IAEA 60 Years
Atoms for Peace and Development

# Status of TENDL

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WPEC-32 Meeting, May 14-15 2020, NEA, Boulogne-Billancourt

# Contents

- TENDL: General statistics
- TENDL-2019: Global comparison with other libraries
  - Thermal cross sections, Res Int and MACS
  - Comparison vs. EXFOR
- Integral validation and other applied use
- Conclusions

# “The split”: IAEA Meeting on long term nuclear data needs (2011)

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**An Alternative Future: An International Evaluated Nuclear Database (“ENDF/I” or “WENDF” or “WEF or …”)**

M.B. Chadwick

*X-CP Computational Physics Division, LANL,*

**What users need: nuclear data libraries of the highest possible quality for all nuclides, incident particles, energies, reaction channels, including uncertainties:**

**A plea for reproducibility**

Arjan Koning

CIELO

All effort on 6 most important isotopes

Successful collaboration between experimentalists, nuclear modelers, evaluators and validators

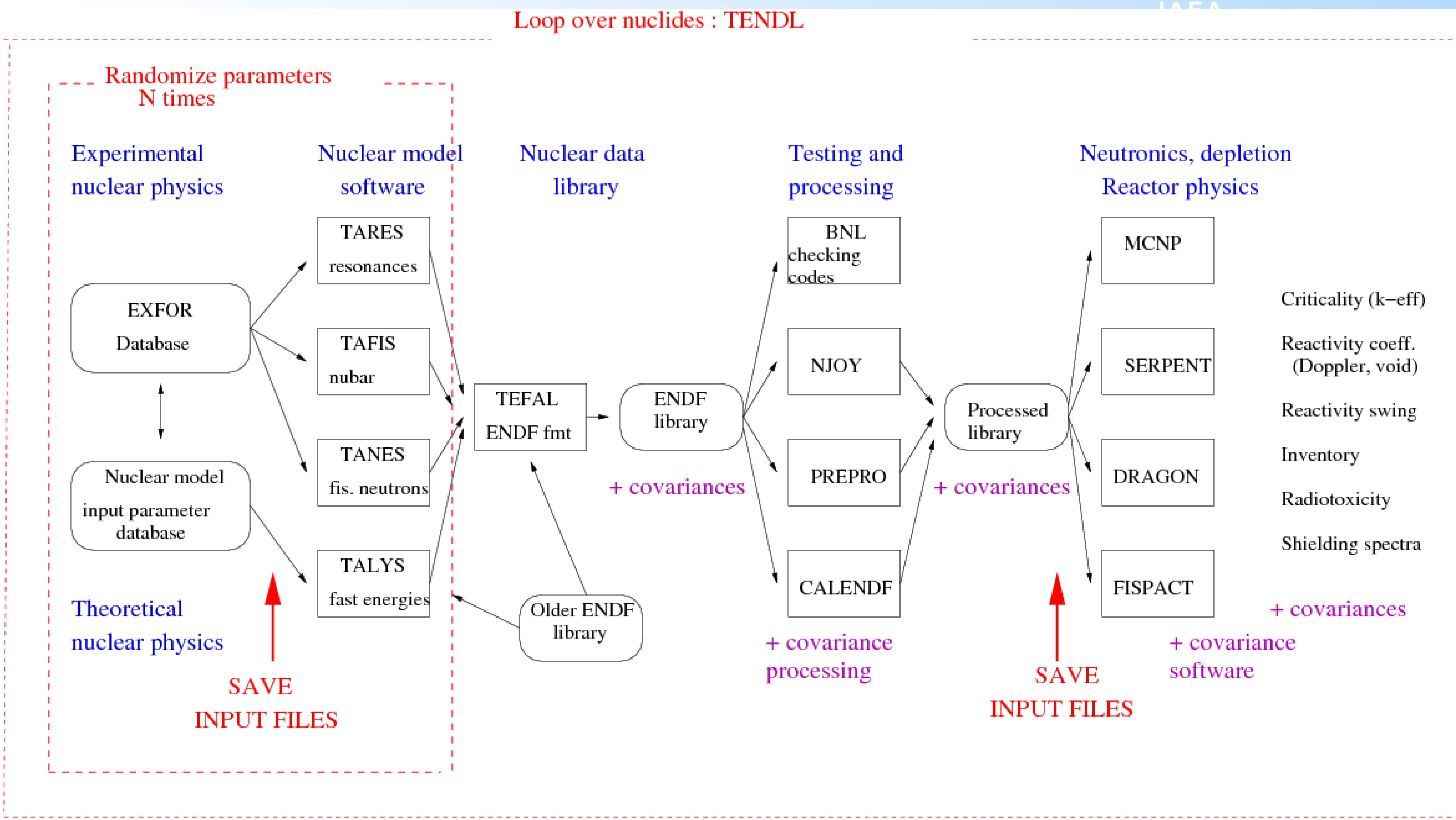
No change in evaluation/validation paradigms

TENDL

All effort distributed among everything

Automated use of “all knowledge up to now”: EXFOR, TALYS, existing libraries CIELO (challenging!), AK + DR

Reproducibility and completeness



Loop over nuclides : TENDL
Randomize parameters
N times
Experimental
nuclear physics
Nuclear model
software
Nuclear data
library
Testing and
processing
Neutronics, depletion
Reactor physics
TARES
resonances
EXFOR
Database
TAFIS
nubar
TANES
fis. neutrons
TALYS
fast energies
Nuclear model
input parameter
database
TEFAL
ENDF fmt
ENDF
library
Older ENDF
library
+ covariances
BNL
checking
codes
NJOY
PREPRO
CALENDF
Processed
library
+ covariances
MCNP
SERPENT
DRAGON
FISPACT
Criticality (k−eff)
Reactivity coeff.
(Doppler, void)
Reactivity swing
Inventory
Radiotoxicity
Shielding spectra
+ covariances
Theoretical
nuclear physics
SAVE
INPUT FILES
+ covariance
processing
SAVE
INPUT FILES
+ covariance
software

# TENDL-2019



## TALYS-based evaluated nuclear data library

Home | Reference & us | Citations | Feedback | TALYS


"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"

How to reference

Sub-library files

1. Neutron
2. Proton
3. Deuteron
4. Triton
5. He3
6. Alpha
7. Gamma

Application libraries & tar

Random files

1. Random fission yields
2. Random thermal scattering
3. Random ENDF-6 files
4. Random ACE files

V&V

### TENDL-2019: (release date: December 31, 2019)

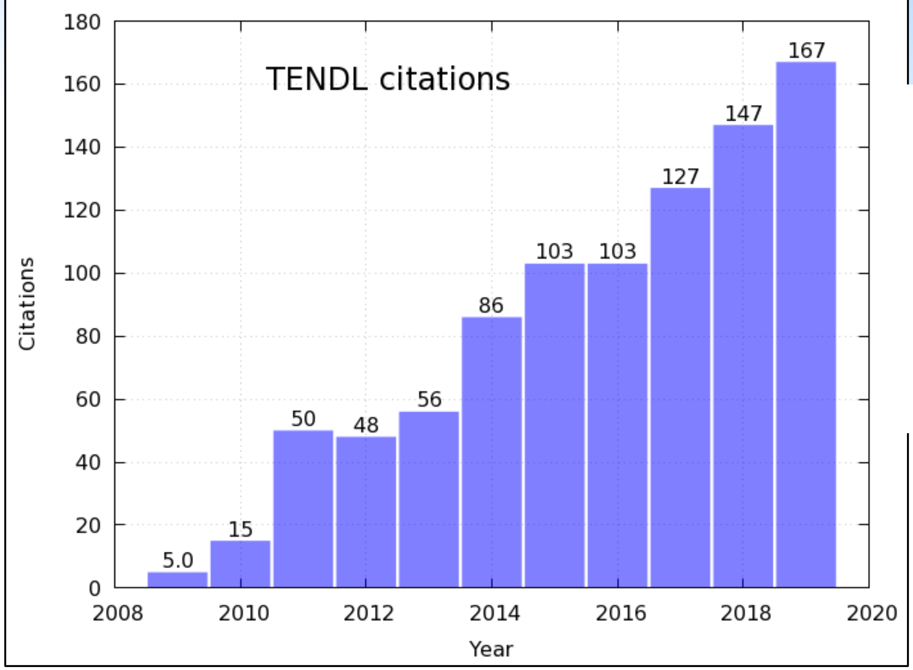
Last update: 13 December 2019

**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 $10^{th}$ version is **TENDL-2019**, 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, and 2017).

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 contributes 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.

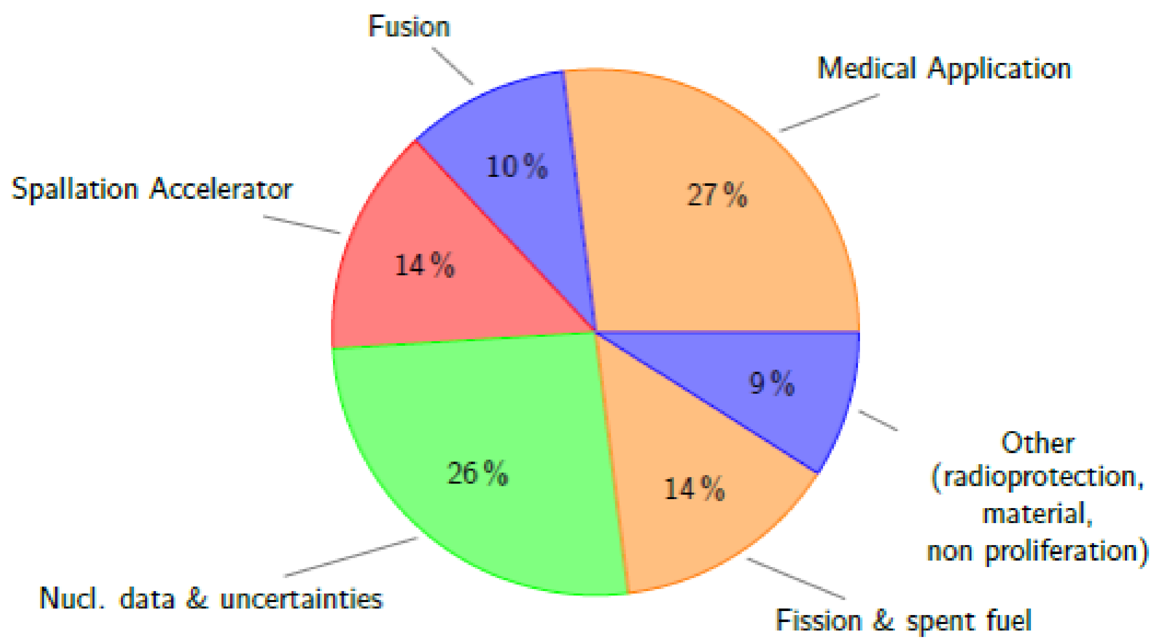
TENDL is not a default or shadow library. Not a single neutron evaluation is based on default calculations. With the HFR approach, all resonances follow statistical hypothesis. For major isotopes, greater care was used during the evaluation process.




Available online at www.sciencedirect.com
ScienceDirect
Nuclear Data Sheets 155 (2019) 1–55
Nuclear Data Sheets
www.elsevier.com/locate/nds

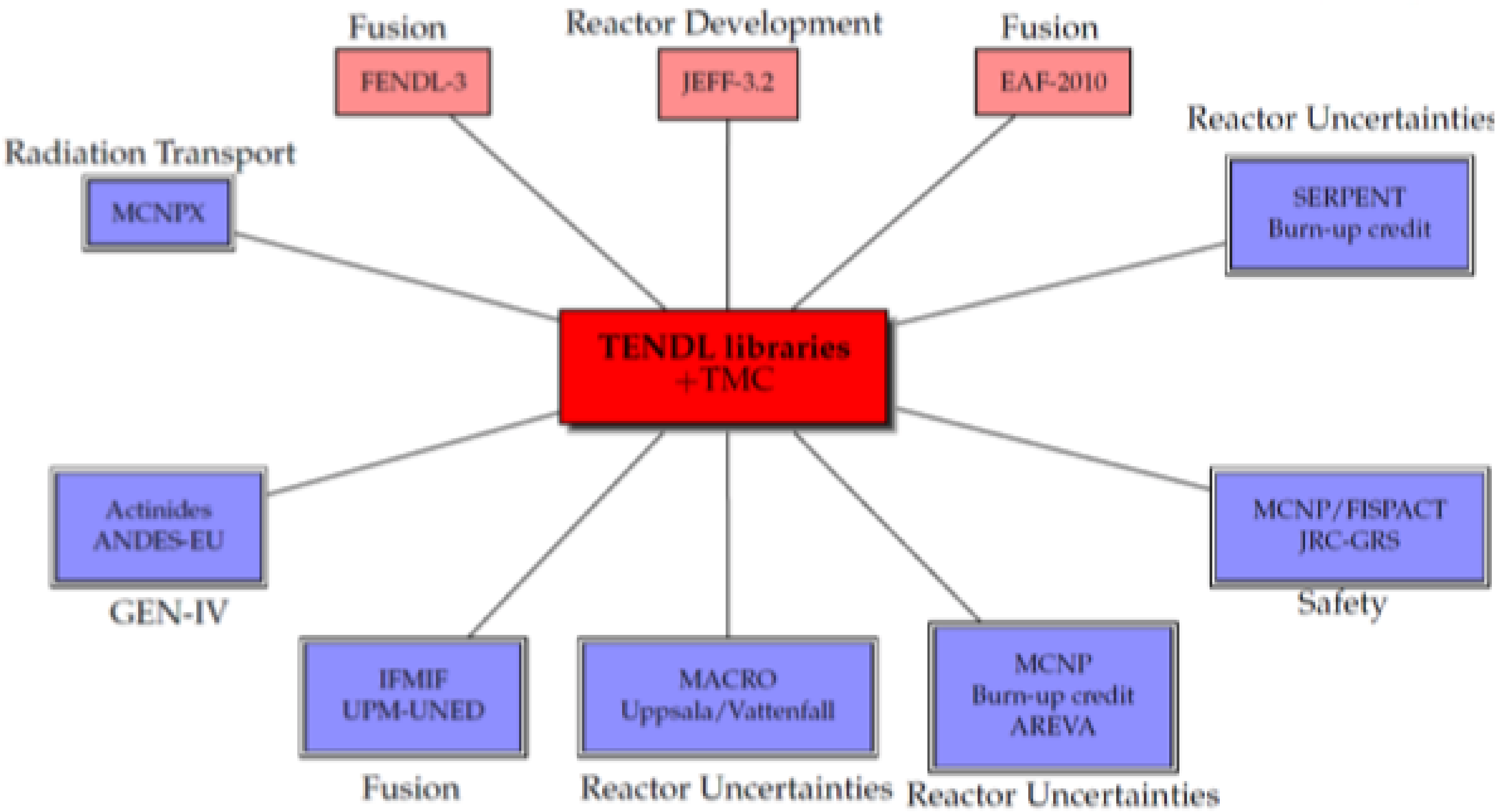
# TENDL: Complete Nuclear Data Library for Innovative Nuclear Science and Technology

A.J. Koning,[1,2,*] D. Rochman,[3] J.-Ch. Sublet,[1] N. Dzysiuk,[4,5] M. Fleming,[6,7] and S. van der Marck[4]



# What is the TENDL project ?

- Fully implemented in FISPACT-II, part of GEANT, CASMO…,
- Used in fission, fusion applications, medical isotope productions



# TENDL-2019, what is new ?



- New T6 (TALYS+TASMAN+TEFAL+TARES+TAFIS+TANES)
  - Newest code versions, (TALYS-1.95 release December 2019)
  - more verifications,
  - Linux RedHat/Mac,
  - tested with latest compilers

- TENDL-2019 available (https://tendl.web.psi.ch/tendl_2019/tendl2019.html)

- Similar structure as the previous TENDL libraries
  - 2813 isotopes, 200 MeV
  - Incident neutrons, protons, deuterons, tritons, He3, alphas, and gammas
  - Uncertainty Quantification based on Bayesian Monte Carlo
  - Complete for secondary distributions: ang. dis, DDX, recoils, discrete and continuum gamma's
  - Complete for covariance data for all that ENDF format allows
  - ACE, multi group
  - ENDF-6 files in different options (MF3 MT5 at 0, 20 or 60 MeV, EAF files)
  - MF32 and/or MF33 for resonance range
  - Automated plots versus EXFOR and other world libraries
  - Random files for use in Total Monte Carlo

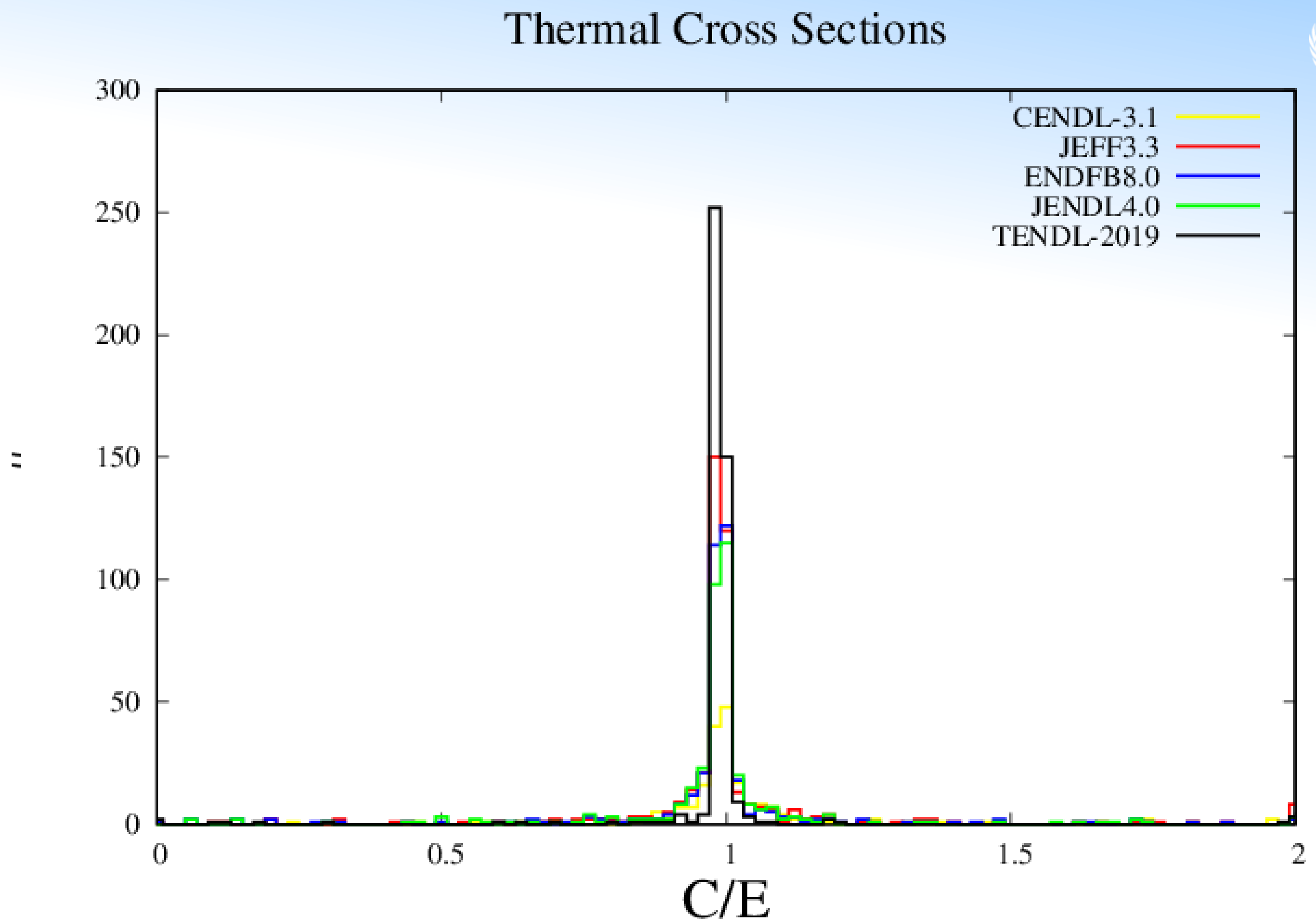
# TENDL-2019, what is new ?



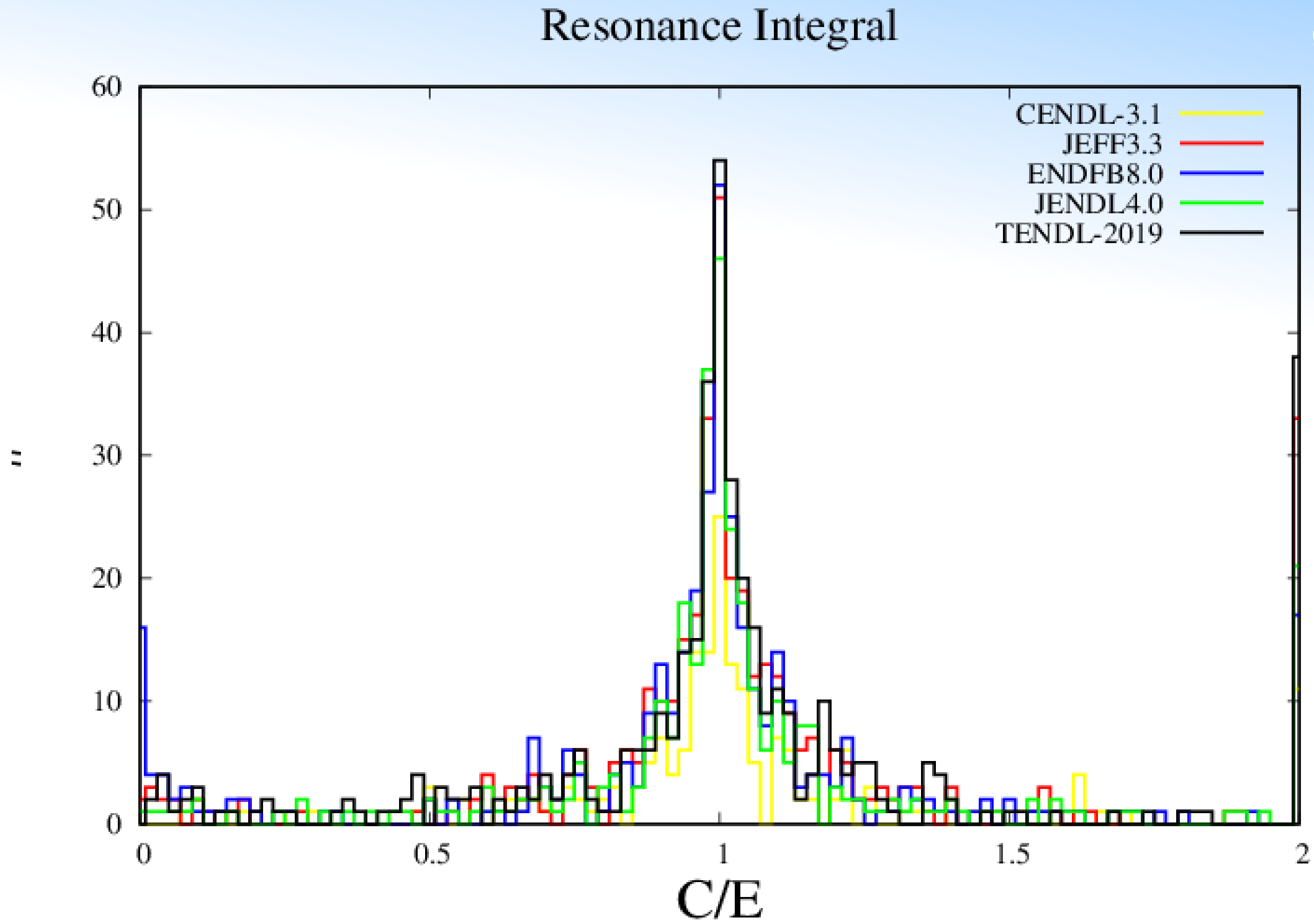
- TARES-1.4: resonance formatting and analyzing tool

- Measured/compiled/evaluated resonances:
  - Based on latest JENDL-4.0, ENDF/B-VIII.0 and JEFF-3.3
  - Based on the latest Atlas, 6th edition (2018)
  - RESONANCETABLES: code to produce unifying and prioritized data library for thermal cross sections, resonance integral, MACS, D_0, Gamma_gamma, S_0 etc. based on Atlas, RIPL, EXFOR
  - **Best of all worlds, expect global superiority in RRR and URR**
- Statistical resonances:
  - Based on CALENDF
  - Translating the unresolved range from TALYS into statistically resolved range
  - Consistency between the RRR, URR and fast range

- Covariances in MF32 and MF33
  - Consistency between both format
  - Consistent with the random files (using the ENDSAM from IJS)



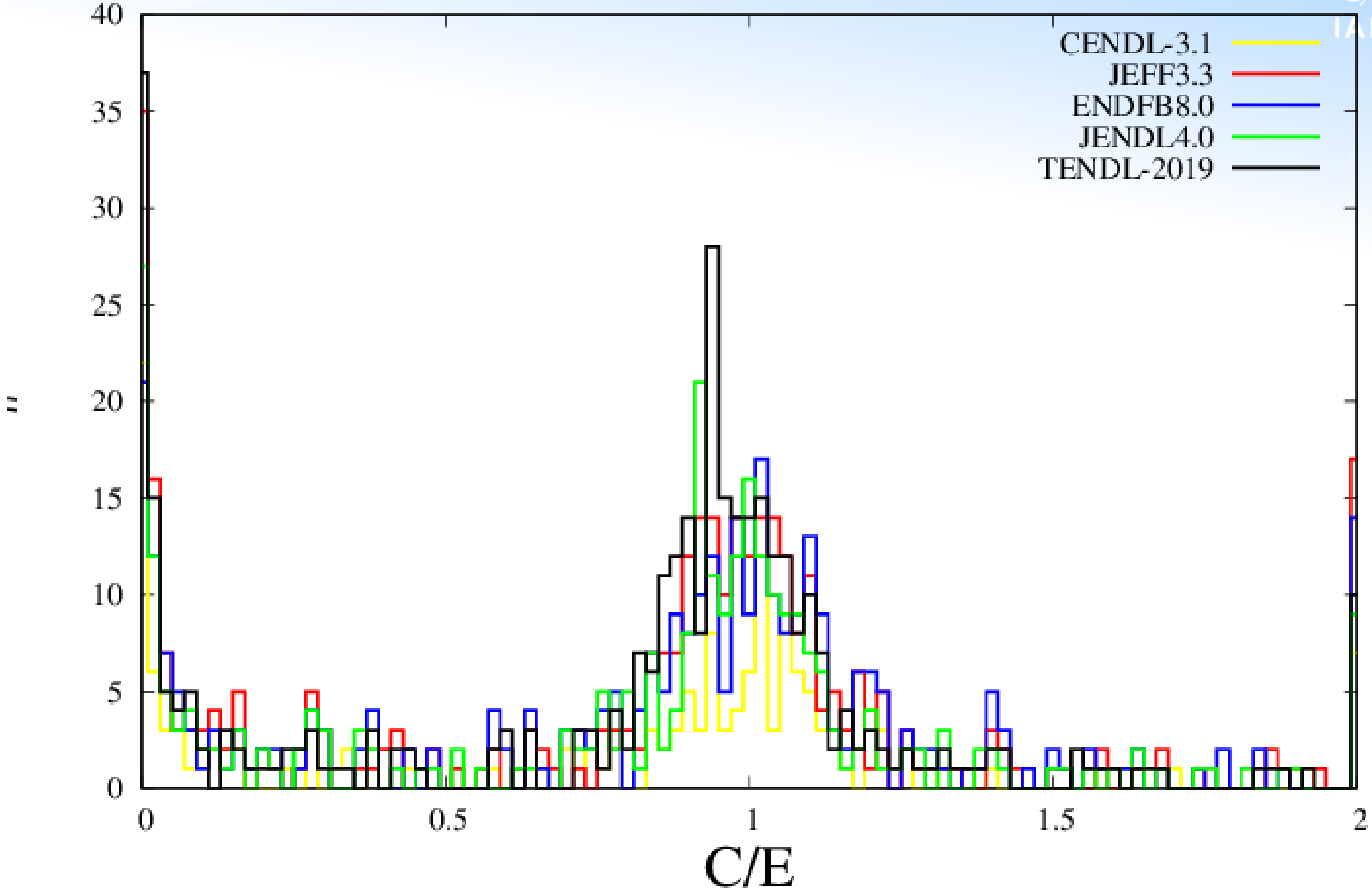

| Lib | F(C/E) | N | N <5% | N < 20% | N < 50% |
|---|---|---|---|---|---|
| CENDL-3.1 | 1.036 | 201 | 129(0.642) | 177(0.881) | 187(0.930) |
| ENDFB-8.0 | 1.022 | 375 | 284(0.757) | 332(0.885) | 351(0.936) |
| JEFF-3.1 | 1.024 | 425 | 315(0.741) | 377(0.887) | 398(0.936) |
| JENDL-4.0 | 1.025 | 359 | 269(0.749) | 320(0.891) | 334(0.930) |
| TENDL-2019 | 1.008 | 446 | 416(0.933) | 431(0.966) | 434(0.973) |





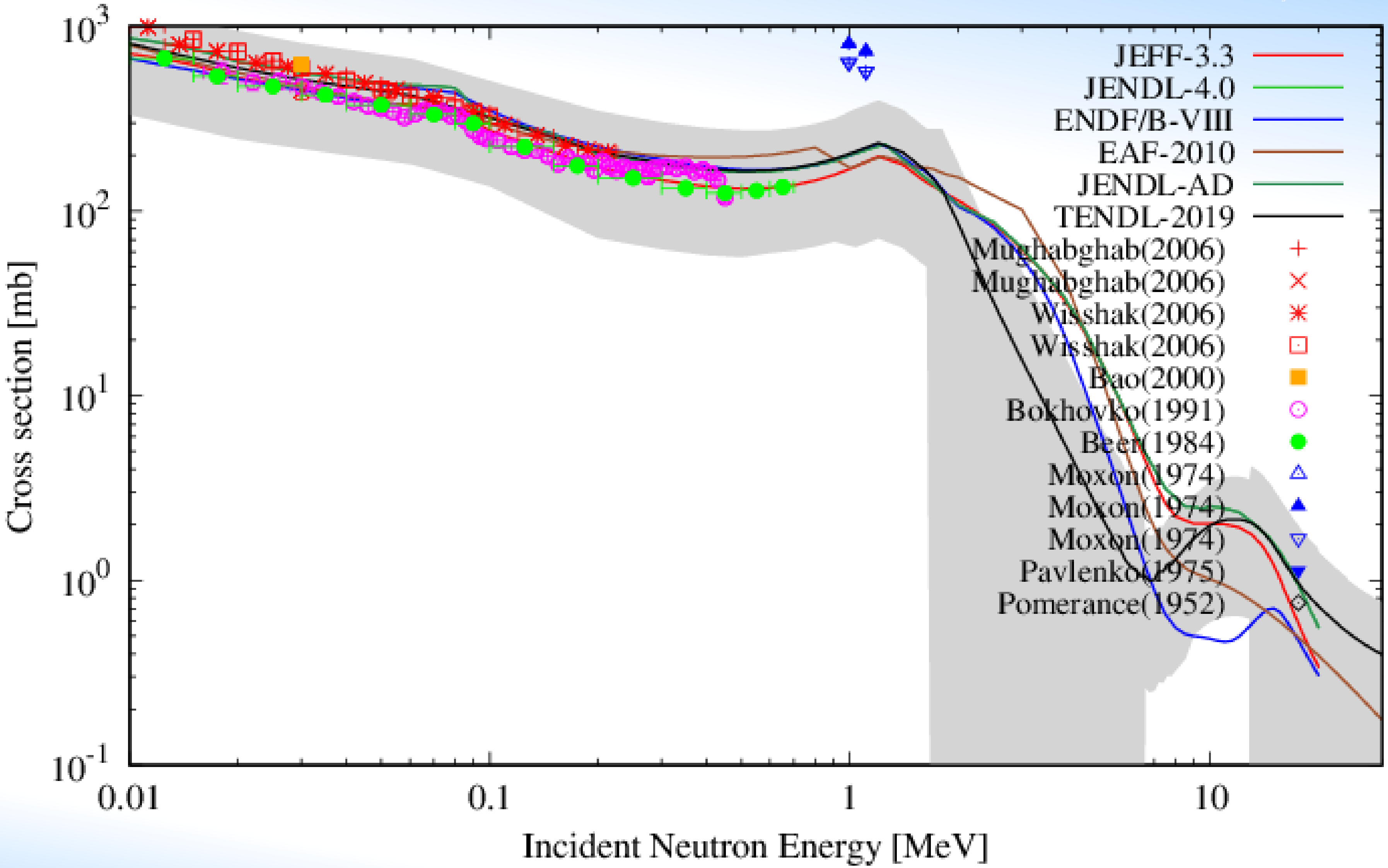

| Lib | F(C/E) | N | N < 5% | N < 20% | N < 50% |
|---|---|---|---|---|---|
| CENDL-3.1 | 1.056 | 194 | 73(0.376) | 126(0.649) | 158(0.814) |
| ENDFB-8.0 | 1.060 | 377 | 138(0.366) | 249(0.660) | 300(0.796) |
| JEFF-3.1 | 1.059 | 386 | 133(0.345) | 257(0.666) | 312(0.808) |
| JENDL-4.0 | 1.054 | 334 | 133(0.398) | 233(0.698) | 275(0.823) |
| TENDL-2019 | 1.058 | 412 | 146(0.354) | 263(0.638) | 321(0.779) |

# Maxwellian-Averaged Cross Sections




| Lib | F(C/E) | N | N < 5% | N < 20% | N < 50% |
|---|---|---|---|---|---|
| CENDL-3.1 | 1.073 | 176 | 29(0.165) | 78(0.443) | 101(0.574) |
| ENDFB-8.0 | 1.082 | 328 | 56(0.171) | 157(0.479) | 208(0.634) |
| JEFF-3.1 | 1.078 | 346 | 67(0.194) | 175(0.506) | 208(0.601) |
| JENDL-4.0 | 1.070 | 292 | 59(0.202) | 149(0.510) | 187(0.640) |
| TENDL-2019 | 1.076 | 357 | 75(0.210) | 196(0.549) | 233(0.653) |

$^{176}Hf(n,\gamma)^{177}Hf$

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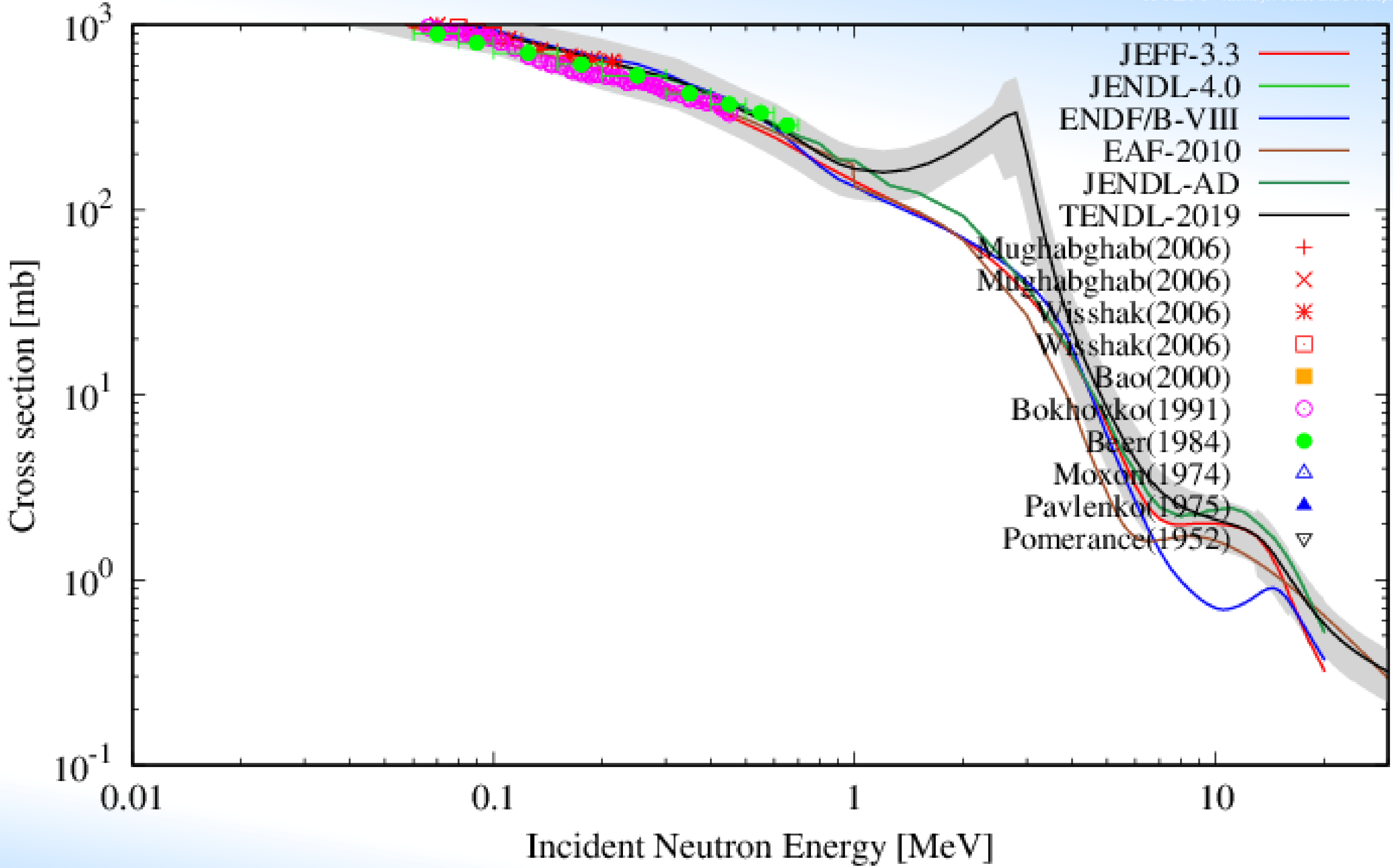
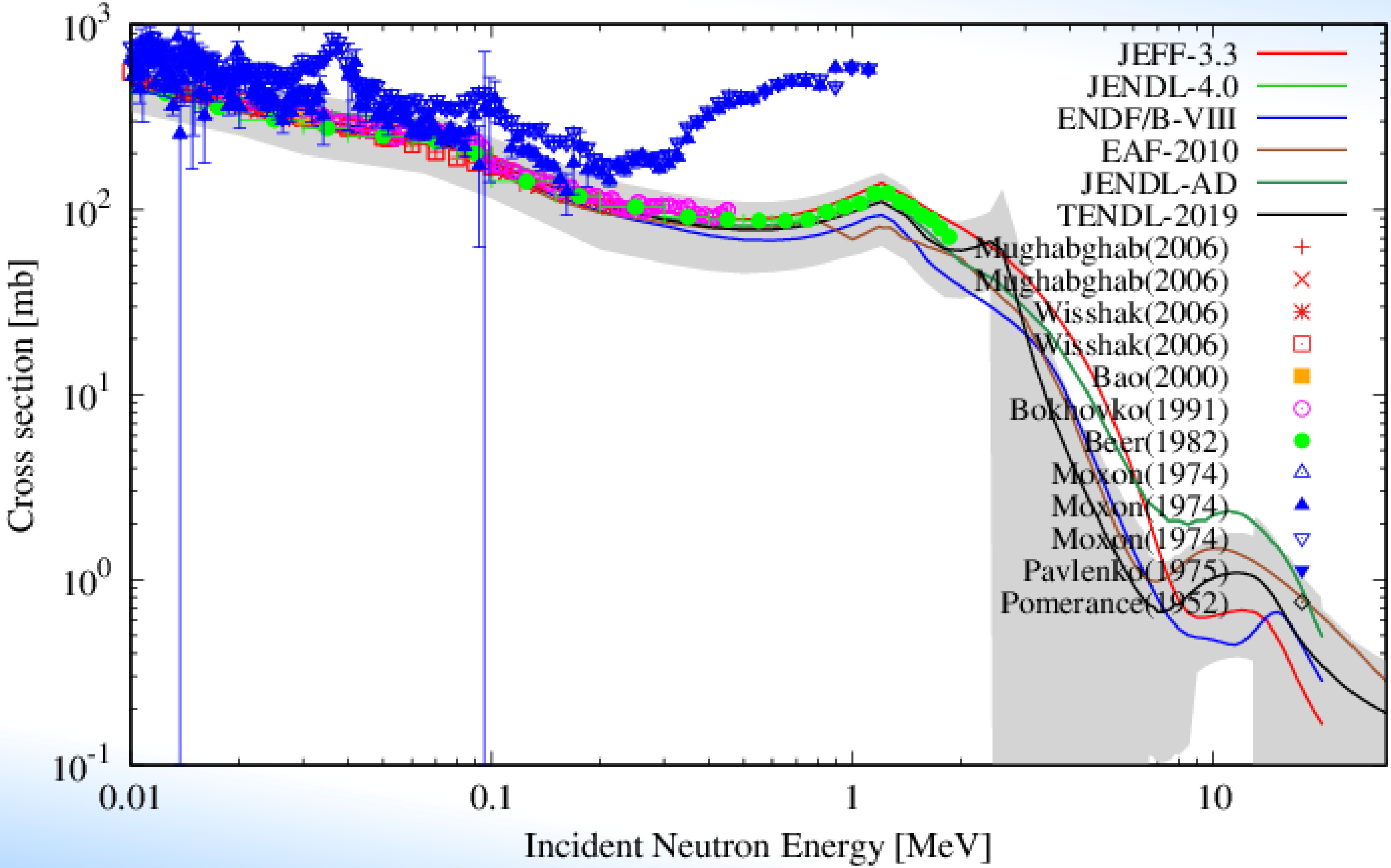
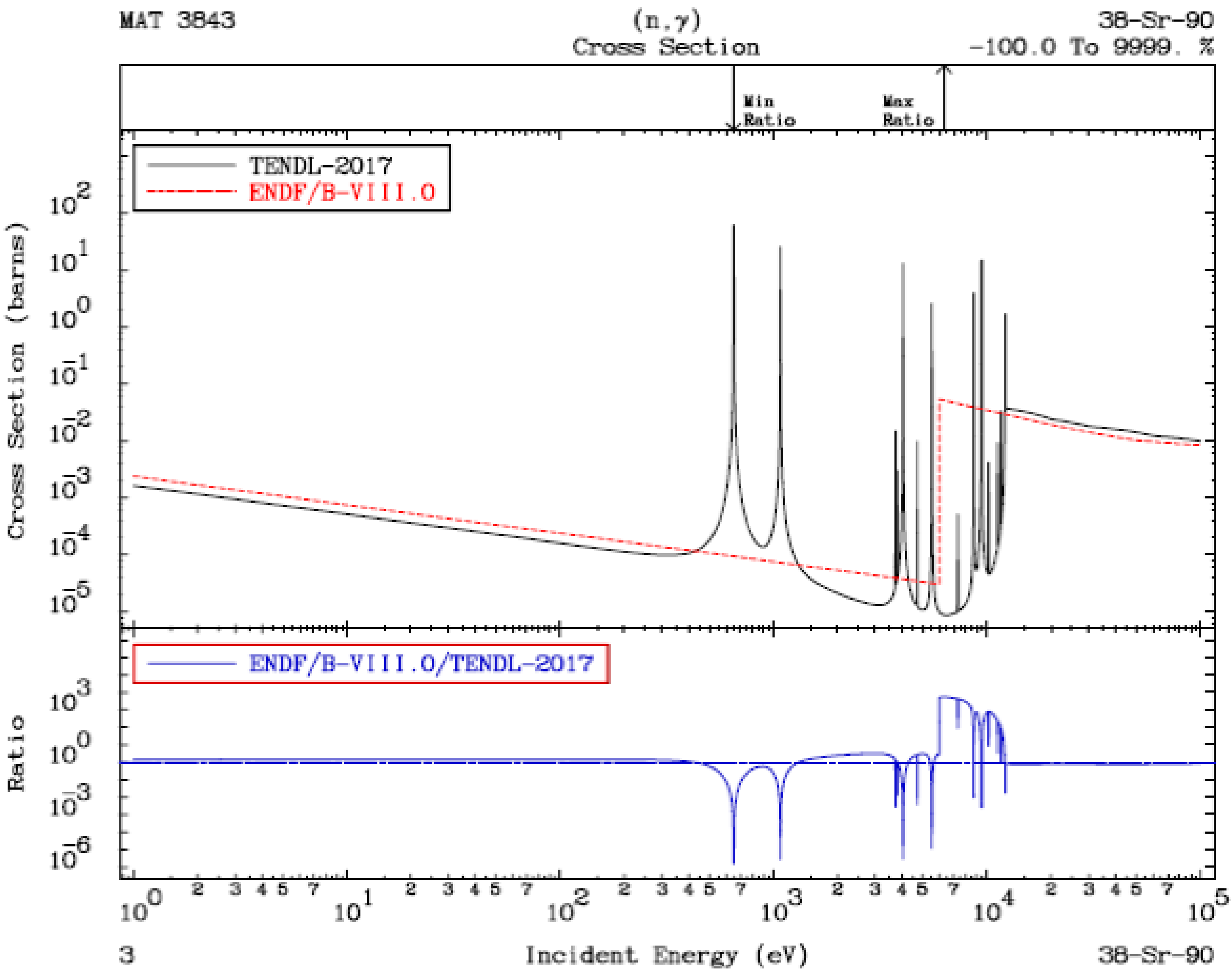
# $^{177}Hf(n,\gamma)^{178}Hf$



# $^{178}Hf(n,\gamma)^{179}Hf$

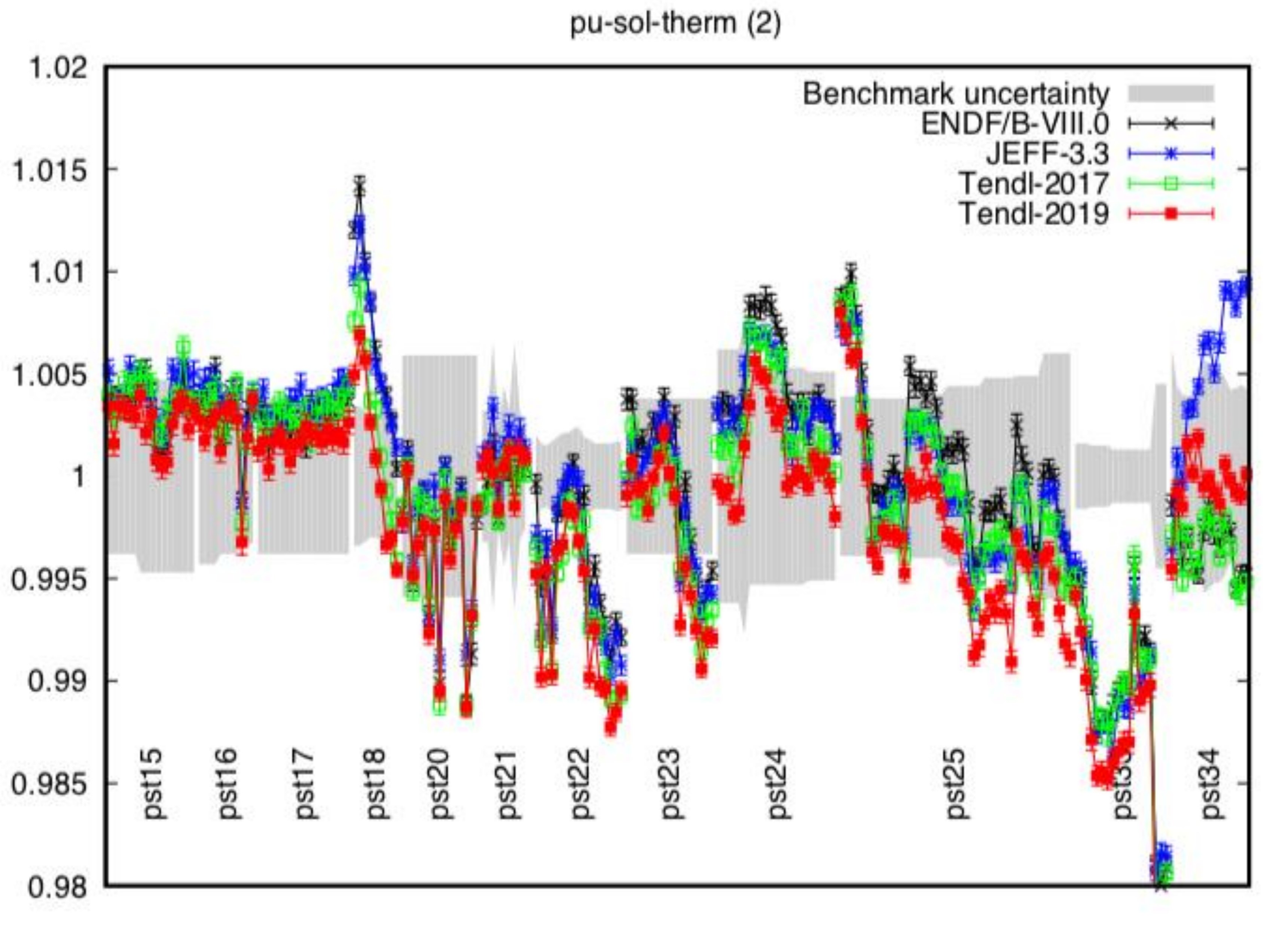


# Comparison with ENDF/B-VIII: Sr-90



# Steven van der Marck MCNP benchmarking (2500 cases)





# Conclusions

- At least one more….: TENDL-2021
- Focus on more different output formats, more applications do not require/want ENDF
  - Straight from TALYS + TARES to GNDS (C. Mattoon)
  - Tables with human/machine readable covariance data
- Automate validation as much as evaluation (challenging!). Now:
  - Criticality validation by van der Marck
  - Decay heat and activation validation by UKAEA (Gilbert et al)
  - Scattered results from other places in 1-2 years after release
- Extinction of evaluators works to advantage of TENDL approach
  - Bulk of materials already better with TENDL (which is NOT a theoretical nuclear data library)
  - However, need to work on our PR for neutron applications
- Strong coupling with Machine Learning, EXFOR usability
- Release T6, the system that produces (among others) TENDL

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# *Thank you!*