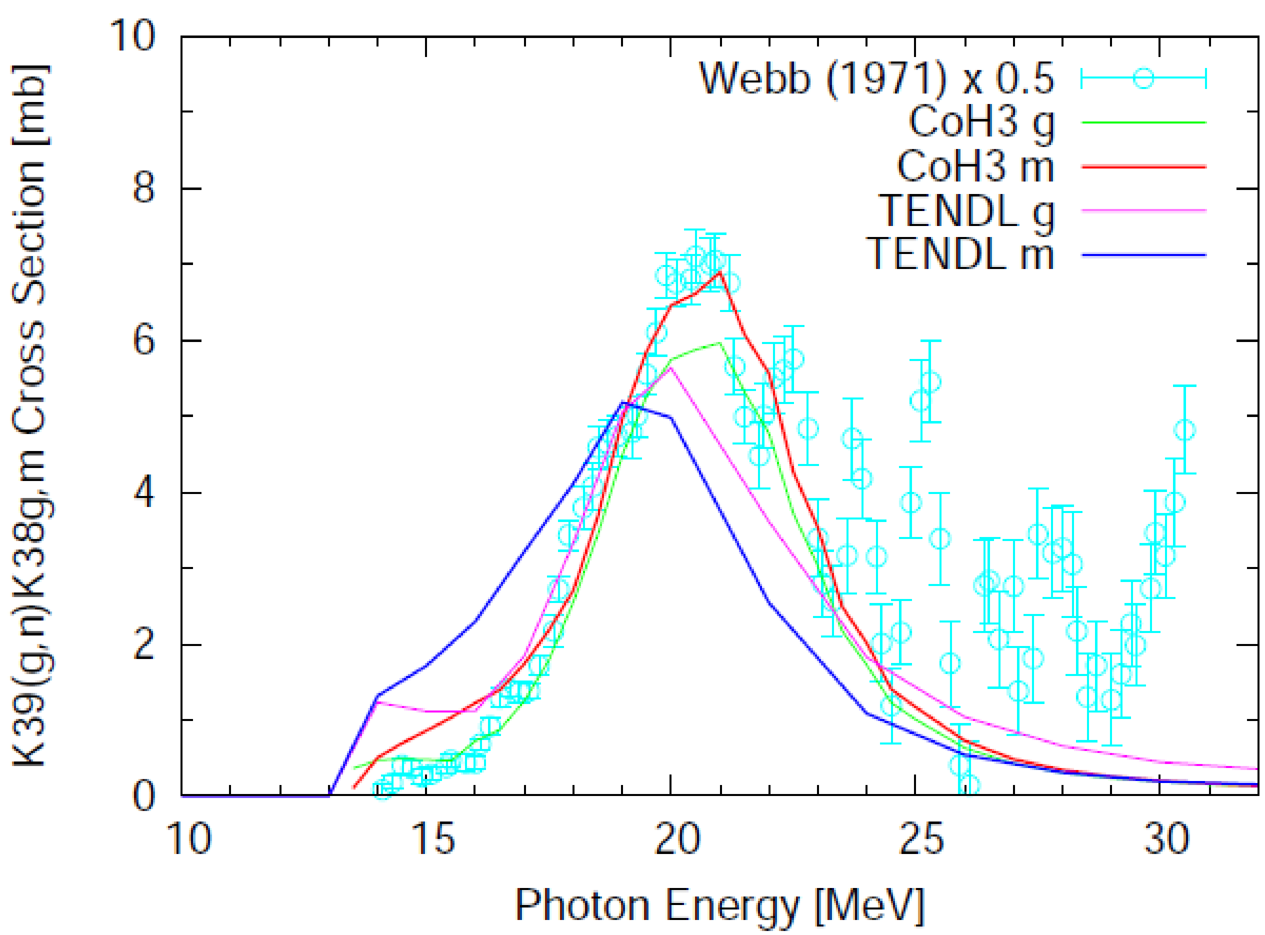
- ^{63,65}Cu data sets from Kawano.
- Latest results (open squares) show reduced bias in k_{eff}, but still have work to do.



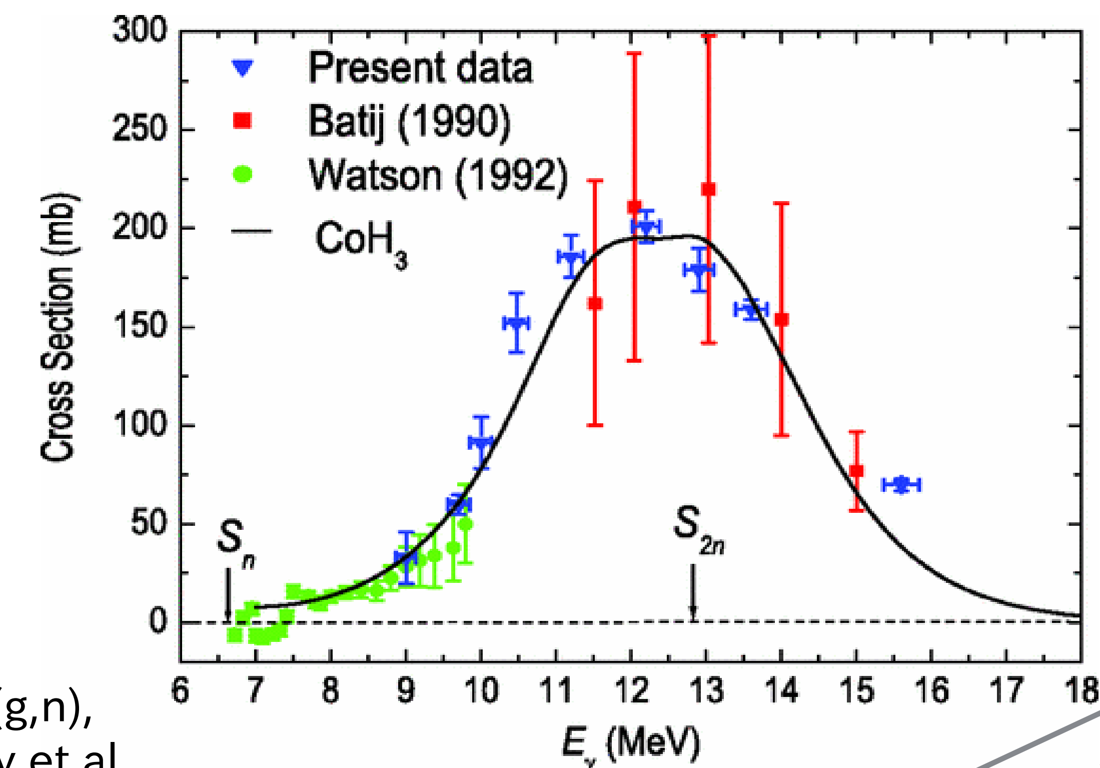
S. Kahler

UNCLASSIFIED

Statistical Hauser-Feshbach Calculation for Photo Reaction



- **Photo-induced reaction**
  - All individual reaction channel cross sections given
  - Produce all the radio-isotopes in the residual nuclides
    - calculation requires nuclear structure database (RIPL-3) to identify the meta-stable states



Am241(g,n),
Tonchev et al.
Phys. Rev. C 82, 054620 (2010)

T. Kawano

In 1990, ENDF/B-VI.0 expanded atomic data to include electrons and atomic relaxation

Based on S. Perkins & Red Cullen's EPDL

- UCRL-50400 Vol. 6 Rev. 4 (1989)
  - photons from 10 eV — 100 GeV

Revised in 1997

- photons extended down to 1 eV, add photoionization to compute anomalous scattering factors, photo-excitation data

Major upgrade in 2001: atomic relaxation (EADL) & electrons (EEDL)

- UCRL-50400 Vol. 31 (1991) — EEDL
- UCRL-50400 Vol. 30 (2001) — EADL
- Electron data translated to ENDF by R. MacFarlane

D. Brown

EPICS2014

Major changes:

- Corrected incorrectly translated electron data (MF/ MT=26/527, <E> from Bremstrahlung)
- Increase file precision with ENDF2C
- “Changes where I felt they were necessary”

Major change not made:

- Revising transition energies to match results of Deslattes, et al., “X-ray transition energies: a new approach to a comprehensive evaluation”, Rev. Mod. Phys. **75**, 35-99 (2003).
- Used for validation

Update seems minor, but important to upgrade all sub libraries as a set to maintain internal consistency

D. Brown

Improved Neutron Capture Gamma-Ray Data for Li and F

- Gammas are 6-12 MeV (σ!)
    - Clear of competing lines
    - More difficult to shield
    - Fingerprint of capturing isotope

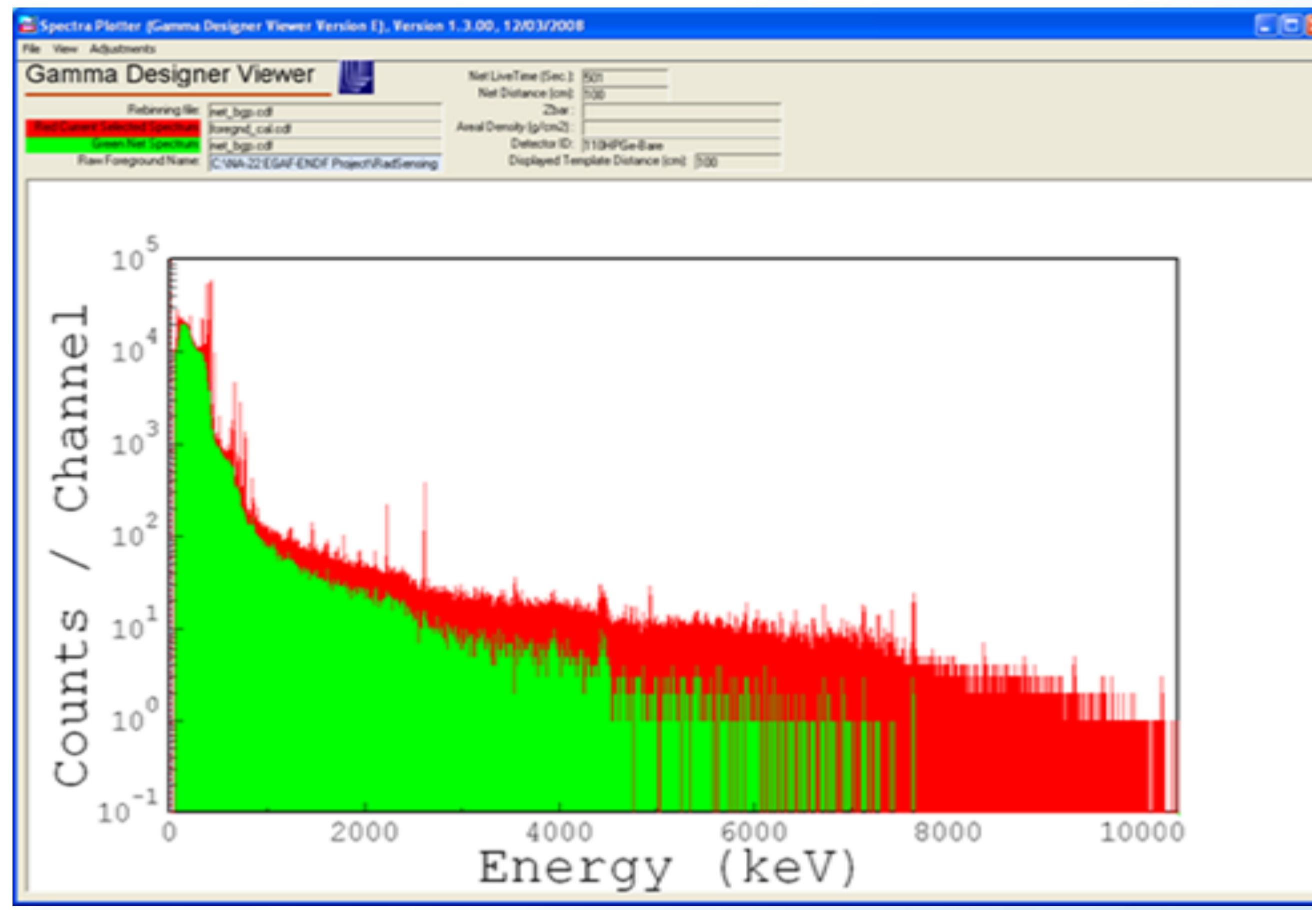
- Passive or active neutron sources

- Neutrons from spontaneous fission implies actinides presence

- Neutrons coupled to gammas

-Thermal Capture Dominates

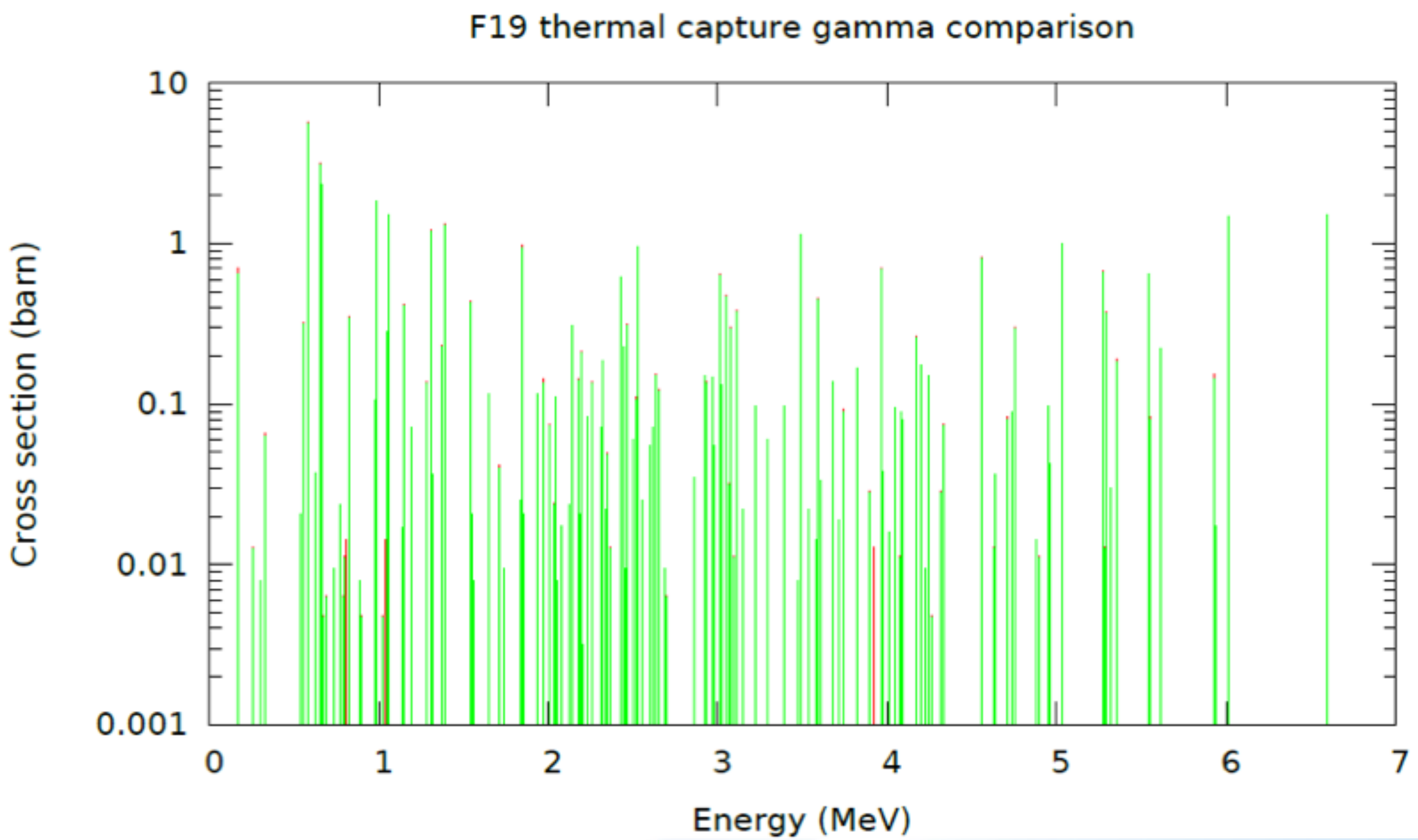
Measurement of gamma spectra from Pu



B. Sleaford

Used in ANY spectroscopy application, Emergency response, Nonproliferation, etc.

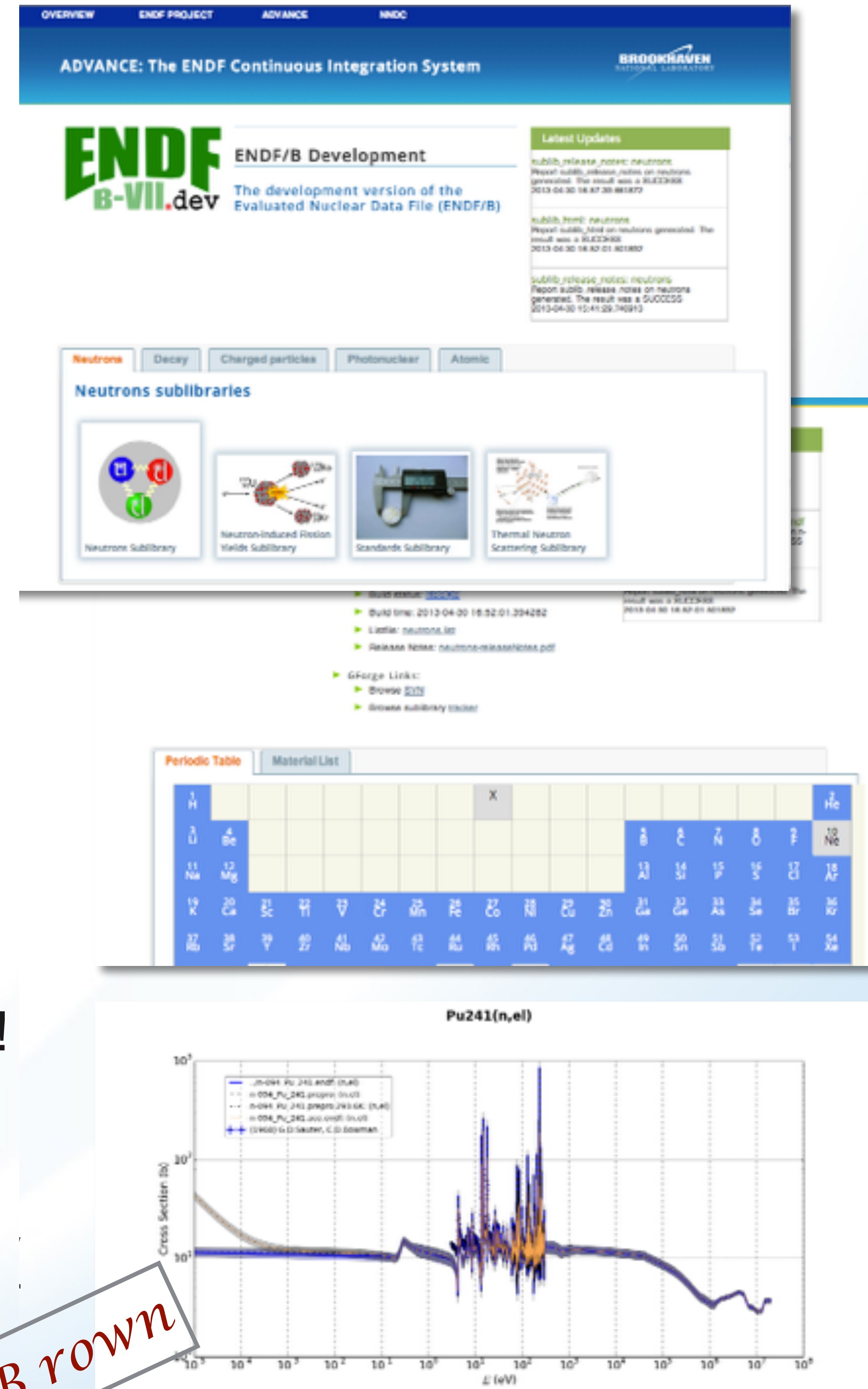
F had few changes in ENDF



B. Sleaford

ADVANCE quality assurance system for ENDF

- **On every commit of every evaluation in ENDF**
  - Check out evaluation
  - Run through a battery of tests
  - Process with customer processing codes
  - Generate comparison plots
  - Generate HTML report of evaluation
- **Automation is better!**
  - Find data problems before the customers!
  - Far faster/better than old PHASE I review
- **Available at http://www.nndc.bnl.gov/endf/b7.dev/qa/index.html**



D. Brown

Major change made this year: Testing atomic data to support EPICS

- **All atomic data tested by**
  - NNDC Codes (STAN, STANEF, CHECKR, FIZCON, PSYCHE)
  - PREPRO (LINEAR)
  - Fudge
- **Generate plots of**
  - photon and electron cross sections
  - photon form factors
  - photon anomalous scattering factors

D. Brown

Major changes (to be) made this year:

Completed

All atomic data tested by

- NNDC Codes (STAN, STANEF, CHECKR, FIZCON, PSYCHE)
- PREPRO (LINEAR)
- Fudge

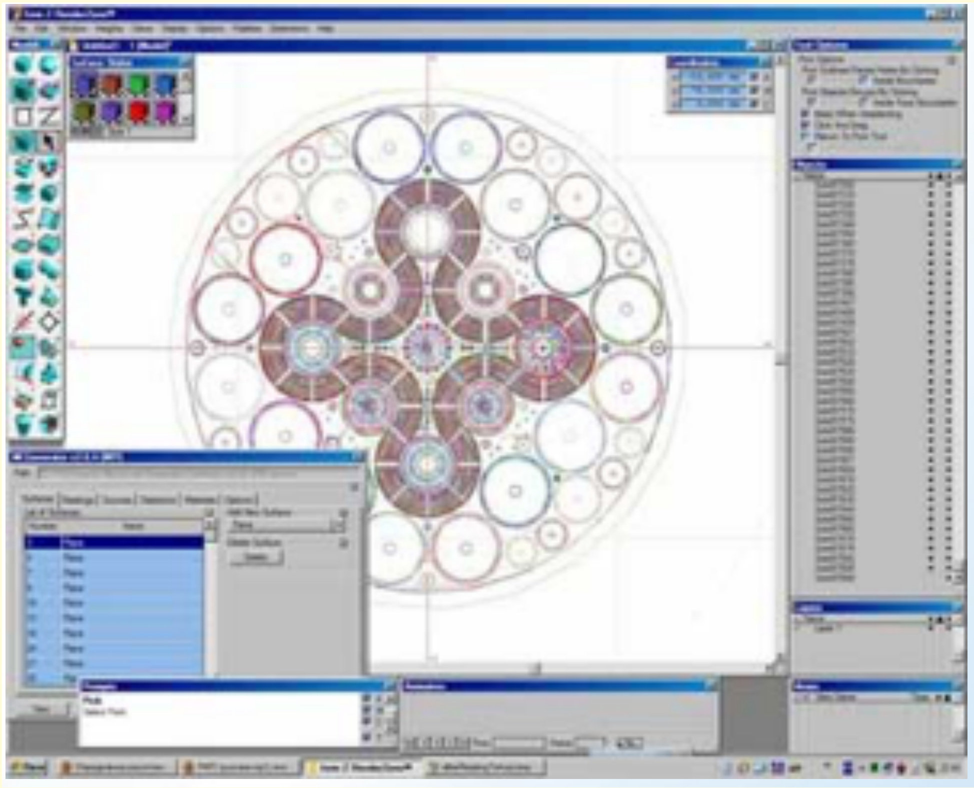
Generate plots of

- photon and electron cross sections
- photon form factors
- photon anomalous scattering factors

To be done this summer

Automated benchmarking

- Have COG and COG library builders
- Have ICSBEP test suite from COG



D. Brown

Improvements to the Decay Sublibrary

Improve antineutrino spectra calculations by including Iβ from TAGS experiments and Iβ following fit to Tengblad 1990 data

92Rb Use the 2006LH01 gamma normalization
137I Run LOGFT , Added 2 E2 gammas, run BRICC
135sb Run LOGFT , Added 2 E2 gammas, run BRICC

95Sr,140Cs,95Y,143La,145La,141Cs,143Ba,91Rb,93Rb,94Rb,144La use Iβ TAGS

82Ge Use ENSDF assuming Iβ(GS)=0
83Ge Use ENSDF assuming Iβ(GS)=1

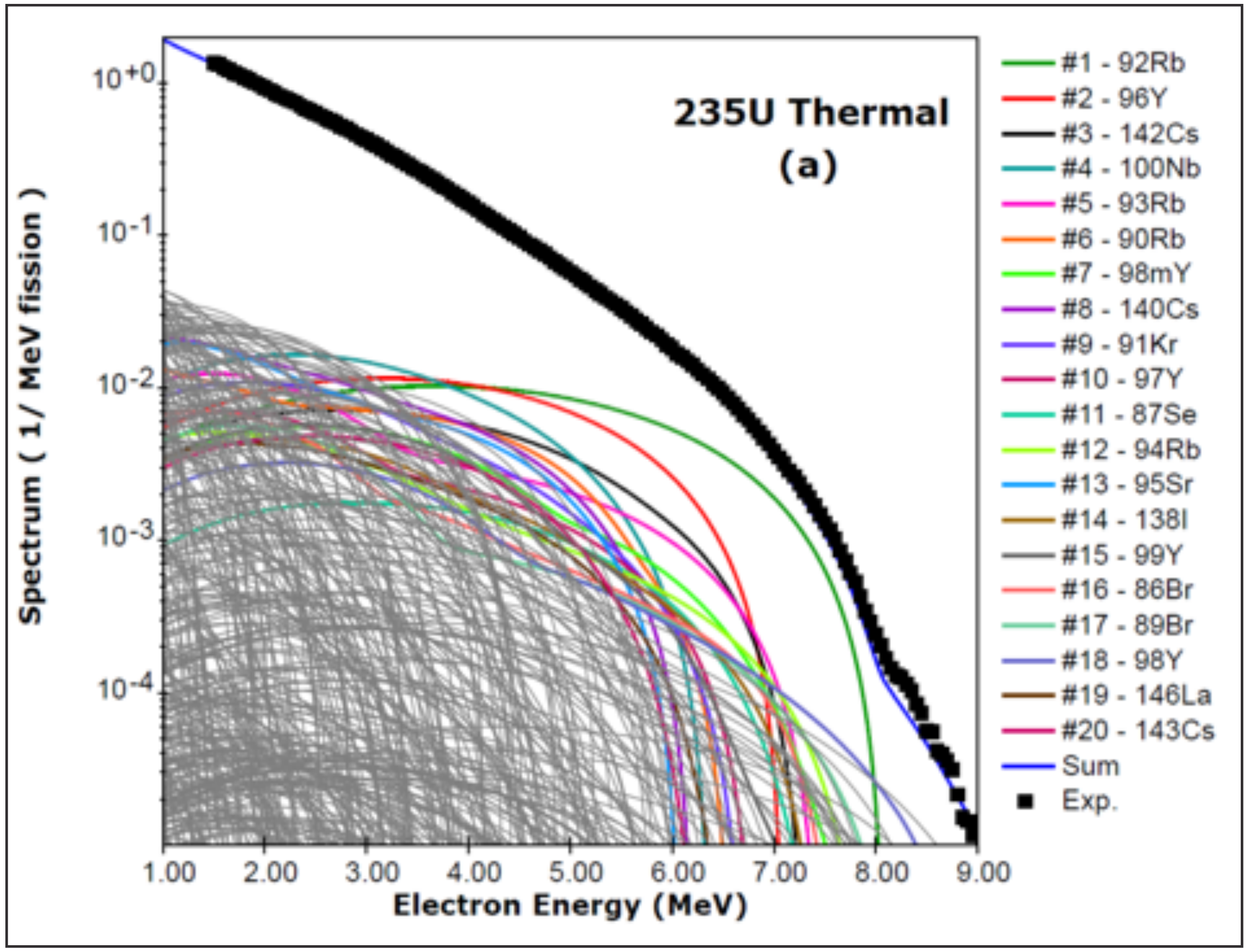
90Br,96Rb,98Y,138I,88B,99Y,89br,134sb,95rb,82As Adjust the beta feeding to match Rudstam's data

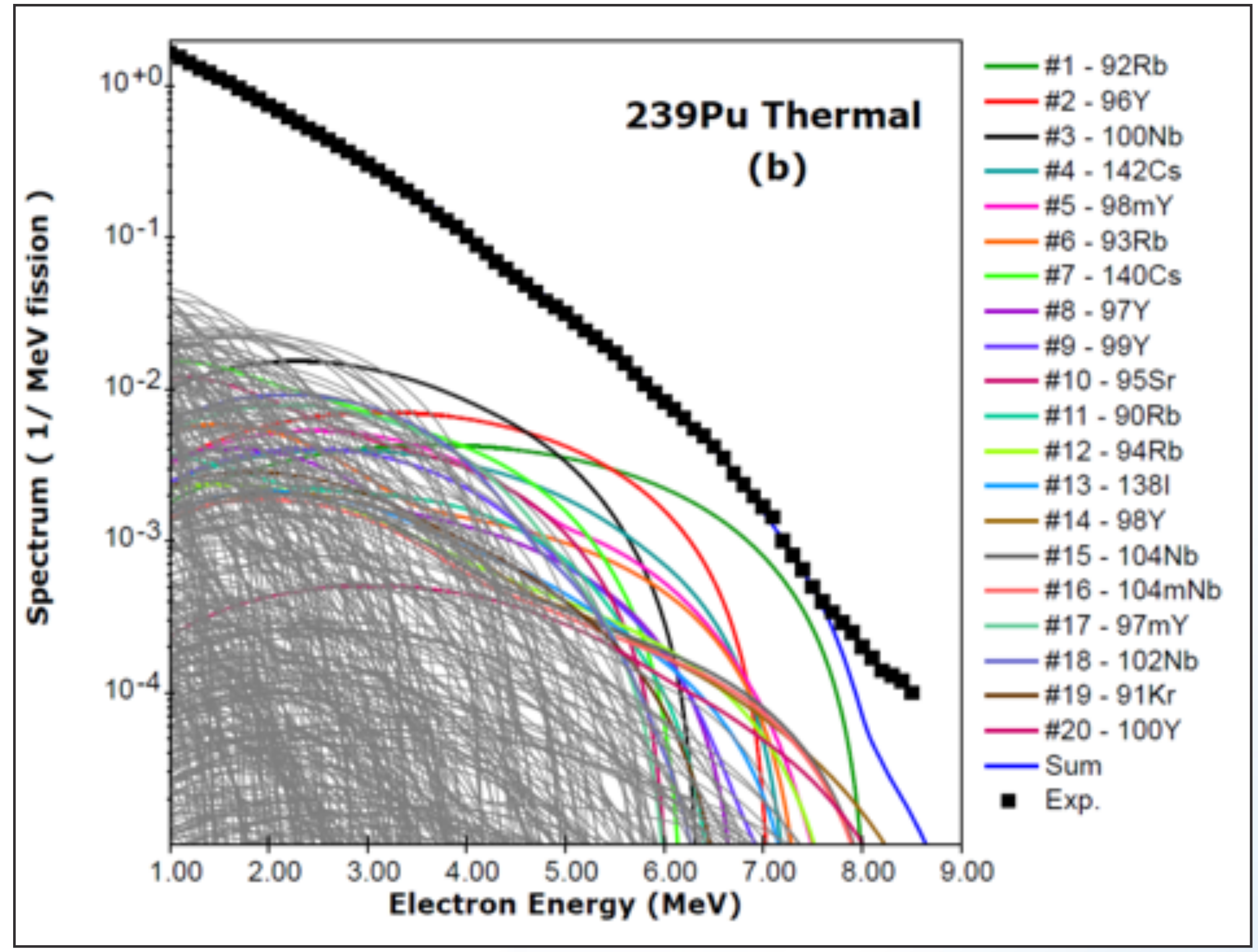
91Br Use Woehr beta feeding, neutron have to be added

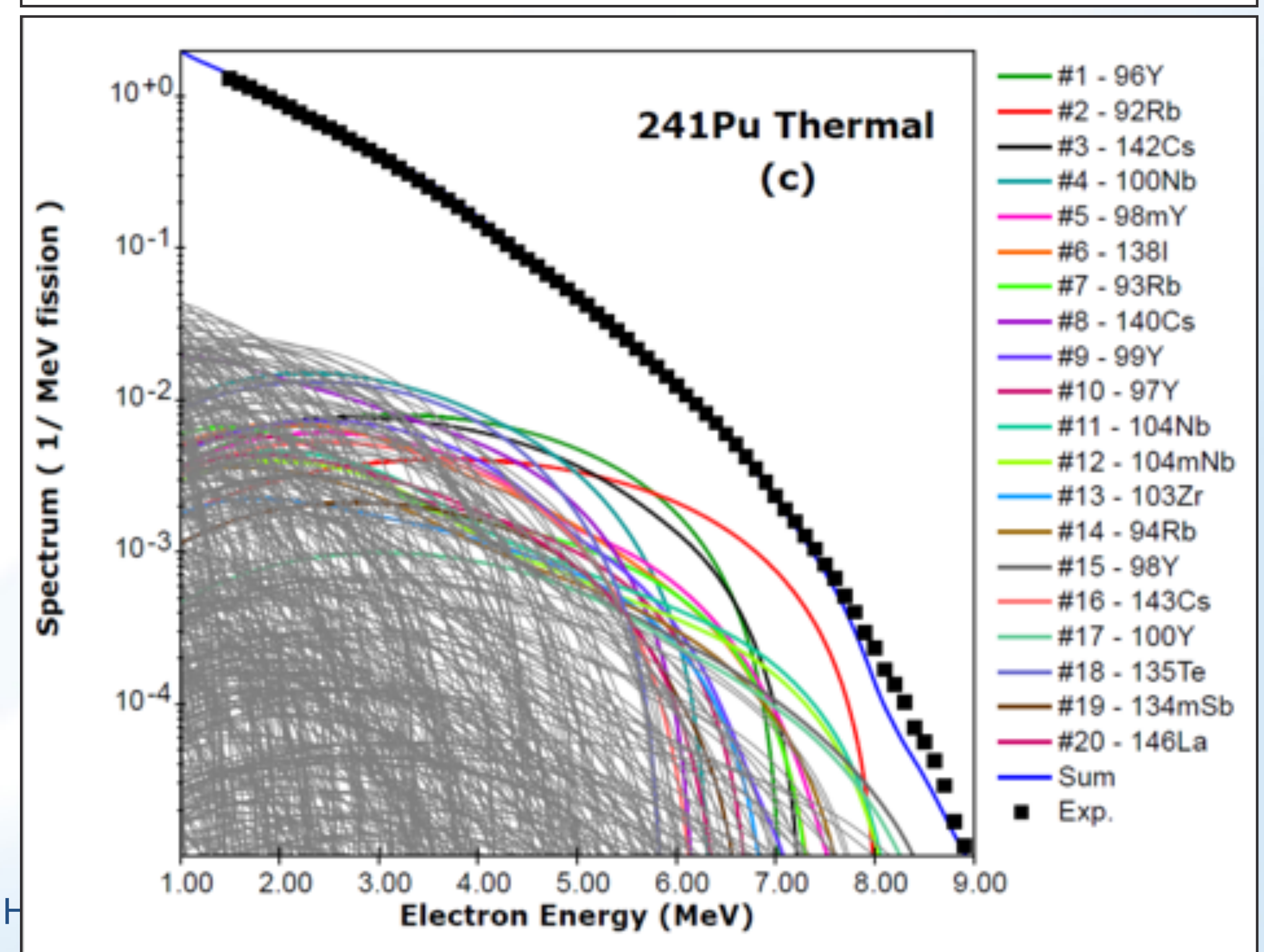
A. Sonzogni

(n,f) β-spectra calculations

No adjustable parameters
Phys. Rev. C **91**, 011301(R) (2015)





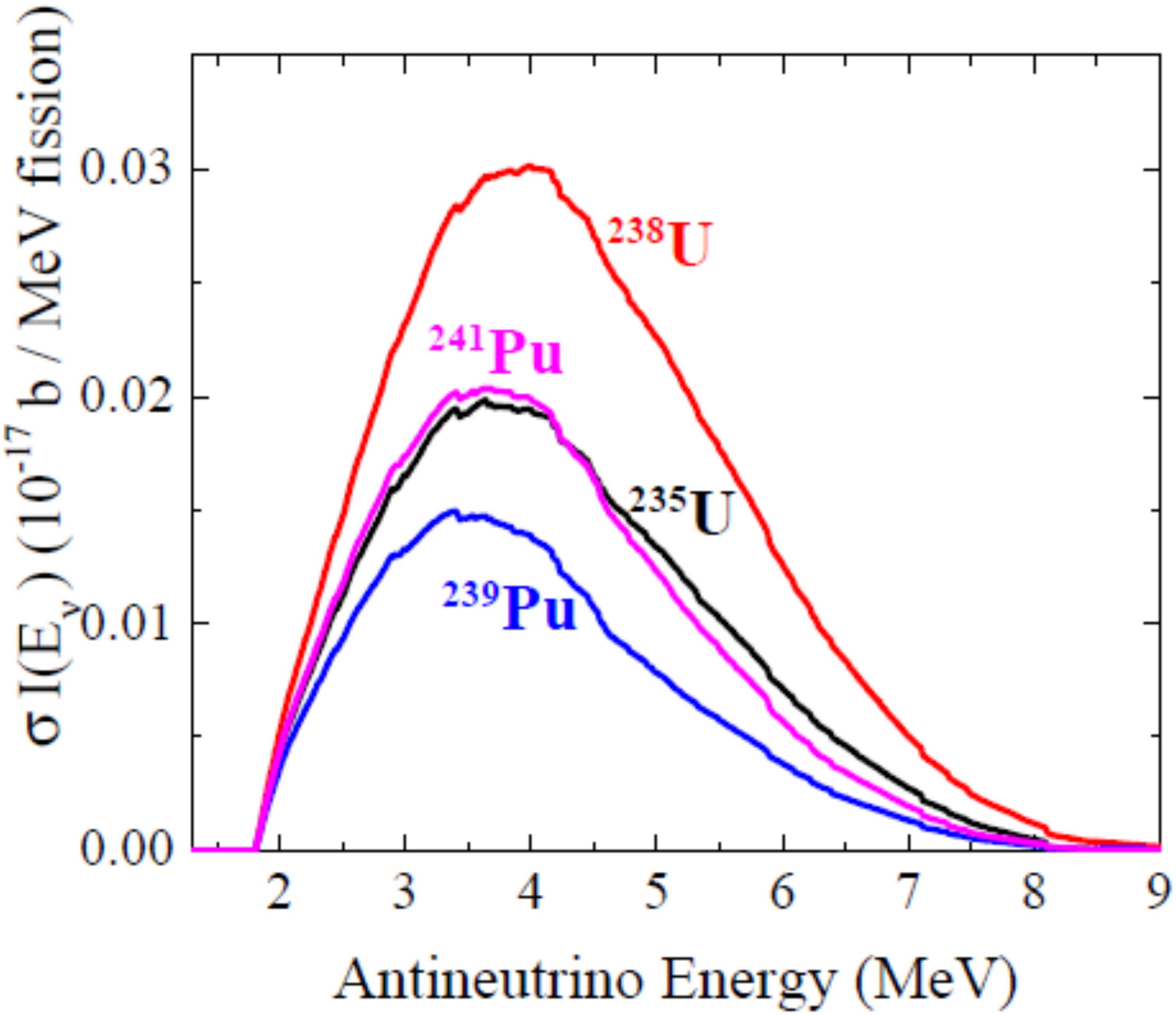


For energies > 5 MeV, the electron and antineutrino spectra are mainly due to about 20 nuclides

The decay of these nuclides is of great interest

A. Sonzogni

$\bar{\nu} + p \rightarrow n + e^+$ cross section integrated spectra



Target	Delayed neutron multiplicity/fission
238U	*4.4E-2*
235U	*1.59E-2*
241Pu	*1.62E-2*
239Pu	*6.45E-3*

The integral of antineutrino multiplicity has a similar behavior as the delayed neutron multiplicity.

A. Sonzogni

IAEA CRP on Beta delayed neutron emitters

Will result in newly evaluated values of Pn and $T_{1/2}$ for delayed neutron emitters, ex, 88Br.   These data will be incorporated in ENSDF as well as the sub-library.

$\overline{\nu_d}$: Delayed nu-bar, number of neutrons for single fission event. It can be calculated as:

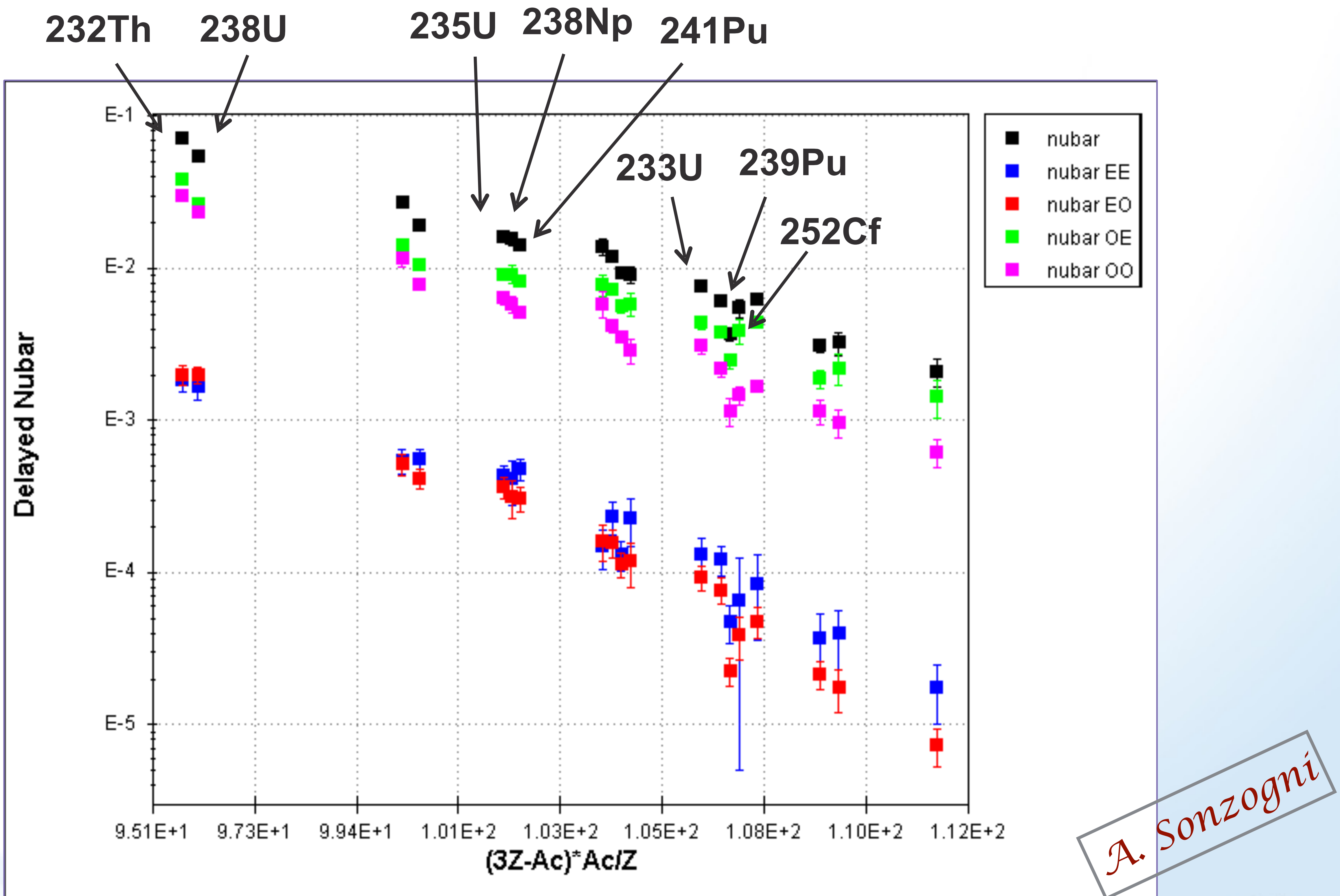
$\overline{\nu_d} = \Sigma\ CFY_i\ Pn_i$, about 0.015/fission for 235U

CFY: cumulative fission yield.

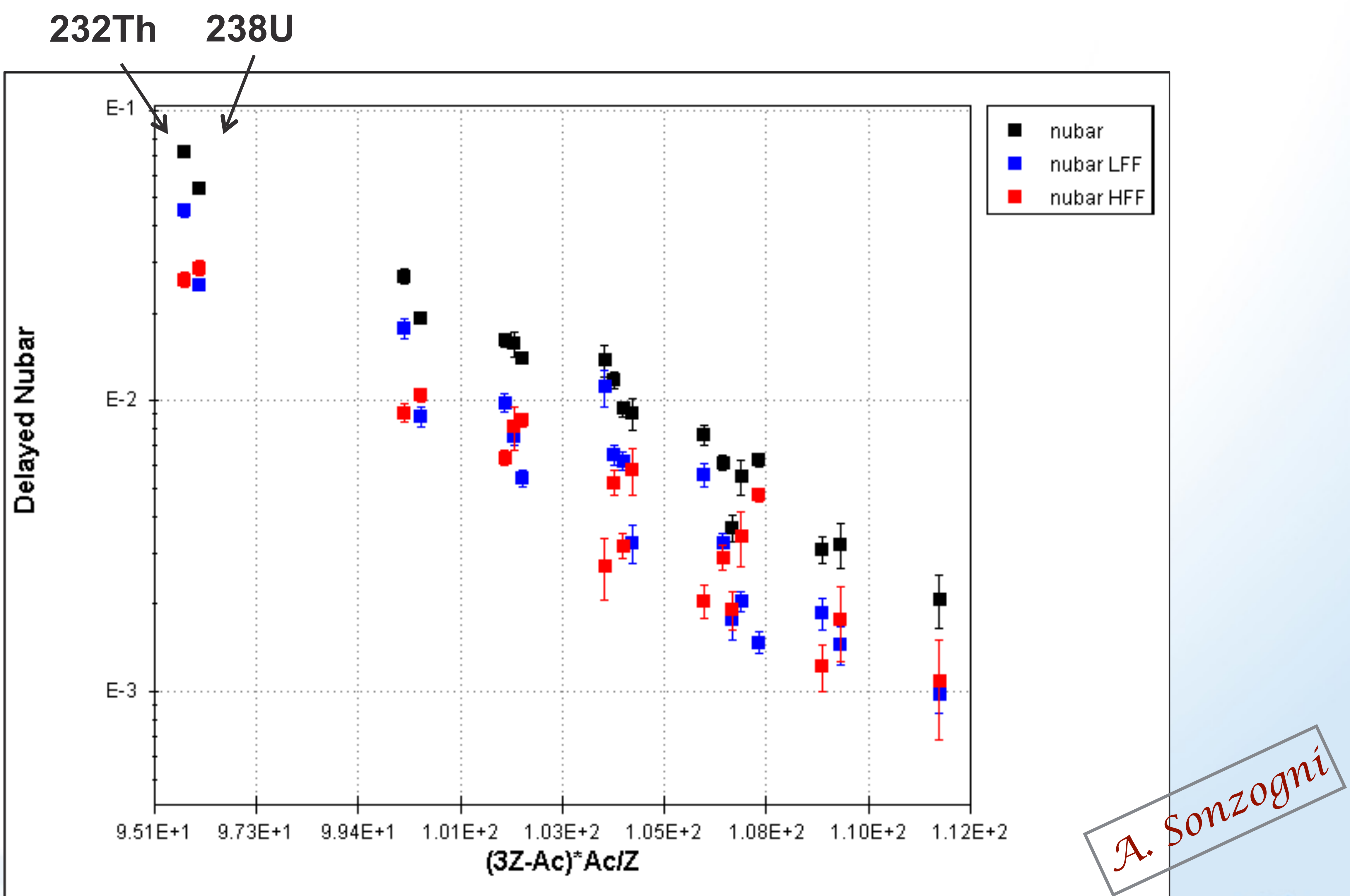
Pn: beta-delayed neutron probability.

A. Sonzogni

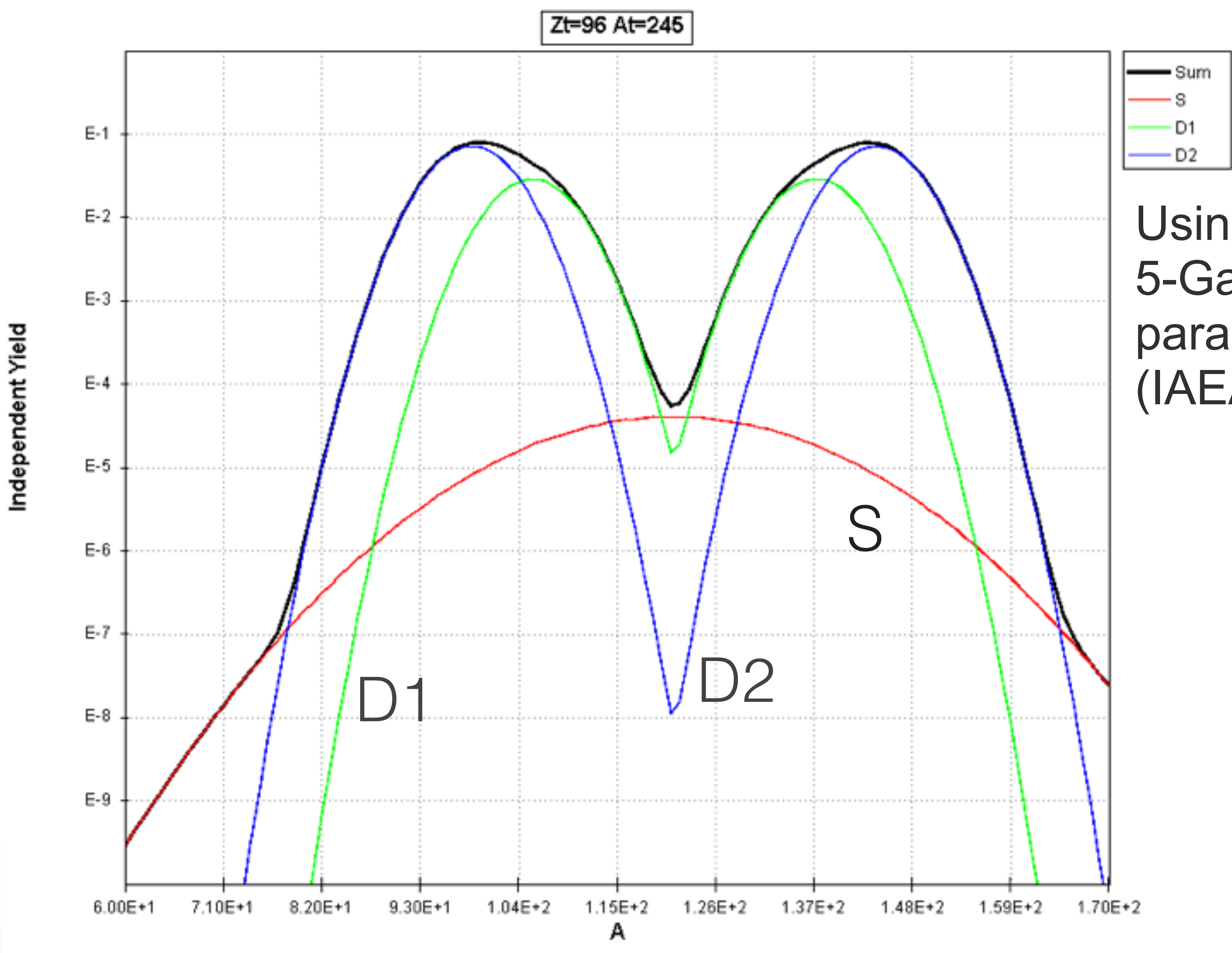
Delayed nu-bars calculated using Pn and CFY



As before, but plotting lighter and heavier fission fragments contributions

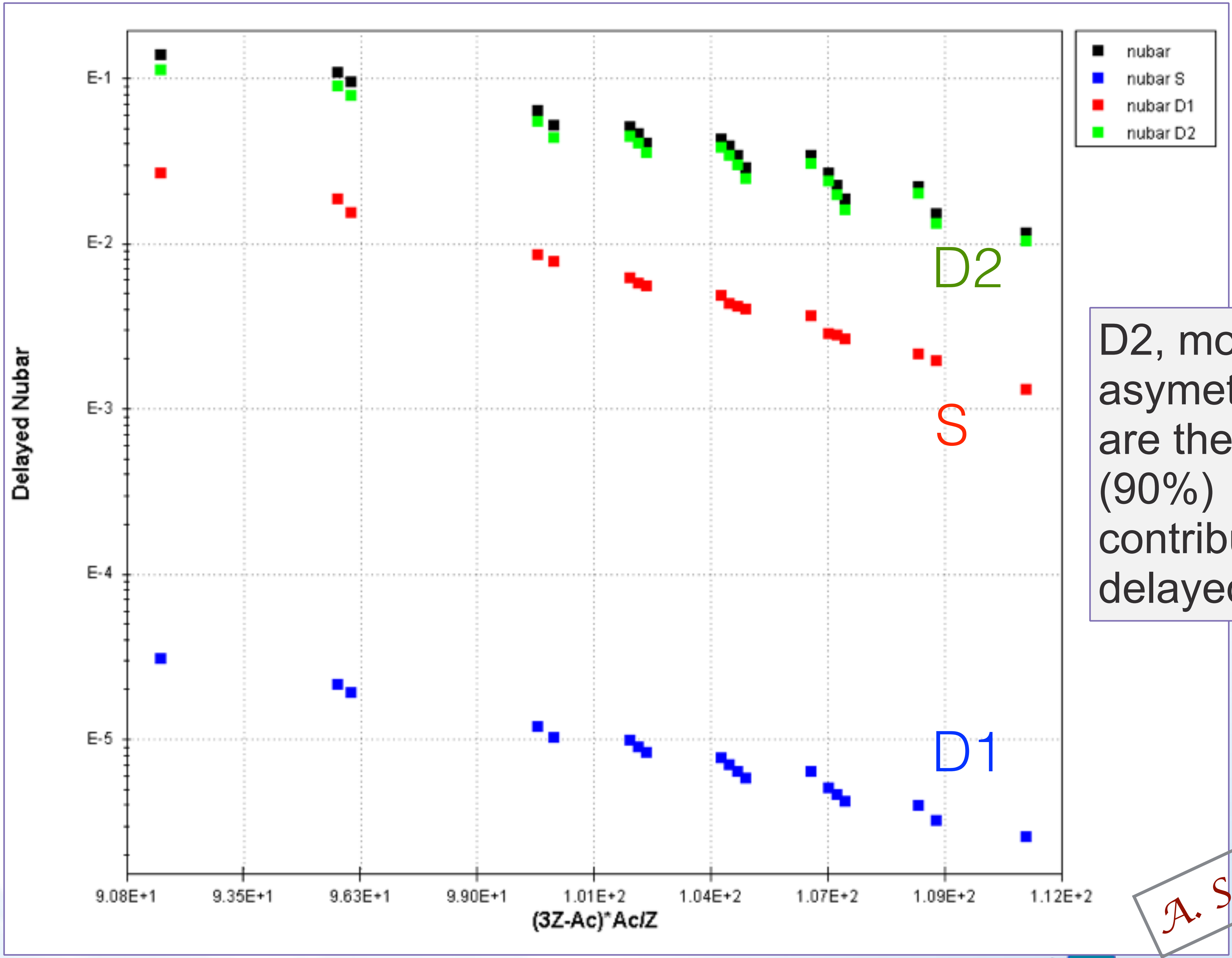


Now looking at the contributions of the different fission modes.



Using Katakura's 5-Gaussian parametrization (IAEA CRP)

A. Sonzogni



D2, most asymetric fission are the main (90%) contributors to delayed nubars

A. Sonzogni

Current Benchmark Evaluation Efforts to Support Integral Nuclear Data

Mini-CSEWG-2015
7 May 2015

John D. Bess
Idaho National Laboratory (INL)

www.inl.gov

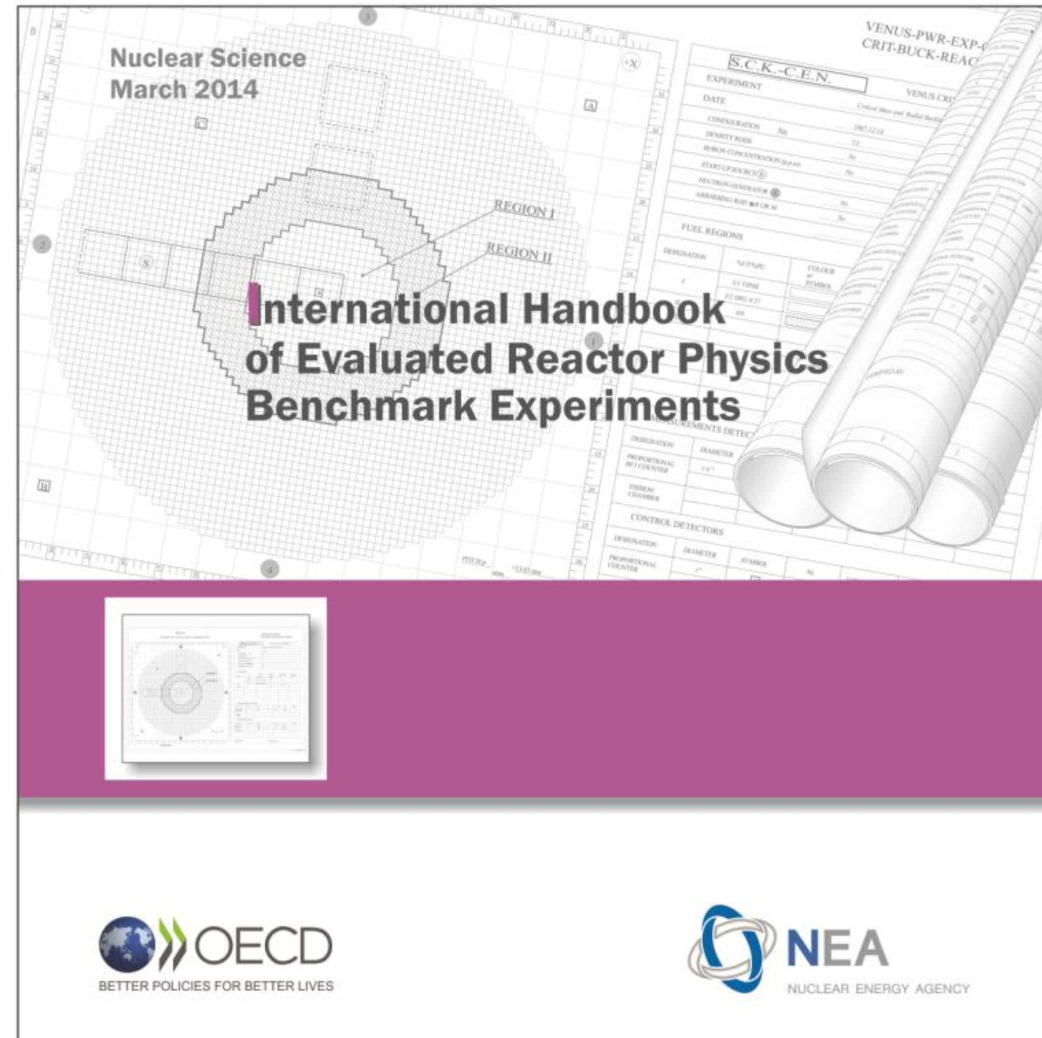
Idaho National Laboratory

Idaho National Laboratory

International Handbook of Evaluated Reactor Physics Benchmark Experiments

March 2015 Edition

- 20 Contributing Countries
- Data from 143 Experimental Series performed at 50 Reactor Facilities
- Data from 139 are published as approved benchmarks
- Data from 4 are published only in DRAFT form



http://irphep.inl.gov/
http://www.oecd-nea.org/science/wprs/irphe/

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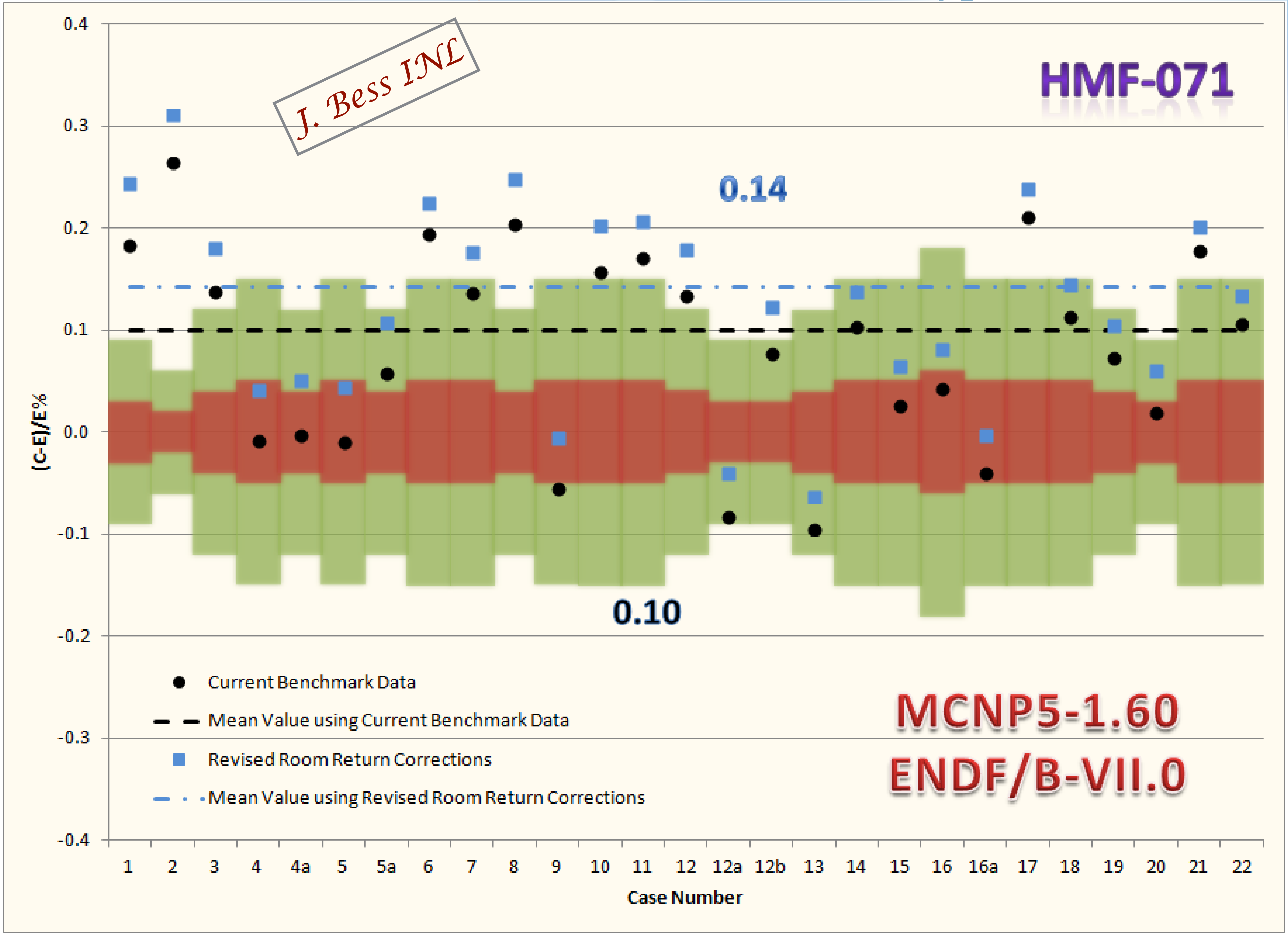
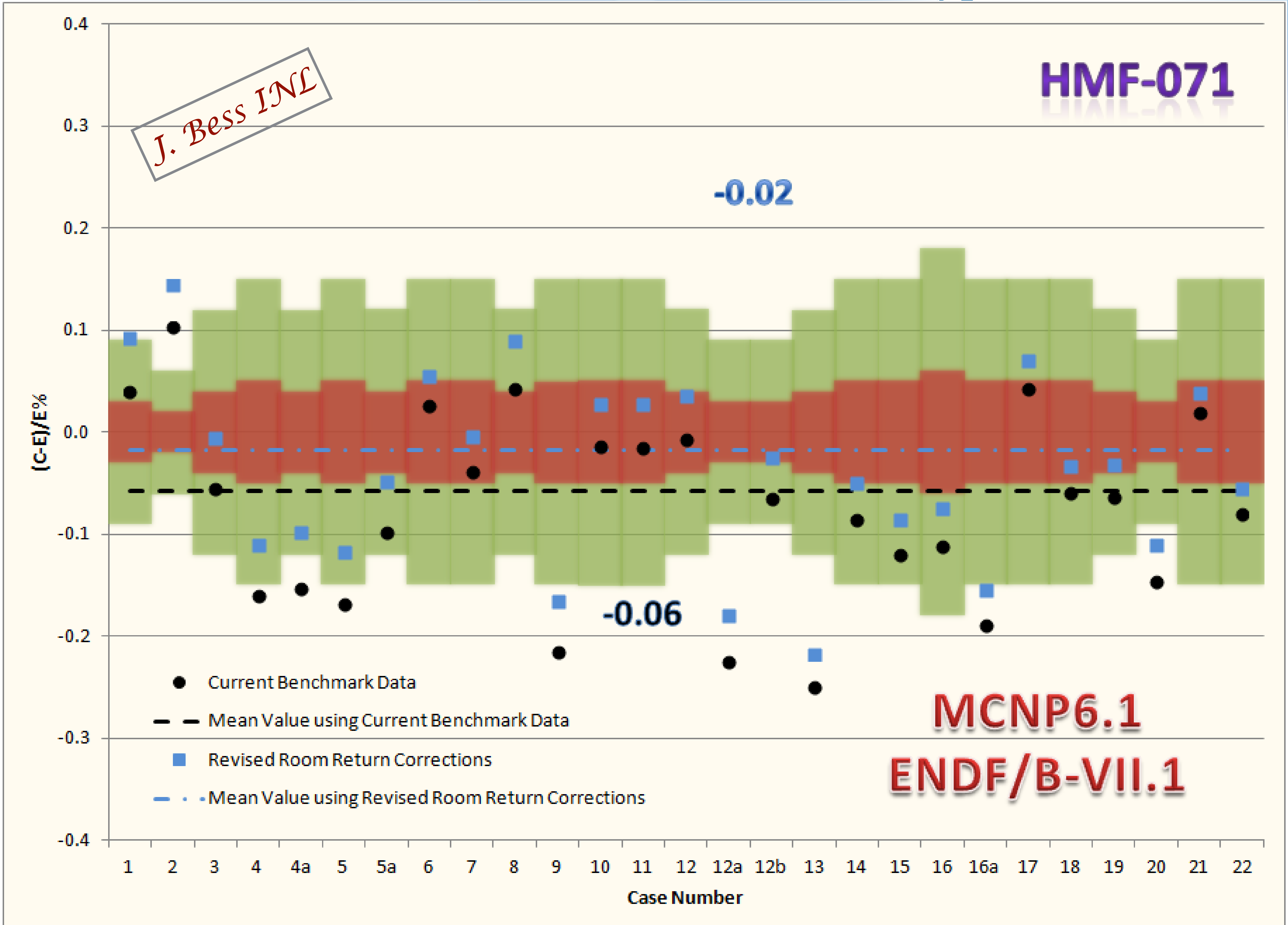


HMF-071
J. Bess INL
0.14
0.10
(C-E)/E%
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
1
2
3
4
4a
5
5a
6
7
8
9
10
11
12
12a
12b
13
14
15
16
16a
17
18
19
20
21
22
Case Number
Current Benchmark Data
Mean Value using Current Benchmark Data
Revised Room Return Corrections
Mean Value using Revised Room Return Corrections
MCNP5-1.60
ENDF/B-VII.0



HMF-071
J. Bess INL
-0.02
-0.06
(C-E)/E%
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
1 2 3 4 4a 5 5a 6 7 8 9 10 11 12 12a 12b 13 14 15 16 16a 17 18 19 20 21 22
Case Number
Current Benchmark Data
Mean Value using Current Benchmark Data
Revised Room Return Corrections
Mean Value using Revised Room Return Corrections
MCNP6.1
ENDF/B-VII.1

For more details see presentations at:

https://indico.bnl.gov/conferenceDisplay.py?confId=965

Mini-CSEWG-2015

chaired by Mike Herman (BNL), Mark Chadwick (Lanl), Dave Brown

from Thursday, May 7, 2015 at **09:00** to Friday, May 8, 2015 at **13:00** (US/Eastern)
at **Berkner (B)**

Thursday, May 7, 2015

09:00 - 12:00 CSEWG Evaluation Committee

Convener: Dr. Mark Chadwick (Lanl)

09:00 **Status of C & H standards evaluations** *10'*
Speaker: Dr. Mark Chadwick (Lanl)
Material: **Slides**

09:10 **FPYs** *10'*
Speaker: Dr. Mark Chadwick (Lanl)

09:20 **Cu and W** *20'*
Speaker: Dr. Luiz Leal (ORNL)
Material: **Slides**

09:40 **Summary of updated data at LANL** *20'*
Speaker: Dr. Toshihiko Kawano (Los Alamos National Laboratory)
Material: **Slides**

Backup slides

What's in the electro-atomic sub library?

- **Elastic transport,**
  - ***transport cross section, σ_{el} (1-E<cosθ>) (b)***
- **Large angle elastic scattering (over cosθ = -l. to 0.999999)**
  - ***integrated LACS cross section (b),***
  - average energy of the scattered electron (MeV),
  - average energy to the residual atom, i.e., local deposition (MeV),
  - angular distribution of the scattered electron.
- **Elastic scattering**
  - ***integrated scattering cross section (b),***
- **Ionization, by subshell**
  - ***integrated cross section (b),***
  - average energy to the scattered and recoil electron (MeV)
  - spectra of the recoil electron (MeV^{-1}).
- **Bremstrahlung**
  - ***integrated cross section (b),***
  - average energy of the secondary electron and photon (MeV) ,
  - spectra of the secondary photon (MeV^{-1}).
- **Excitation**
  - ***integrated cross section (b),***
  - average energy to the residual atom, i.e., local deposition (MeV).

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What's in the photo-atomic sub library?

- **Coherent scattering,**
  - ***integrated cross section (b),***
  - ***form factor,***
  - ***real and imaginary anomalous scattering factors,***
  - average energy of the scattered photon (MeV),
- **Incoherent scattering**
  - ***integrated cross section (b),***
  - ***scattering function,***
  - average energy of the scattered photon and recoil electron (MeV).
- **Total photoelectric reaction**
  - ***integrated cross section (b),***
  - average energy to the residual atom, i.e., local deposition (MeV),
  - average energy of the secondary photons and electrons (MeV).
- **Photoelectric reaction, by subshell**
  - ***integrated cross section (b),***
  - average energy to the residual atom, i.e., local deposition (MeV),
  - average energy of the secondary photons and electrons (MeV) .
- **Pair production reaction**
  - ***integrated cross section (b),***
  - average energy of the secondary electron and positron (MeV) .
- **Triplet production reaction**
  - ***integrated cross section (b),***
  - average energy of the secondary electron and positron (MeV) .

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What's in the photo-atomic sub library?

- **Coherent scattering,**
  - ***integrated cross section (b),***
  - ***form factor,***
  - ***real and imaginary anomalous scattering factors,***
  - average energy of the scattered photon (MeV),
- **Incoherent scattering**
  - ***integrated cross section (b),***
  - ***scattering function,***
  - average energy of the scattered photon and recoil electron (MeV).
- **Total photoelectric reaction**
  - ***integrated cross section (b),***
  - average energy to the residual atom, i.e., local deposition (MeV),
  - average energy of the secondary photons and electrons (MeV).
- **Photoelectric reaction, by subshell**
  - ***integrated cross section (b),***
  - average energy to the residual atom, i.e., local deposition (MeV),
  - average energy of the secondary photons and electrons (MeV) .
- **Pair production reaction**
  - ***integrated cross section (b),***
  - average energy of the secondary electron and positron (MeV) .
- **Triplet production reaction**
  - ***integrated cross section (b),***
  - average energy of the secondary electron and positron (MeV) .

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