IAEA
60 Years
Atoms for Peace and Development

Status of TENDL

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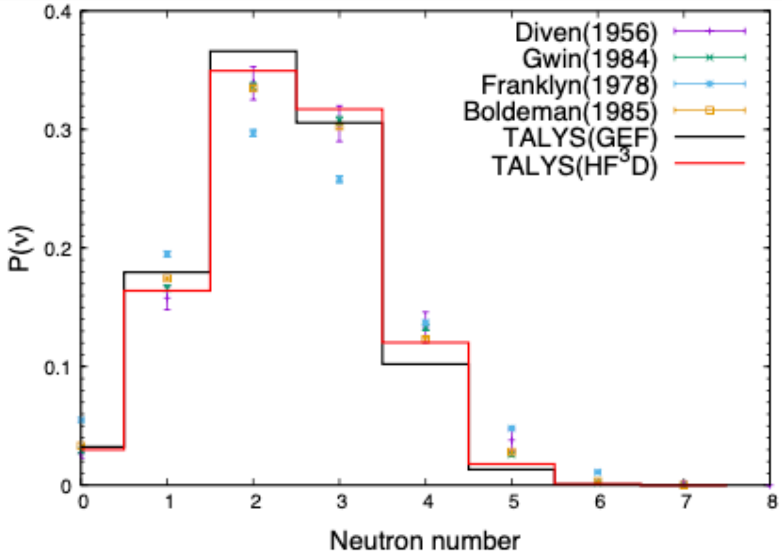
TALYS-1.96/TALYS-2.0

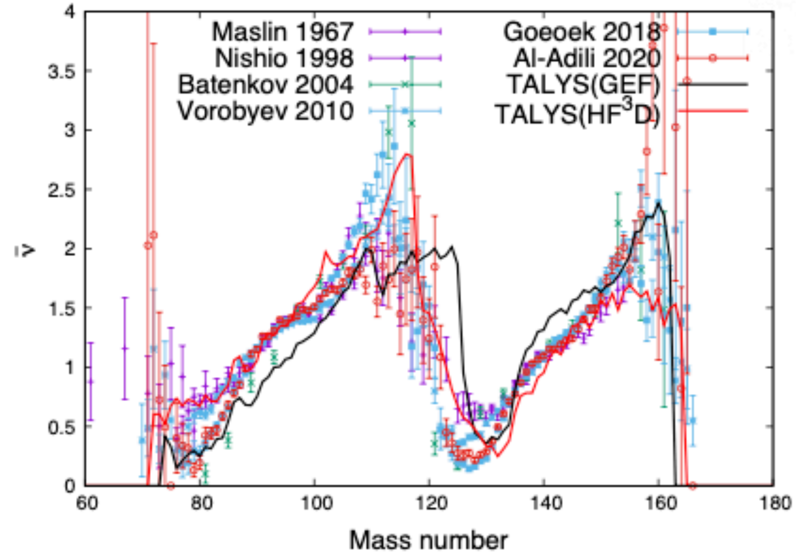
- Some important new features since TALYS-1.95 (Dec 2019)
  - Explicit evaporation of fission fragments via Hauser-Feshbach: FY, nubar, nu(A), PFNS, etc.
  - Latest photon strength function models from IAEA CRP: SMLO, QRPA, M1 PSF with low energy upbend (Stephane Goriely)
  - Ability to use RIPL optical models for actinides
  - Improved deuteron break-up model by M. Avrigeanu
  - Good global description of subactinide and charged-particle induced fission cross sections
  - Phenomenological descriptions of nubar (Wahl) and PFNS (Iwamoto)
- TALYS-1.96 was released 30 December 2021, TALYS-2.0 not yet

Fission yields and neutron observables

- TALYS can loop over itself:
  - First do (n,f) calculation for cross section
  - Then loop over all excited fission fragments and evaporate them with Hauser-Feshbach and all TALYS capabilities for level densities, OMP's etc.
- Zooming in on the truth with the help of
  - Toshihiko Kawano (LANL)
  - Jean-Francois Lemaitre (CEA-DAM)
  - Ali Al-Adili and Fredrik Nordstrom (Uppsala)
  - Shin Okumura (IAEA) and Kazuki Fujio (Titech)
- Fission fragment databases (for many actinides) now in TALYS-1.96:
  - GEF (Schmidt and Jurado)
  - SPY (Lemaitre)
  - HF3D (Kawano and Okumura)
  - More volunteers welcome!!!!

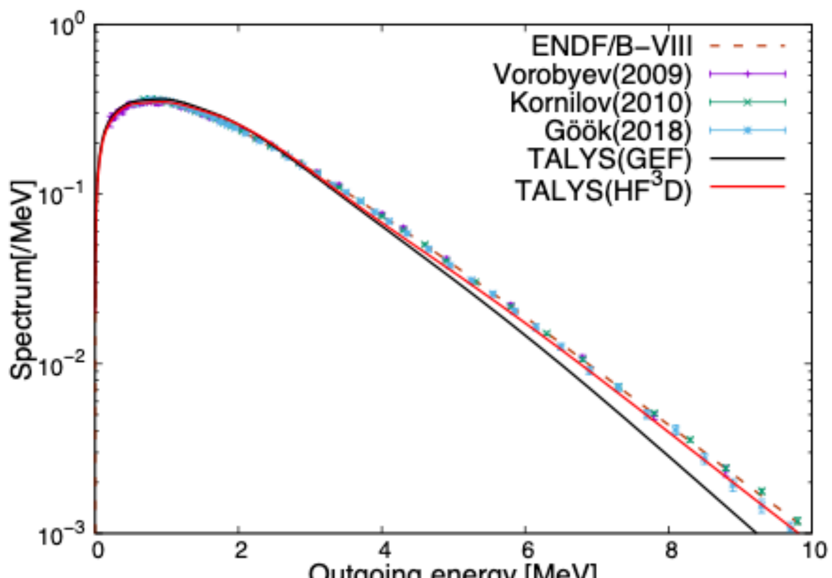
Calculated neutron observables: $^{235}U+n_{th}$





Average number neutrons

TALYS(GEF)	2.275
TALYS(HF^3D)	2.353
JENDL	2.420



Work from K. Fujio in IAEA-NDS-0239

TENDL: TALYS Evaluated Nuclear Data Library

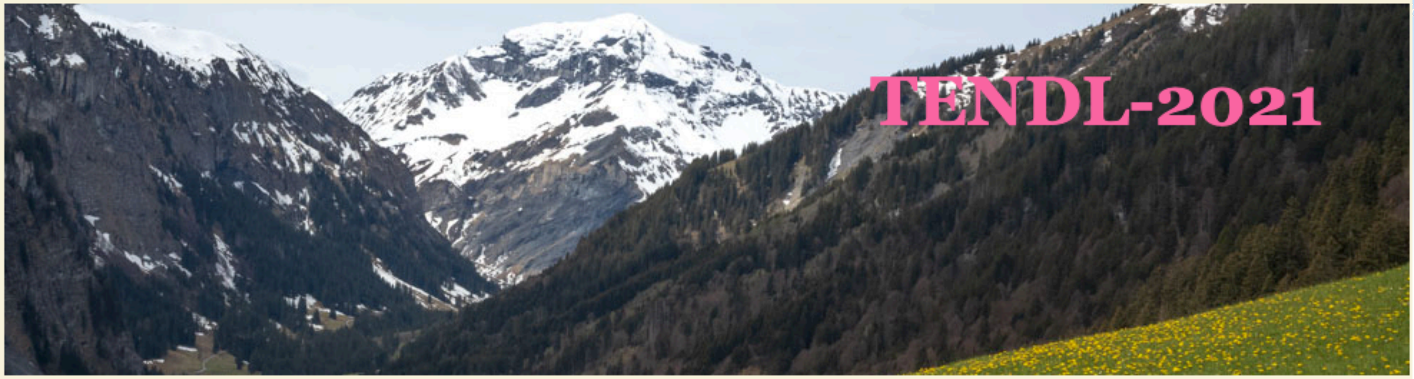
- General purpose nuclear reaction data library
- Simultaneous focus on
    - Reproducibility ✓
    - Completeness ✓
    - Quality (ongoing, never enough)
- TENDL ranges from detailed experimental evaluations to global TALYS calculations
- Extent:
    - Neutrons, photons, protons, deuterons, tritons, Helium-3, alpha-particles
    - TSL, astrophysical reaction rates (new), FY
    - 2813 nuclides (all stable or with half-life > 1 sec.)
    - 0-200 MeV
    - All cross sections and secondary distributions (particle and gamma spectra)
    - UQ with covariances or statistical distributions (Total Monte Carlo, “random files”)
    - A variety of data formats: ENDF, PENDF, ACE, GNDS, HDF5, ASCII

- TENDL-2021 was released in December 2021
- https://tendl.web.psi.ch/tendl_2021/tendl2021.html

TALYS-based evaluated nuclear data library

Years

or Peace and Development



"We believe that our great goal can be achieved with systematism and reproducibility. We are so outside the box, that the box is a point"

TENDL-2021: (release date: December 30, 2021)

Last update: February 23, 2022

TENDL is a nuclear data library which provides the output of the **TALYS** nuclear model code system for direct use in both basic physics and applications. The 11th version is **TENDL-2021**, which is based on both default and adjusted **TALYS** calculations and data from other sources (previous releases can be found here: 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2017 and 2019).

Up to 2014, TENDL was produced at NRG Petten. Since 2015, TENDL is mainly developped at PSI and the IAEA (Nuclear Data Section). Still, many people contribute to TENDL with the testing and processing of the files.

TENDL contains evaluations for seven types of incident particles, for all isotopes living longer than 1 second: Z=1 ^{1}H to Z=115 ^{291}Mc (about 2800 isotopes), up to 200 MeV, with covariances.

TENDL is **not** a default or shadow library. Not a single neutron evaluation is based on default calculations. With the HFR approach, all resonances follow statistical hypothesis. For major isotopes, greater care was used during the evaluation process.

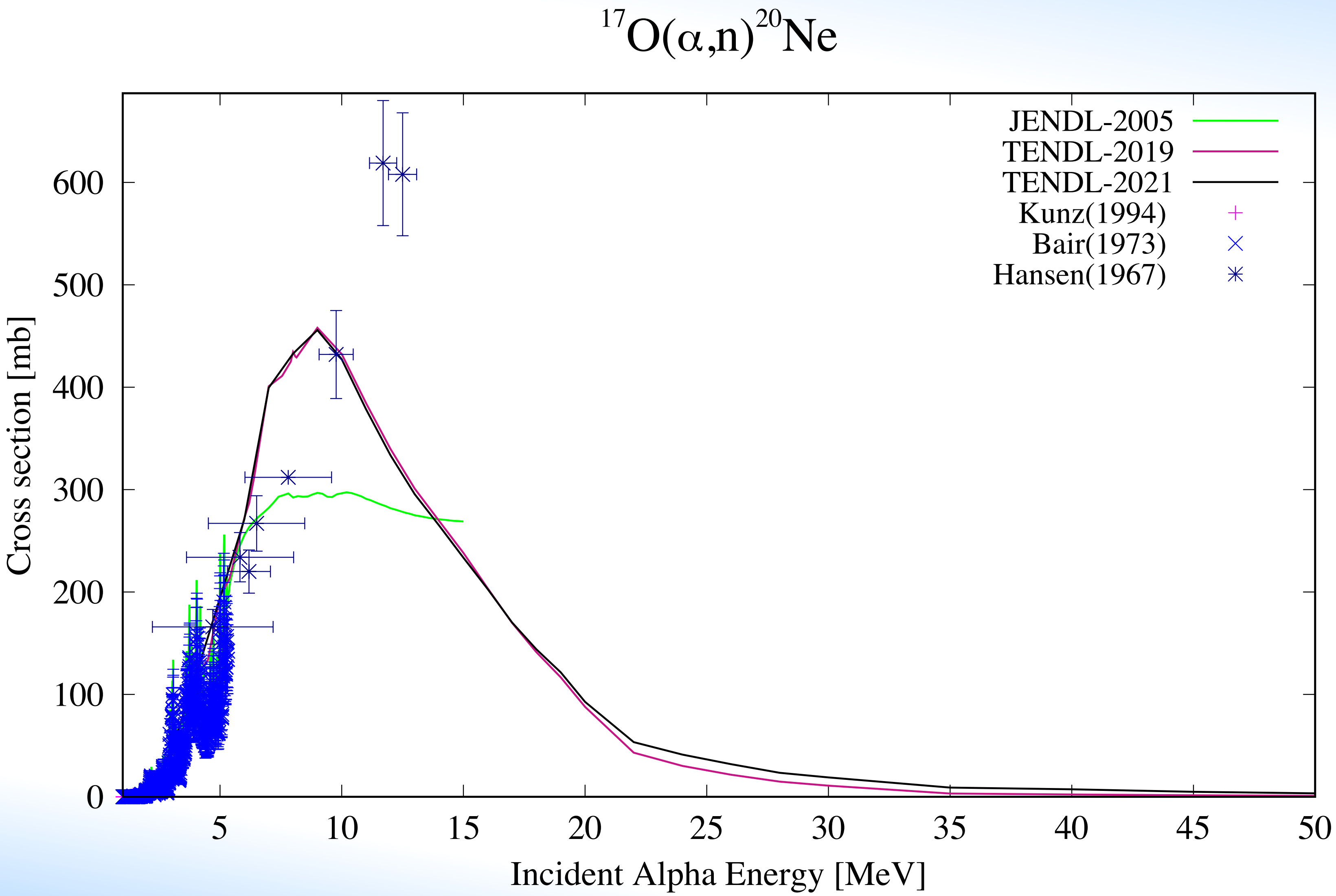
All TENDL-2021 neutron files are original except 24. The 24 following files are taken from JEFF-4.0T0: ^{1,2,3}H, ^{3,4}He, ^{6,7}Li, ^{10,11}B, ^{7,9}Be, ^{12,13}C, ^{14,15}N, ^{16,17,18}O, ^{19}F, ^{232}Th, ^{233,235,238}U and ^{239}Pu.

A set of tools, called T6, was used to produce it. T6 stands for TALYS, TEFAL, TASMAN, TARES, TAFIS and TANES. Each code produces a part of the library. Processing tools such as NJOY, CALENDF, PREPRO are also used in T6. These codes, and the processing steps are developed by A.J. Koning, D. Rochman and J.Ch. Sublet. Still, the help and feedback of the whole nuclear data, processing and user community is extremely useful. TENDL would not exist without the constructive remarks from all over the world.

TENDL-2021

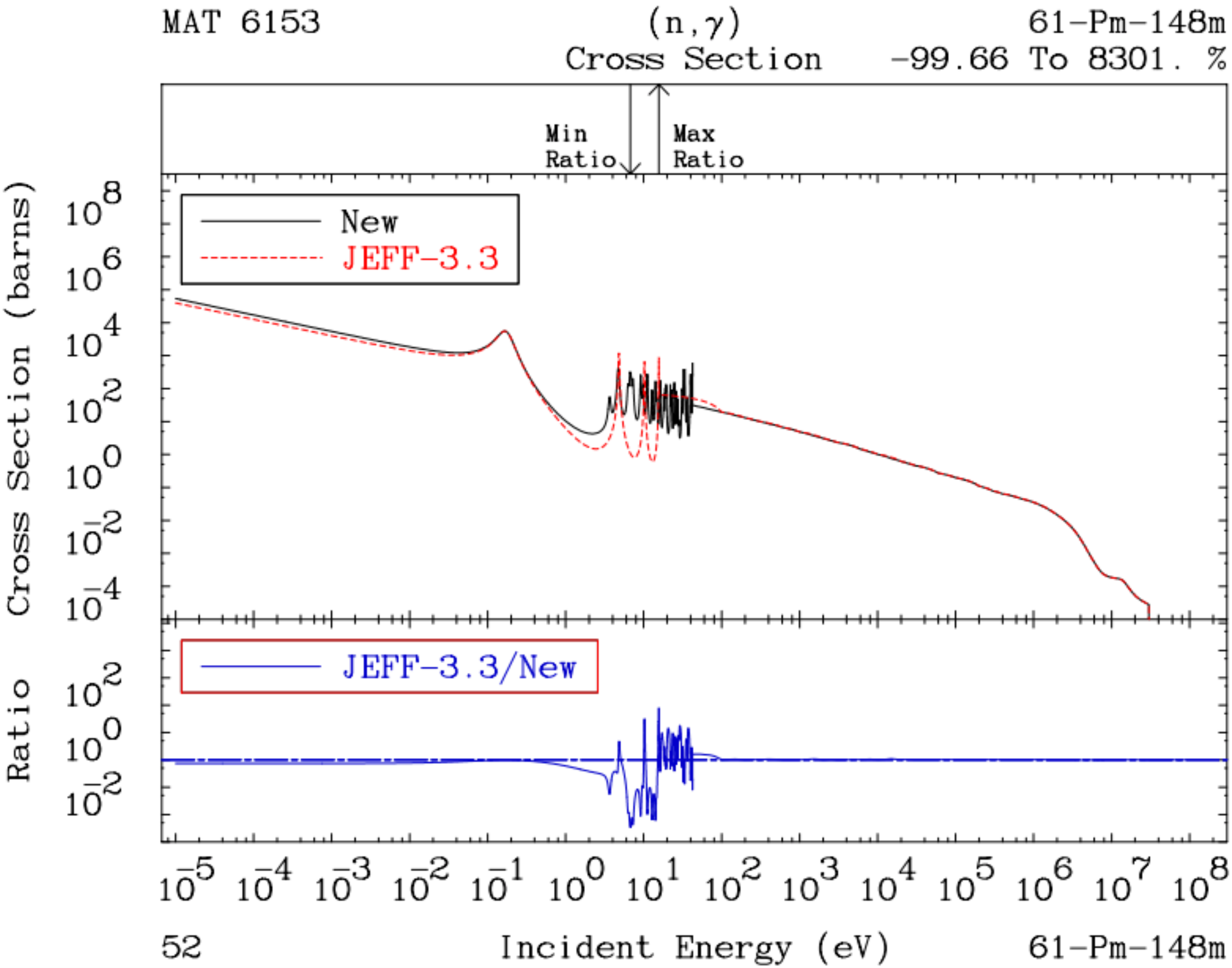
- Important differences with TENDL-2019
  - Improved resonance parameters from JEFF community (CEA-Cadarache)
  - Globally improved description of (n, γ) thanks to new photon strength functions (Goriely) and automated fitting to EXFOR data with TASMAN code
  - Photonuclear data library based on new photon strength functions
  - Improved overall description of all charged-particle libraries
    - Improved numerical binning in multiple emission
    - Adjusted global fitting parameter for (alpha,n) reactions
    - Adjusted break-up parameters for deuteron reactions
    - Notable improvement of proton library, especially for (p,n)
    - Good global description of charged-particle induced fission

TALYS does not provide resonance structure



New evaluations for TENDL-2021 and JEFF-4

- Revised resonance parameters by CEA-Cadarache (Gilles Noguere, David Bernard, Olivier Bouland):
  - $^{107,109}Ag$
  - ^{135}Xe
  - ^{133}Cs
  - ^{148m}Pm
  - $^{151,153,154,155}Eu$
  - $^{173,175,176}Lu$
- All revised parameters inserted in Dimitri Rochman’s TARES code
- Fast neutron range evaluation by Arjan Koning and Stephane Goriely
- Combined set of ‘best’ parameters stored in the T6 system to enable automatic file production
- Same approach used by Titech (Chiba et al) using the TALYS system T6 for LLFP and e.g. ^{36}Cl



MAT 6153
(n,γ)
Cross Section
61-Pm-148m
-99.66 To 8301. %
Min Ratio
Max Ratio
New
JEFF-3.3
Cross Section (barns)
JEFF-3.3/New
Ratio
Incident Energy (eV)
52
61-Pm-148m

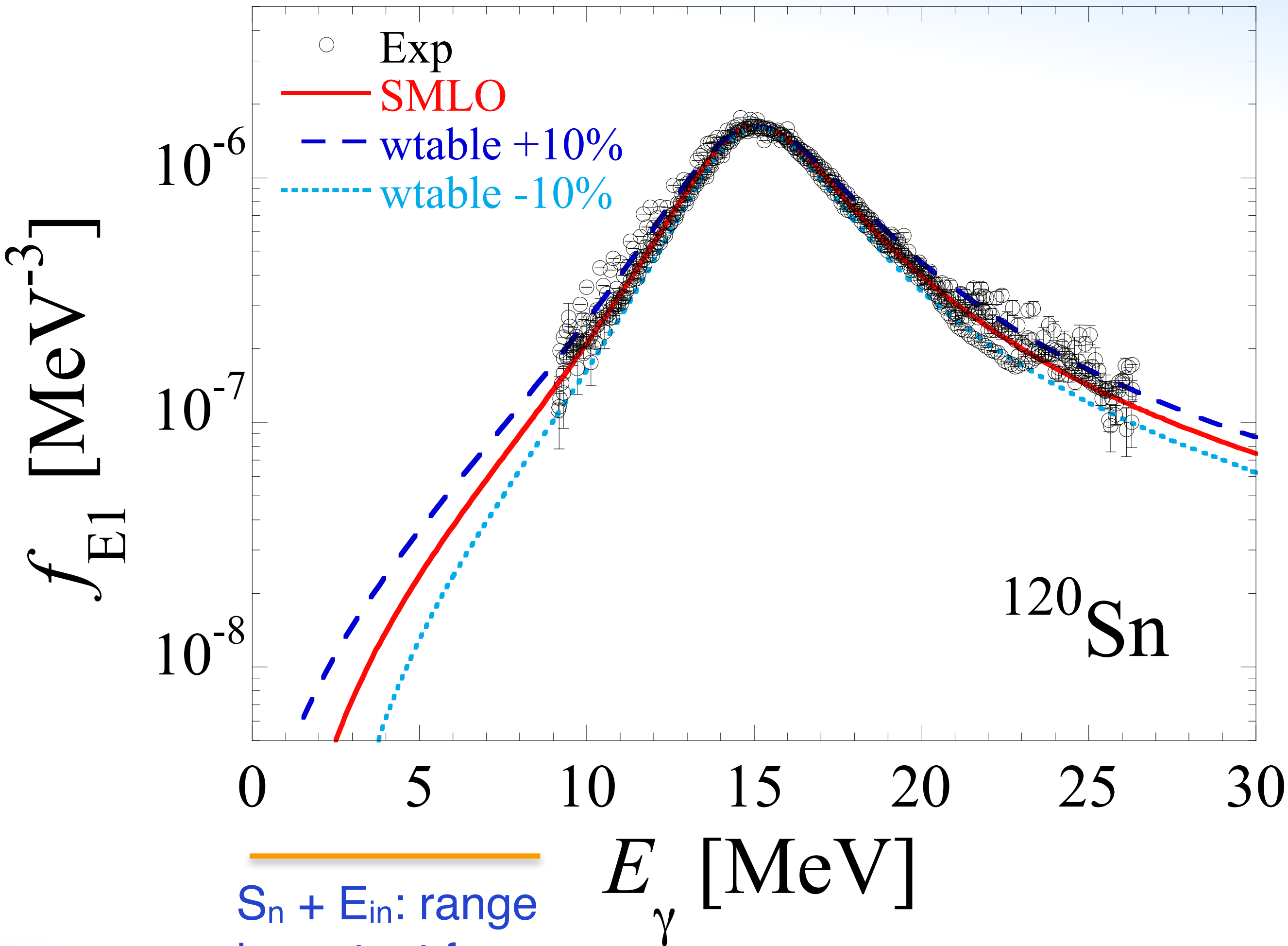
TALYS Application to (n, γ) cross sections

- Adjust width of the E1 SMLO photon strength function (TALYS: ‘wtable’) to match **the best nuclear data library** with
  - Best reproduction of MACS, around 30 keV
  - Best reproduction of experimental (n,γ) cross section from the top of the RR - 100 keV/1 MeV
  - Best nuclear data library **before** TENDL-2021:
    - JENDL-4.0: 97 target isotopes
    - JENDL-AD: 2 target isotopes
    - CENDL-3.2: 2 target isotopes
    - TENDL-2019: 106 target isotopes
    - JEFF-3.3: 8 target isotopes
    - ENDF/B-VIII.0: 61 target isotopes

```
n-Eu153.tasman
#Esearch 0.01 0.1 102
#libinclude 102 endfb8.0
```

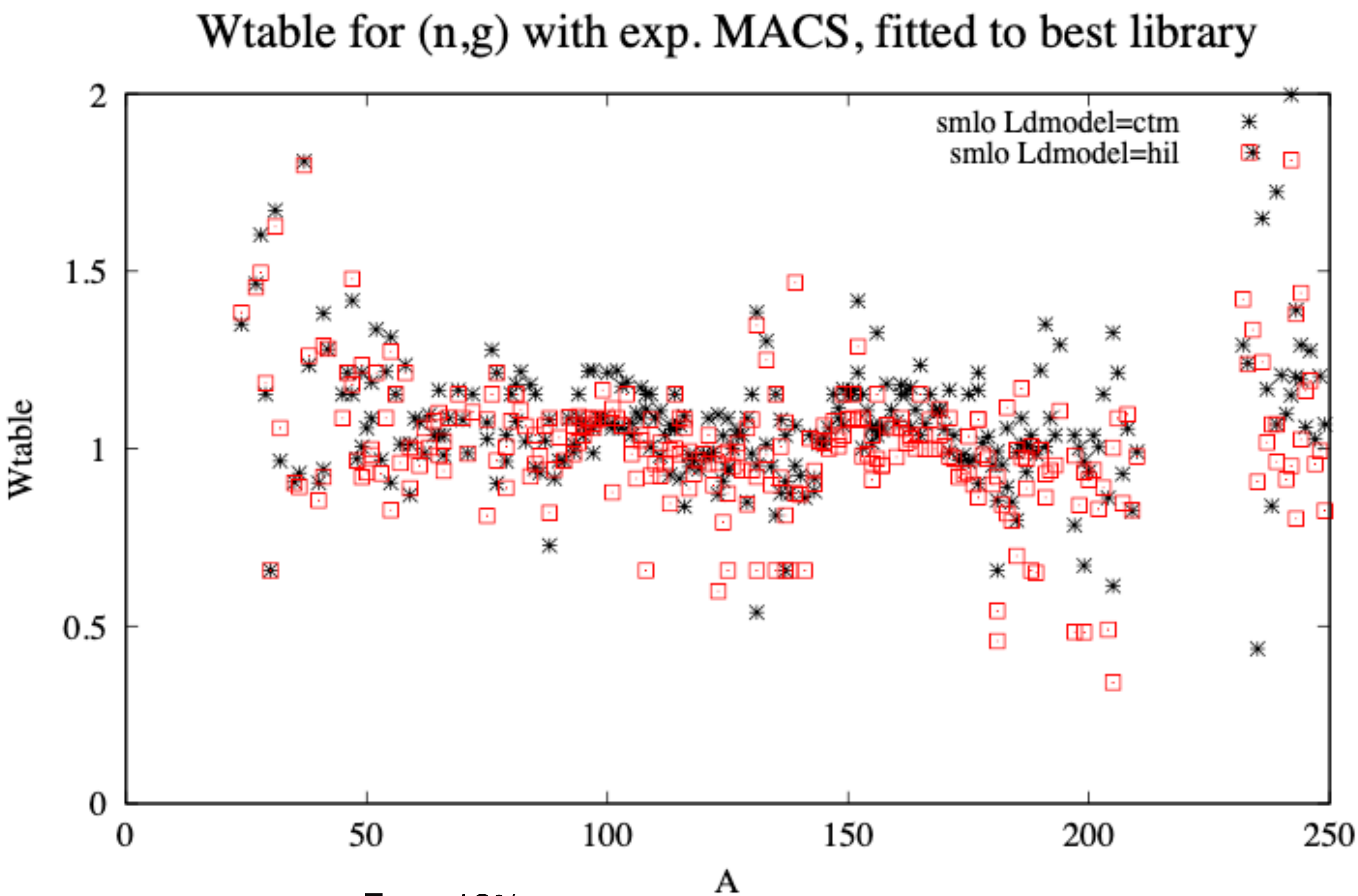
- **Autotalys** automatically optimizes ‘wtable’ to match **above libraries in a restricted energy range**, e.g. autotalys -element Eu -mass 151 -Ltarget 000 -Liso 0 -proj n -bins 40 -search -energyfile /Users/koning/samples/psf/smlo/ctm/energies -best -noautosearch -noparauto -talysfile /Users/koning/samples/psf/smlo/ctm/talys.add -tasmanfile /Users/koning/samples/psf/smlo/ctm/tasman.add

Adjusted width parameter does not affect original photon strength function very much



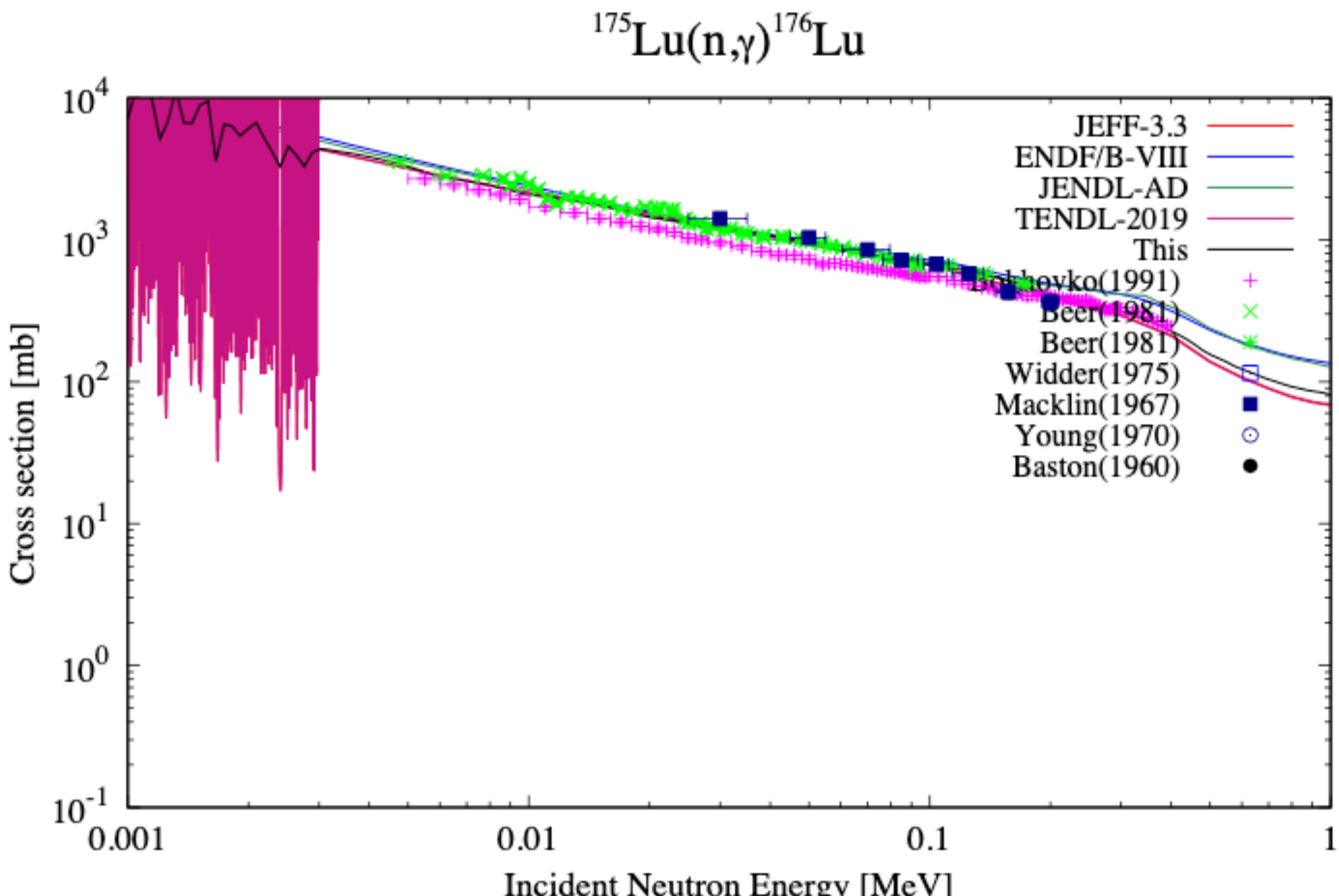
$S_n + E_{in}$: range important for (n,γ)

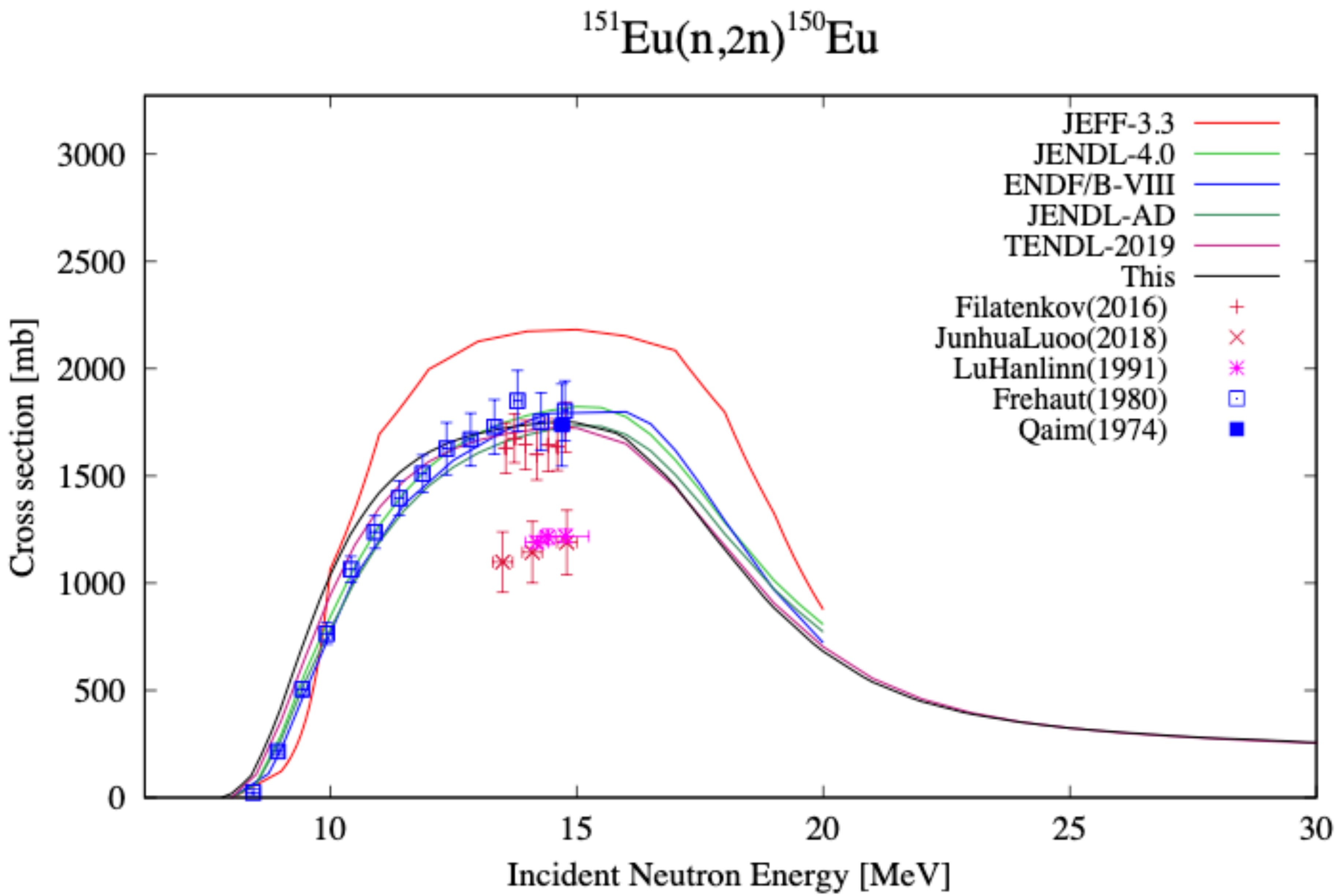
$$\langle \Gamma_\gamma \rangle = \frac{D_0}{2\pi} \sum_{X,L,J,\pi} \int_0^{S_n+E_n} T_{XL}(\varepsilon_\gamma) \times \rho(S_n + E_n - \varepsilon_\gamma, J, \pi) d\varepsilon_\gamma$$



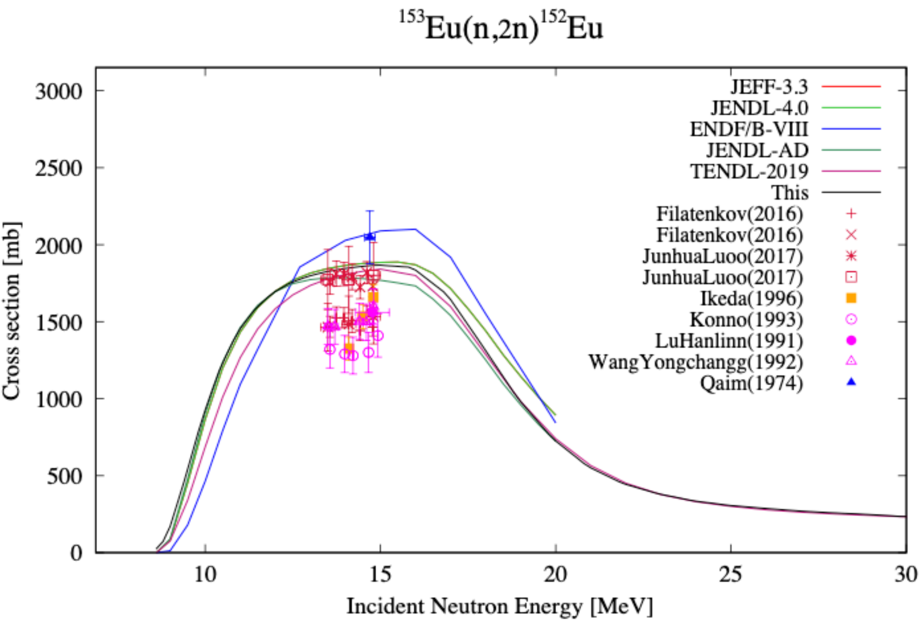
Wtable for (n,g) with exp. MACS, fitted to best library
smlo Ldmodel=ctm
smlo Ldmodel=hil
Wtable
A
0
0.5
1
1.5
2
0
50
100
150
200
250

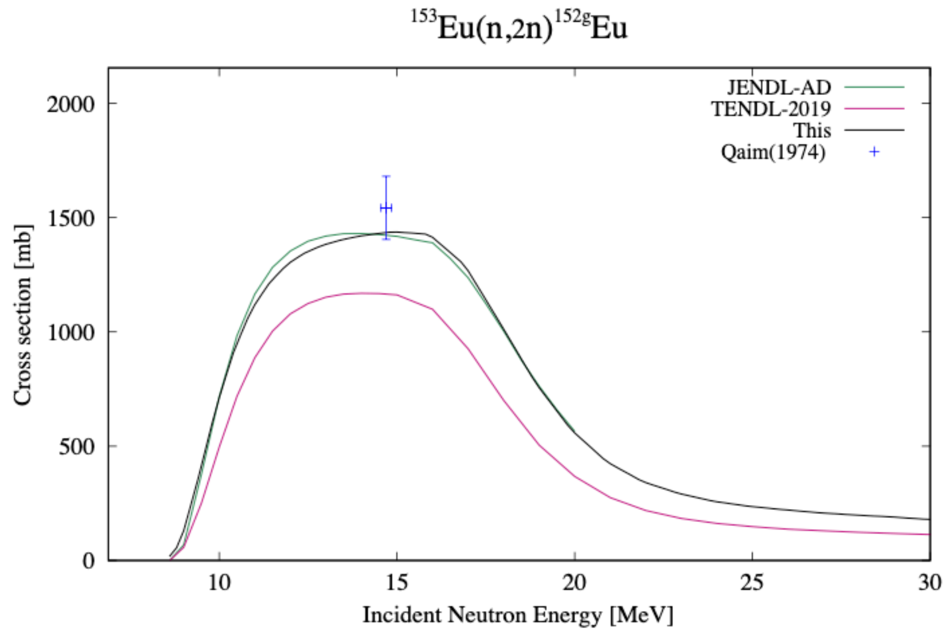
F_{rms} : 12%

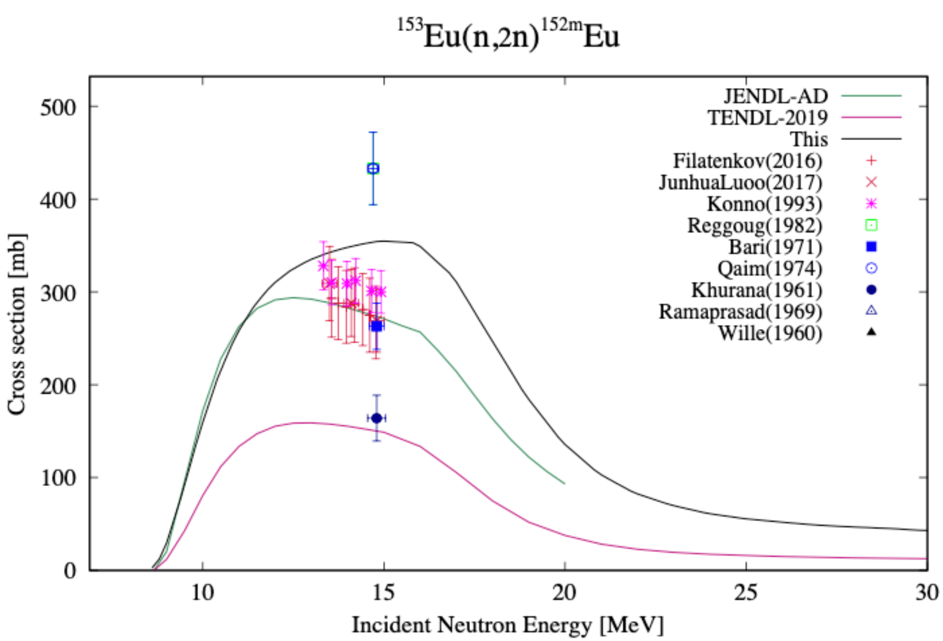

$^{175}Lu(n,\gamma)^{176}Lu$
JEFF-3.3
ENDF/B-VIII
JENDL-AD
TENDL-2019
This
Bokhovko(1991)
Beer(1981)
Beer(1981)
Widder(1975)
Macklin(1967)
Young(1970)
Baston(1960)
Cross section [mb]
Incident Neutron Energy [MeV]

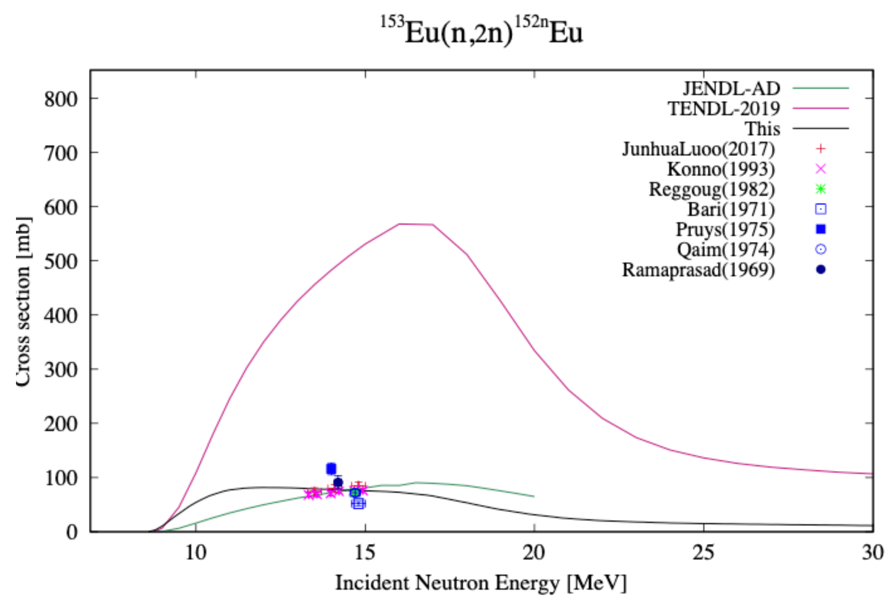

^{151}Eu(n,2n)^{150}Eu
Cross section [mb]
Incident Neutron Energy [MeV]
0
500
1000
1500
2000
2500
3000
10
15
20
25
30
JEFF-3.3
JENDL-4.0
ENDF/B-VIII
JENDL-AD
TENDL-2019
This
Filatenkov(2016)
JunhuaLuoo(2018)
LuHanlinn(1991)
Frehaut(1980)
Qaim(1974)

Consistency for isomeric production









Al, Ni and Ti from JEFF-4T0 (=TENDL-2021) are not good, use TMC to improve

Table 1: Al, Ni and Ti benchmarks for different libraries and associated χ^2

For ^{27}Al

	Exp	JEFF-3.3	JEFF4.0T0	ENDF/B80	JENDL4.0	JEFF4.0T1	run 227	run 0
imf6-1	1.00000 ± 230	0.99268 ± 10	0.99402	0.99296	0.98956	1.00175	0.99223	0.99256
imf14-1	0.99580 ± 220	1.00298 ± 26	0.99906	0.99639	0.99677	1.00212	0.99787	0.99893
imf14-2	0.99270 ± 220	1.00515 ± 28	0.99799	0.99412	0.99561	1.00079	0.99715	0.99804
hmf22-1	1.00000 ± 190	0.99721 ± 10	0.99893	0.99735	0.99420	1.00528	0.99719	0.99731
hmf60-1	0.99550 ± 240	1.00993 ± 28	1.00132	1.00227	1.00835	1.00699	1.00059	1.00116
hmf67-2	0.99380 ± 240	0.99996 ± 27	0.99350	0.99488	1.00195	1.00248	0.99250	0.99302
hmf90-1	0.99940 ± 70	1.00393 ± 24	1.00535	1.00285	1.00214	1.01084	1.00309	1.00371
hmf90-2	0.99930 ± 70	1.00048 ± 25	1.00116	0.99841	1.00018	1.00484	0.99984	0.99987
pmf9-1	1.00000 ± 270	0.99920 ± 33	1.00074	0.99970	0.99656	1.01626	0.99872	0.99841
pmf39-1	1.00000 ± 220	0.99146 ± 34	0.99251	0.99147	0.98932	1.00540	0.99142	0.99119
hmf84-1	0.99940 ± 190	0.99855 ± 30	1.00038	0.99909	0.99573	1.00681	0.99875	0.99850
χ^2_{Al}/N		14.3	10	5.5	11	41	6.1	7.4

For Ti

	Exp	JEFF-3.3	JEFF4.0T0	ENDF/B80	JENDL4.0	JEFF4.0T1	run 227	run 0
hmf84-12	0.99940 ± 200	1.00065 ± 33	1.00726	0.99688	0.99841	1.01212	0.99738	0.99823
hmf79-1	0.99960 ± 150	1.00049 ± 34	1.00283	0.99997	0.99775	1.00385	0.99971	1.00040
hmf79-2	0.99960 ± 140	1.00020 ± 34	1.00355	0.99923	0.99747	1.00551	0.99942	0.99981
hmf79-3	0.99960 ± 150	1.00198 ± 32	1.00669	0.99981	1.00018	1.01114	1.00006	1.00091
hmf79-4	0.99960 ± 140	1.00288 ± 36	1.00896	1.00030	1.00078	1.01341	1.00084	1.00210
hmf79-5	0.99960 ± 150	1.00209 ± 32	1.00783	1.00036	0.99978	1.01215	1.00059	1.00095
χ^2_{Ti}/N		1.9	21	0.4	0.8	49	0.5	0.8

For Ni

	Exp	JEFF-3.3	JEFF4.0T0	ENDF/B80	JENDL4.0	JEFF4.0T1	run 227	run 0
hmf84-10	0.99930 ± 220	1.00012 ± 34	1.00392	0.99576	0.99650	1.01304	0.99441	0.99595
hmf84-22	0.99940 ± 200	0.99842 ± 28	1.00075	0.99561	0.99473	1.00533	0.99458	0.99450
pmf45-1	1.00000 ± 470	1.01171 ± 35	1.01465	1.00837	1.01069	1.02982	1.00447	1.00569
pmf45-2	1.00000 ± 460	1.01324 ± 17	1.01217	1.00572	1.00793	1.02783	1.00200	1.00458
pmf45-3	1.00000 ± 440	1.01324 ± 17	1.01703	1.01038	1.01279	1.03175	1.00665	1.00865
pmf45-4	1.00000 ± 460	1.01345 ± 35	1.01588	1.00873	1.01268	1.02994	1.00559	1.00793
pmf45-5	1.00000 ± 450	1.01623 ± 35	1.02028	1.01357	1.01564	1.03510	1.01003	1.01324
pmf45-6	1.00000 ± 490	1.01357 ± 35	1.01371	1.01530	1.01338	1.01797	1.01571	1.01523
pmf45-7	1.00000 ± 500	1.01514 ± 37	1.01492	1.01712	1.01483	1.01944	1.01675	1.01686
χ^2_{Ni}/N		6.9	9.5	5.6	6.6	34	4.7	5.0
χ^2_{all}/N		7.7	13	3.8	6.0	41	3.8	4.4

Feedback on ESFR by Paco Alvarez, Benchmark Selection by Steven van der Marck

Other TENDL developments

- Bypassing ENDF-6: TAGNDS, with J.C. Sublet and Caleb Mattoon
- Direct feeding into the Medical isotope Browser nds.iaea.org/mib
- Automated fitting to all cross sections from EXFOR, including actinides, use of ML to estimate TALYS parameters for neighbouring nuclides
- To have our integral validation as automated as our evaluation (‘validation on the spot’) (very challenging)
- 517 citations in 2021-2022 on very different subjects

Summary

- TALYS-1.96 released 30 December 2021. TALYS-2.0 will follow. All satellite software for TALYS (TASMAN: statistics, optimisation and uncertainties, TEFAL: ENDF formatting), autotalys to GitHub
- TENDL-2021 was released end of December 2021:
  - Improved nuclear data for charged particles and photons
  - Improved fast neutron cross sections thanks to new photon strength functions
- Strong collaboration with JEFF-4:
  - Improved resonance parameters, in this case from CEA-Cad, are inserted into the T6/autotalys evaluation system

For each isotope:

2010: Use TENDL, if you have nothing else

2020: Use TENDL, unless you have something better

2030: ~~Explain why you don't use TENDL~~ don't know yet

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Thank you!