IAEA 60 Years
Atoms for Peace and Development

Status of TENDL

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IAEA, Vienna

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Contents

- TENDL-2017
- Examples: Differential data
- Examples: Integral data
- Future of TALYS and TENDL

TENDL: Complete nuclear data library for innovative nuclear science and technology

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

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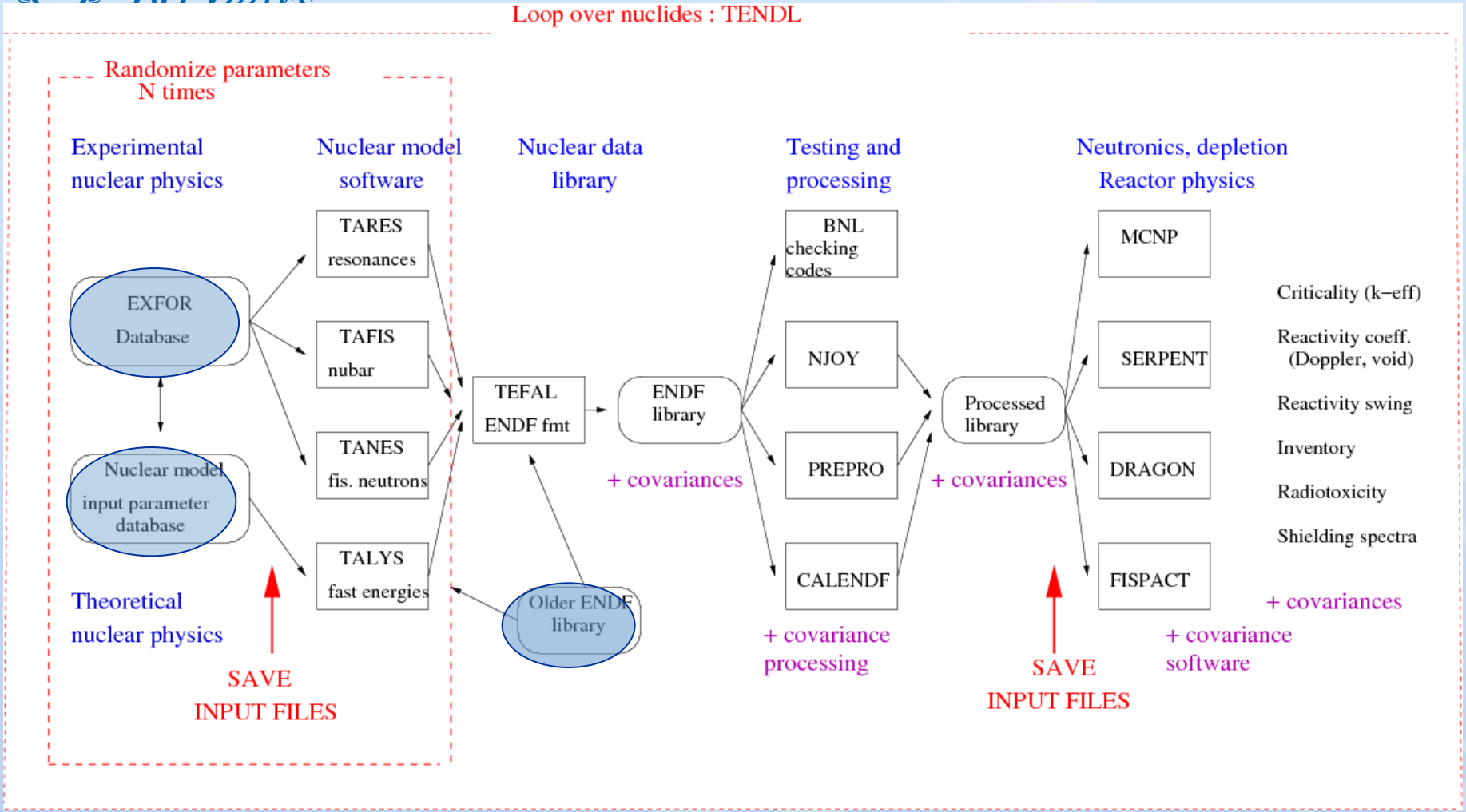
[2] *Laboratory for Reactor Physics Systems Behaviour, Paul Scherrer Institut, Villigen, Switzerland*
[3] *NRG, Westerduinweg 3, 1755 LE Petten, Netherlands*
[4] *Nuclear Energy Agency, OECD, 92100 Boulogne-Billancourt, France*
[5] *United Kingdom Atomic Energy Authority, Culham Science Centre, Abingdon OX14 3DB, United Kimgdom*

(Dated: May 11, 2018; Received xx July 2018; revised received xx September 2018; accepted xx October 2018)

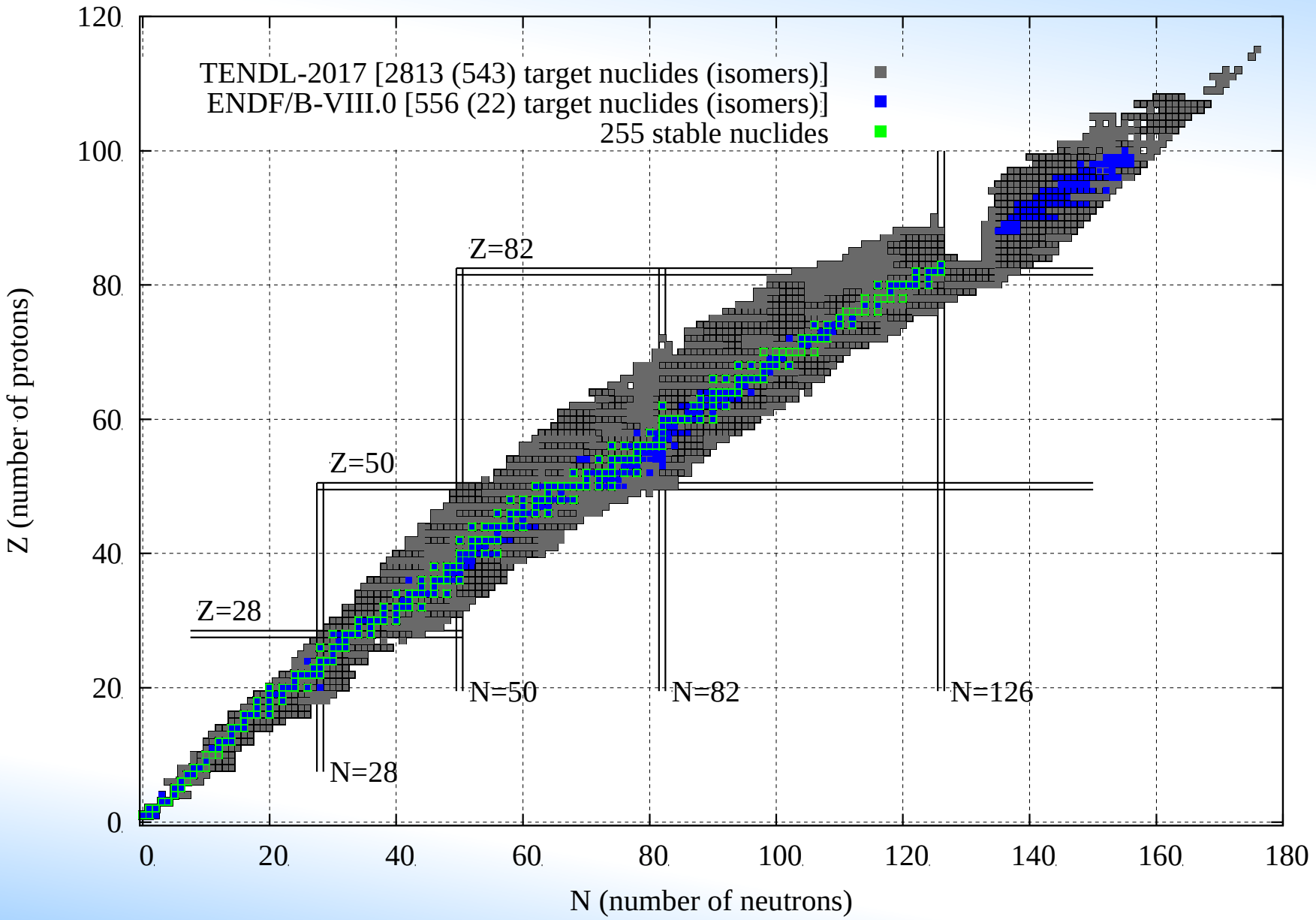
- In preparation for Nuclear Data Sheets, January 2019

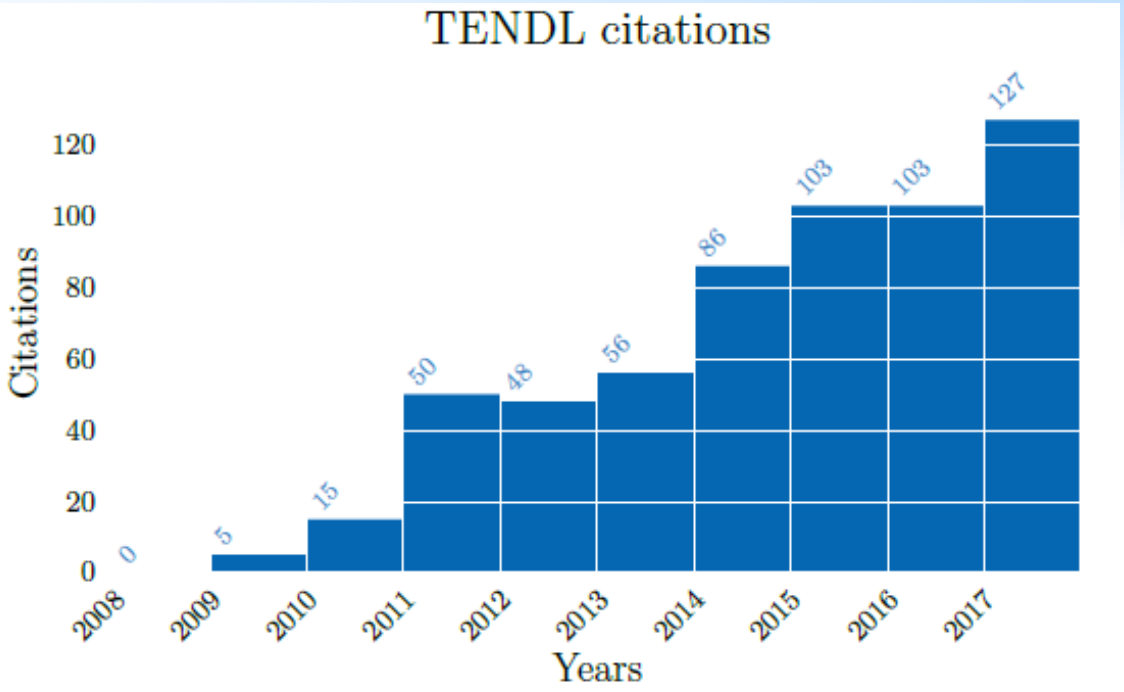
TENDL nuclear data library

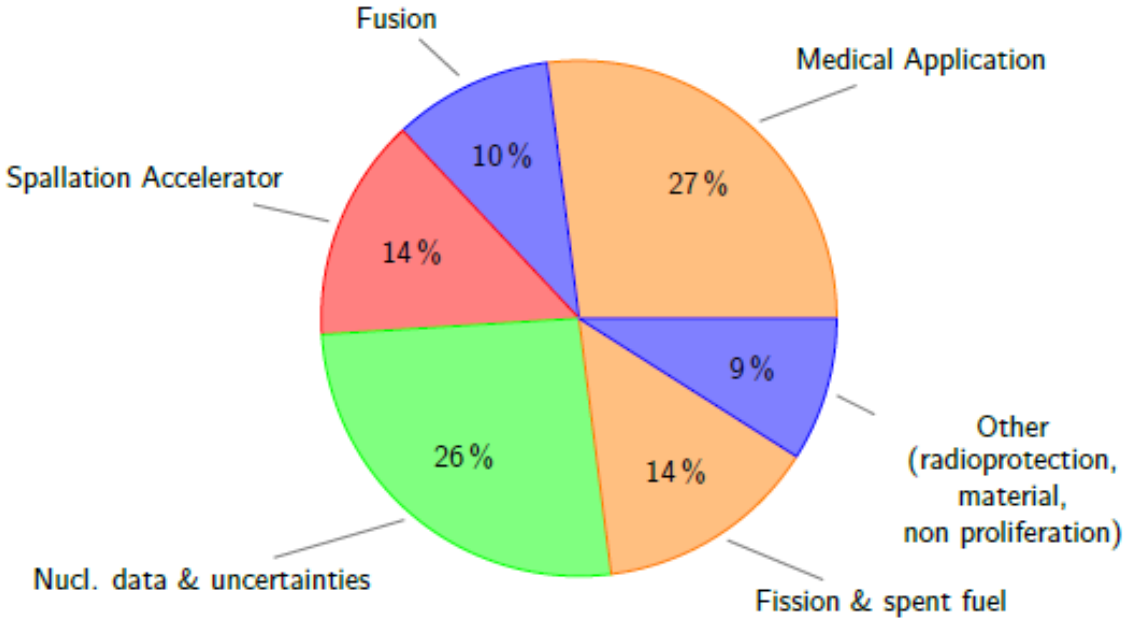


A.J. Koning and D. Rochman ,"Modern nuclear data evaluation with the TALYS code system“, Nuclear Data Sheets 113, 2841 (2012).

Nuclear landscape: Isotopic targets




TENDL citations
Citations
Years
0
5
15
50
48
56
86
103
103
127
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017


Fusion
Medical Application
Spallation Accelerator
10 %
27 %
14 %
9 %
26 %
14 %
Other
(radioprotection,
material,
non proliferation)
Nucl. data & uncertainties
Fission & spent fuel

TENDL-2015 additions to other libraries

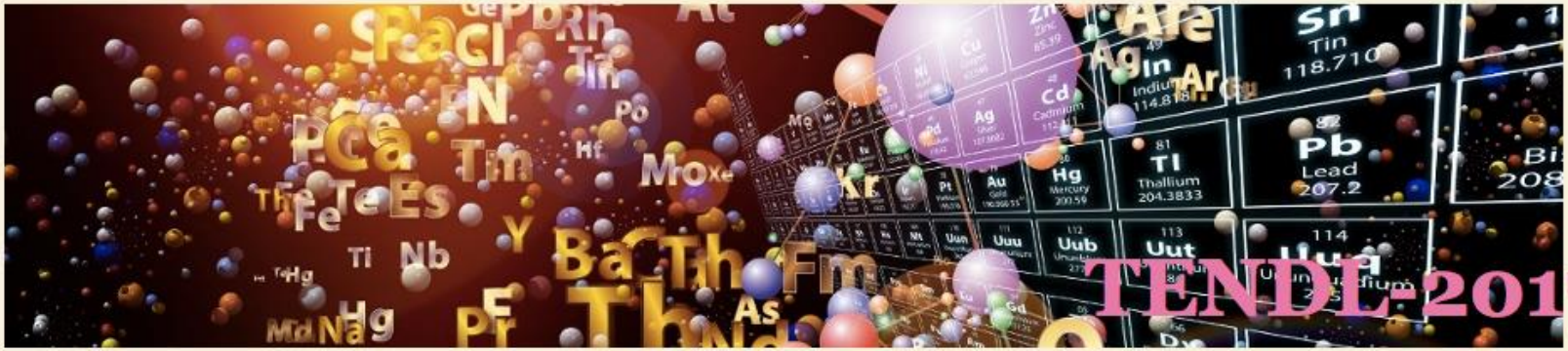
- ENDF/B-VIII: 28 nuclides
- JEFF-3.3:
  - >150 nuclides for incident neutrons
  - Photonuclear
  - Charged-particles

TENDL-2017 Home

- https://tendl.web.psi.ch/tendl_2017/tendl2017.html

TALYS-based evaluated nuclear data library

Home | Reference & us | Citations



"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

tar & Ace files

Random files

1. Random fission yields

TENDL-2017: (release date: December 30, 2017)

Last update: 29 December 2017

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 9th version is **TENDL-2017**, 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, and 2015).

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 (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

TENDL-2017 forms, ENDF-6 and other containers

Tabulated data (fast neutron range)

1. Tabular elastic angular distributions (En - angle - cross section)
2. Tabular (n,inl 1) angular distributions (En - angle - cross section)
3. Tabular gamma-ray intensities (En - Eg - cross section)
4. Tabular residual cross sections (En - Residual product - cross section)
5. Tabular spectra (En - Eout - particle - cross section)
6. Tabular total and partial cross sections (En - cross section)

Evaluated formatted data (i.e. ENDF)

1. The TENDL file
2. Pointwise cross sections at 293 K (pendf)
3. ACE file at 293 K (ace.gz and xsdir)
4. Special ENDF file with MF32c and MF12/MT102 (so-called s20 file)
5. EAF file (European Activation File) and associated covariances
6. ACF file (Activation File)

Processed plots

1. Plots of the cross sections and other quantities: plot
2. Plots from PREPRO: plot
3. Comparison TENDL and ENDF/B-VIII.0: plot
4. Comparison TENDL and JEFF-3.3: plot
5. Comparison TENDL and JENDL-4.0: plot
6. Comparison TENDL and IRDFF-1.0: plot
7. Comparison TENDL and CENDL-3.1: plot
8. Processed cross sections and covariances with NJOY in 187 groups: matrix and plot
9. Processed cross sections and covariances with NJOY in 44 groups: matrix and plot
10. Processed cross sections and covariances with NJOY in 33 groups: matrix and plot
11. Processed angular distribution and covariances with NJOY in 187 groups: matrix
12. Processed angular distribution and covariances with NJOY in 187 groups: plots
13. Processed angular distribution and covariances with NJOY in 33 groups: matrix
14. Processed angular distribution and covariances with NJOY in 33 groups: plots

TENDL-2017 forms, ENDF-6 and other containers

- Mirror: https://www-nds.iaea.org/public/download-endf/TENDL-2017/Original/TENDL-2017.htm

tar files

Last update: 26 April 2018

The TENDL-2017 library can be retrieved with tar (*.tgz) files for each sub-library. To untar the files, use the command: tar -zxvf.

1. Neutron

   2813 ENDF files (3.1 Gb),
   List of MAT numbers: iso-mat.tendl-n.txt.

   List of 556 ZAID numbers for ACE: Ace-Readme.tendl17c.txt.

   556 ACE files files (2.1 Gb),

2. Proton

   2804 ENDF files (2.0 Gb)
   283 stable targets ACE files (160 Mb),
   and special files "so" (1.1 Gb).

3. Deuteron

   2811 ENDF files (2.5 Gb)

The ACE forms also serve: SERPENT and OpenMc

+soon the TRIPOLI forms

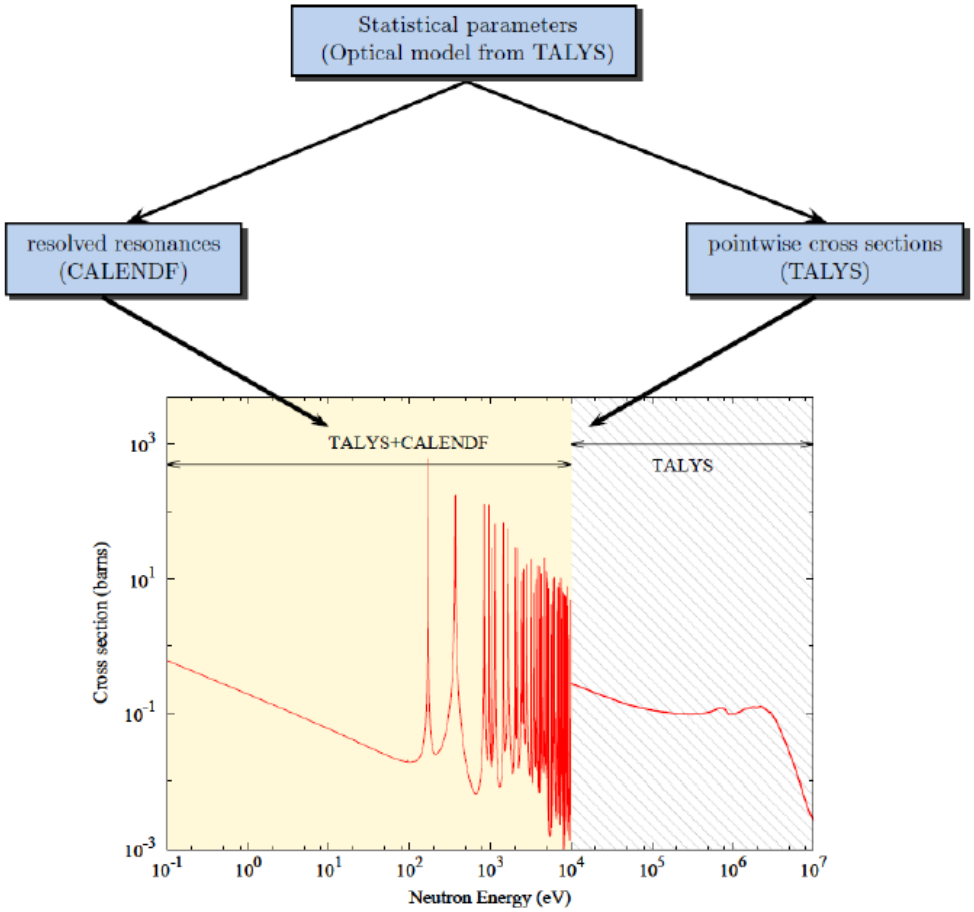
Current TENDL: 2017

- December 2017: Release of TENDL-2017
  - Neutrons:
    - Improvement of cross section values by Natalia Dzysiuk for fusion and fission product nuclides
    - General improvement of resonance parameters by Dimitri Rochman
    - Last (?) remaining ENDF format deficiencies removed
    - No more MF32, all covariance data pointwise in MF33 down to 1e-5 eV.
  - Photons:
    - Adjustment of TALYS parameters to experimental data
  - Protons, deuterons, tritons, He-3, alpha particles:
    - ENDF format completion for recoils

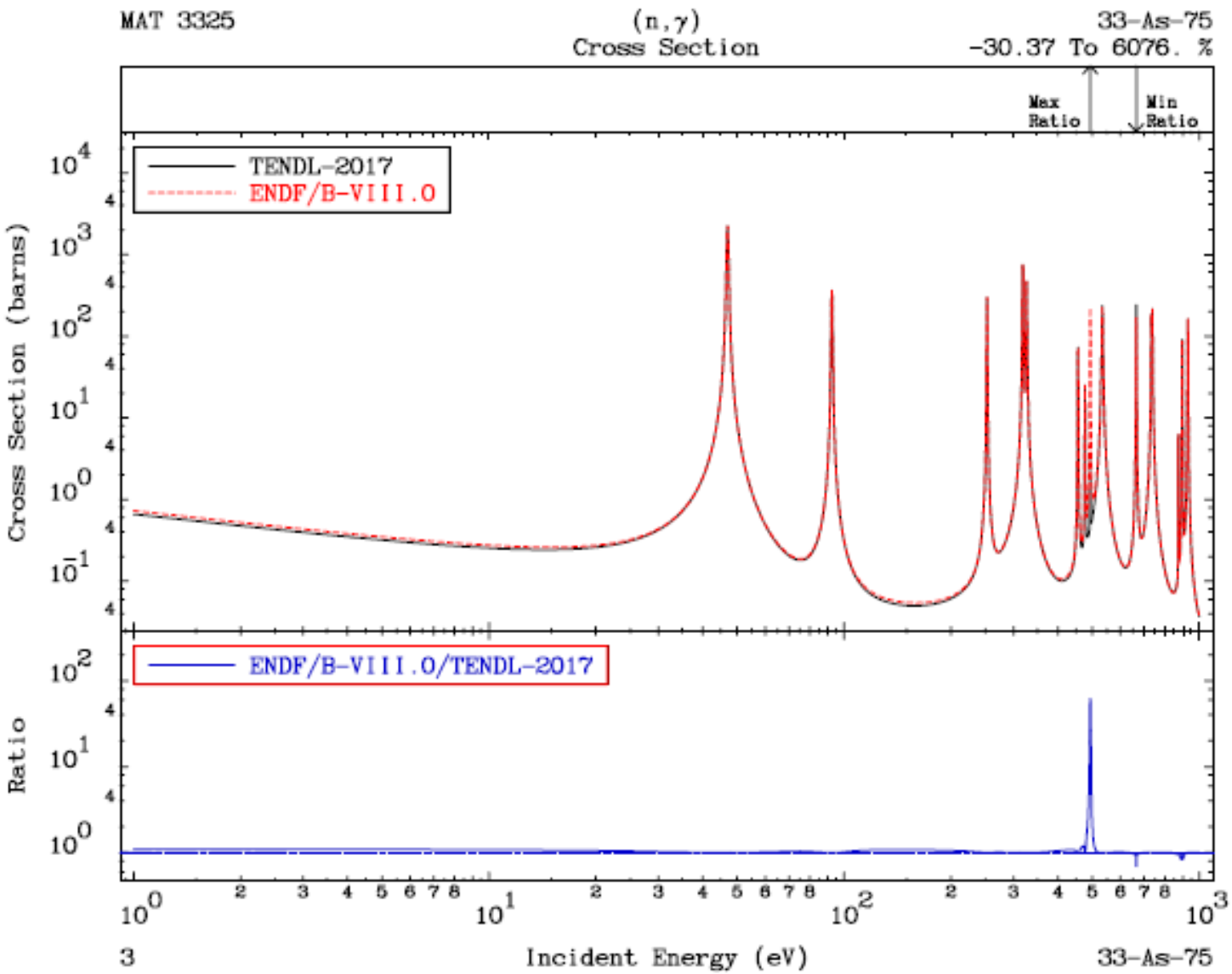
TENDL in the resonance range

- In TENDL, all 2800 isotopes have unique resonances
  - Only about 10 % of the resonances are measured,
  - The rest comes from the HFR method (statistical resonances),

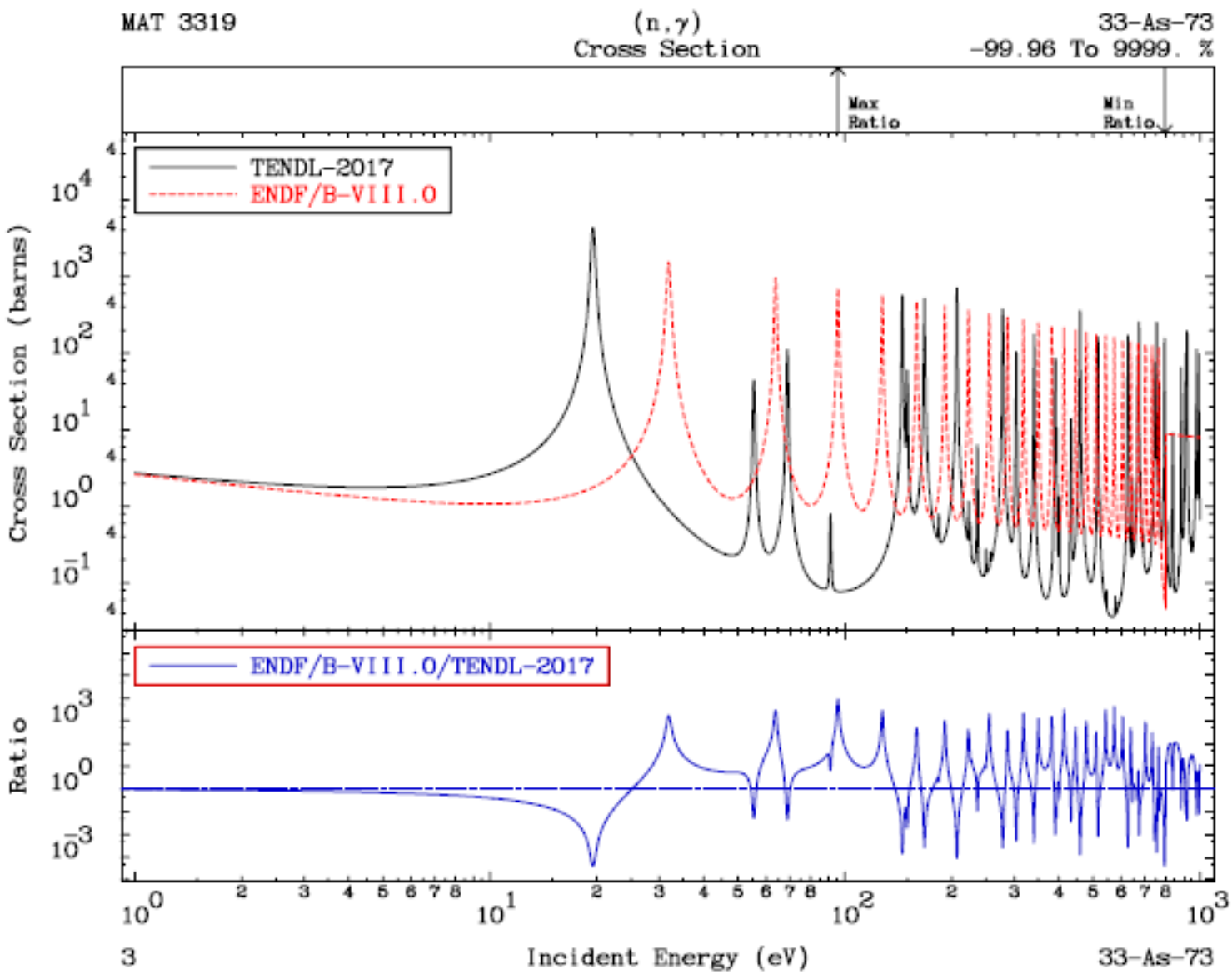
- Presented in ANE 50 (2013) 60
  - Combine the 3 previous models (ld, omp and γ-str) to produce statistical resonances
- Uses the following scheme:
  - TALYS (input: ld + omp + γ-str)
  - CALENDF (input: TALYS output)
  - Output: statistical resonances



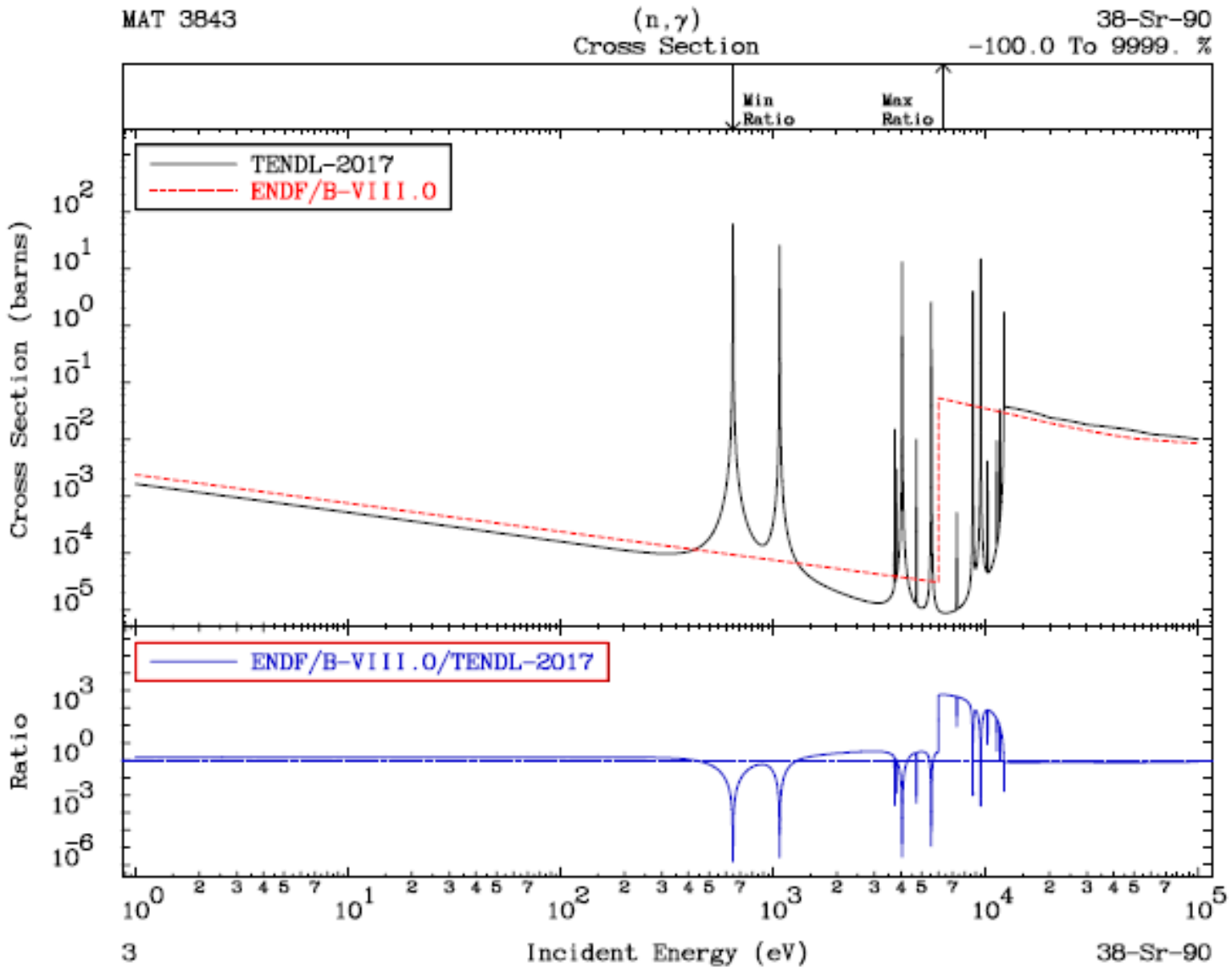
Comparison with ENDF/B-VIII: As-75



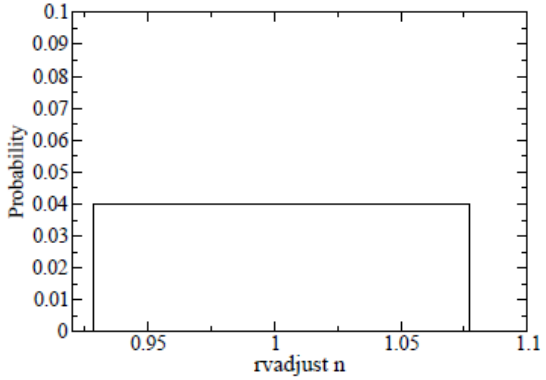
Comparison with ENDF/B-VIII: As-73

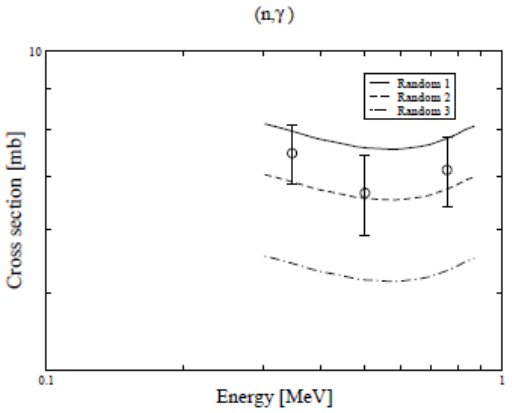


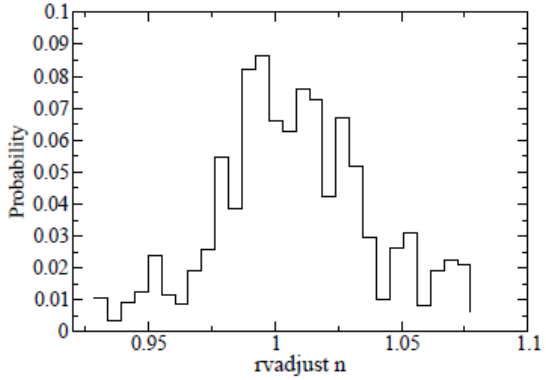
Comparison with ENDF/B-VIII: Sr-90

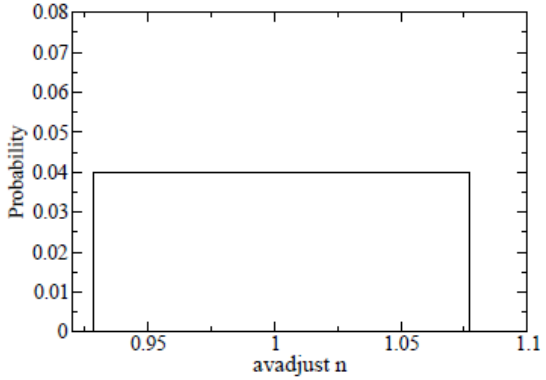


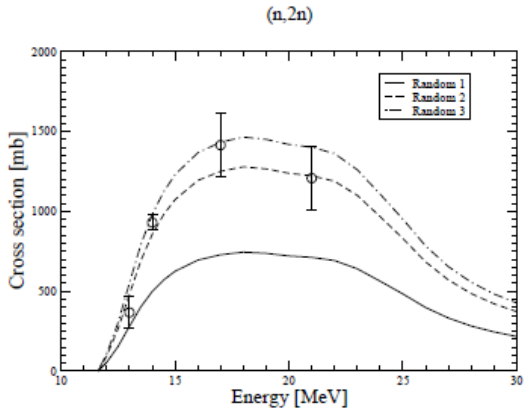
Bayesian Monte Carlo with TALYS: model parameter distribution (step 1)

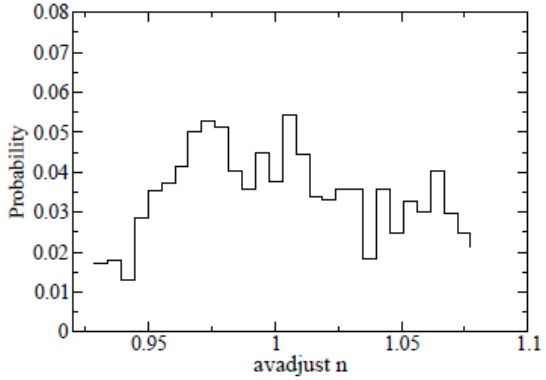






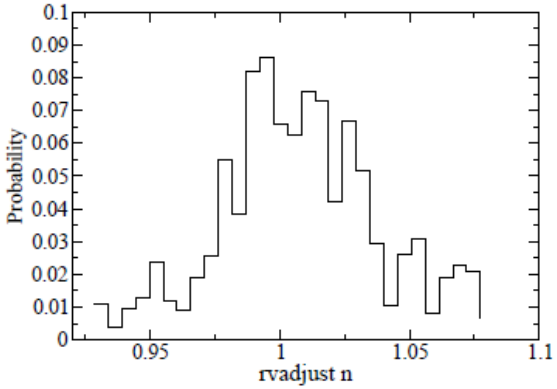


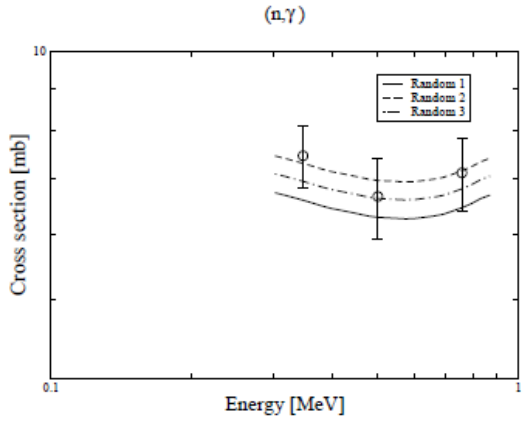


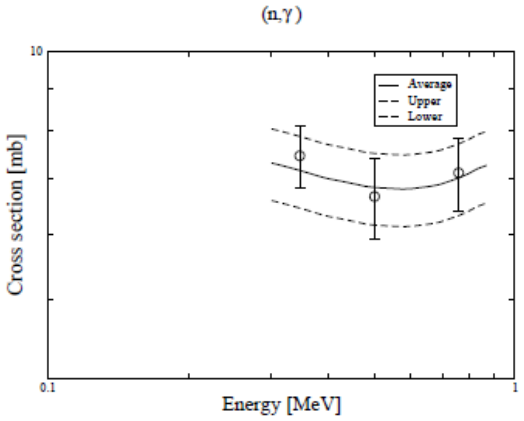


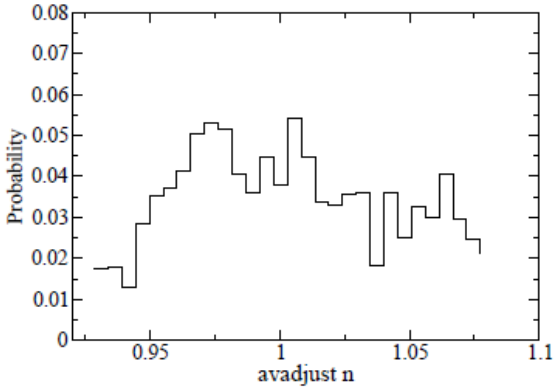
$$L(\mathbf{p};\mathbf{x}) = \exp(-\chi^2/2),$$

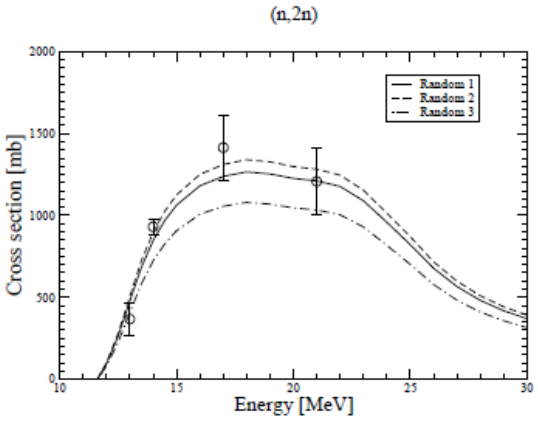
Bayesian Monte Carlo with TALYS: cross section distribution (step 2)

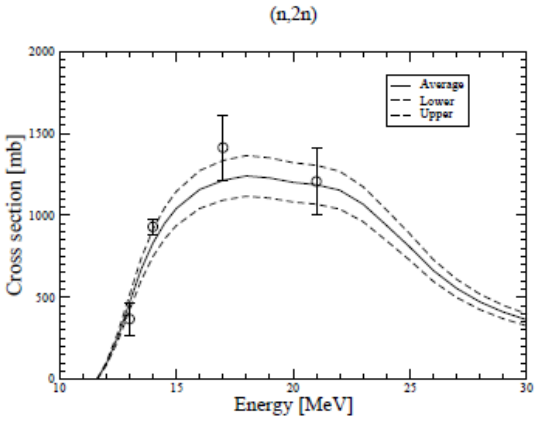




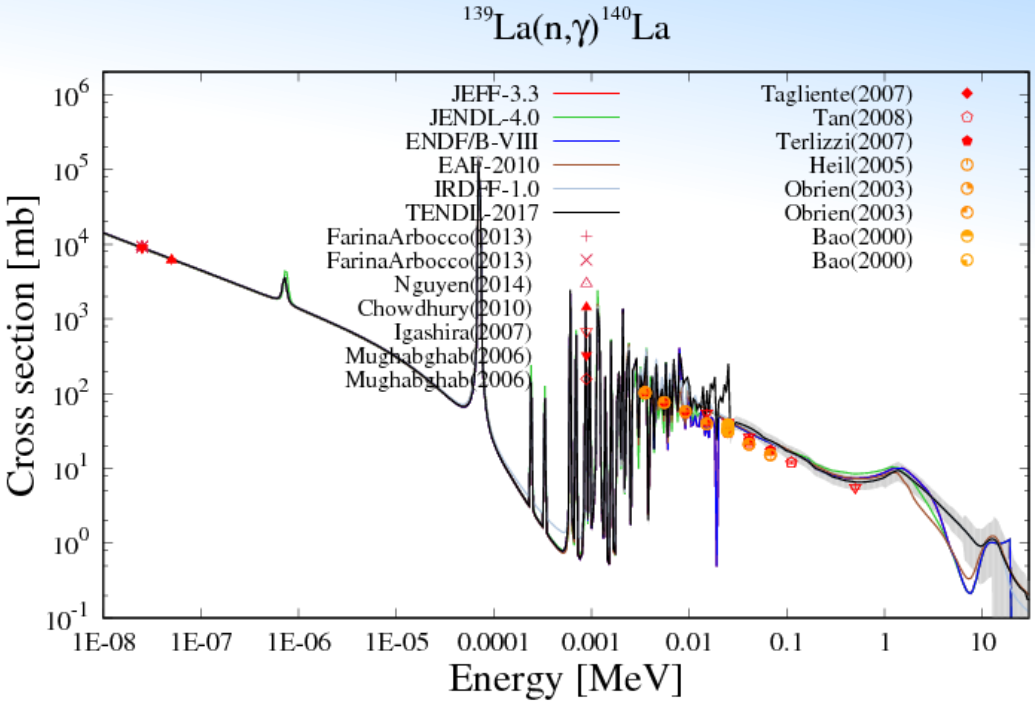




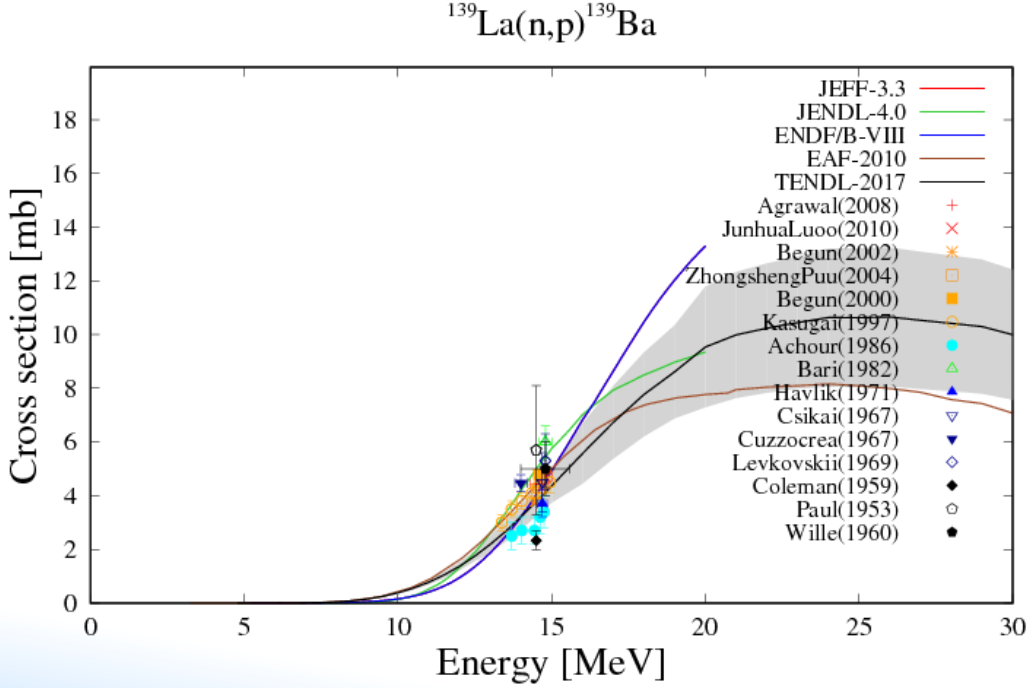


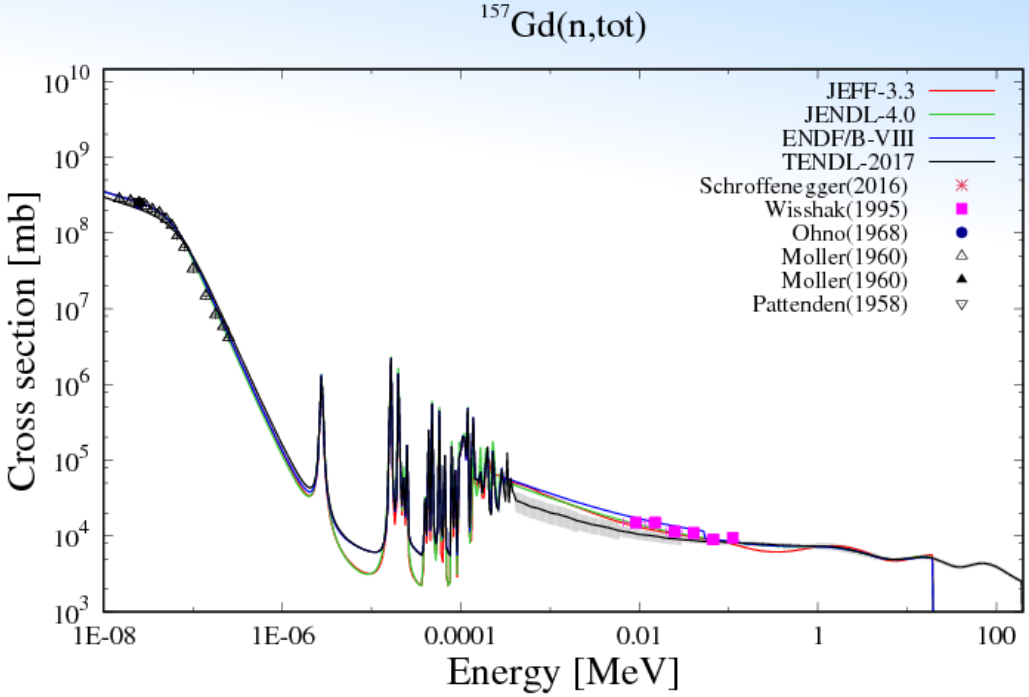


$$L(\mathbf{p};\mathbf{x}) = \exp(-\chi^2/2),$$



Plots for **all** particles, target nuclides, reaction channels and nuclear data libraries available at ftp://ftp.nrg.eu/pub/www/talys/plots





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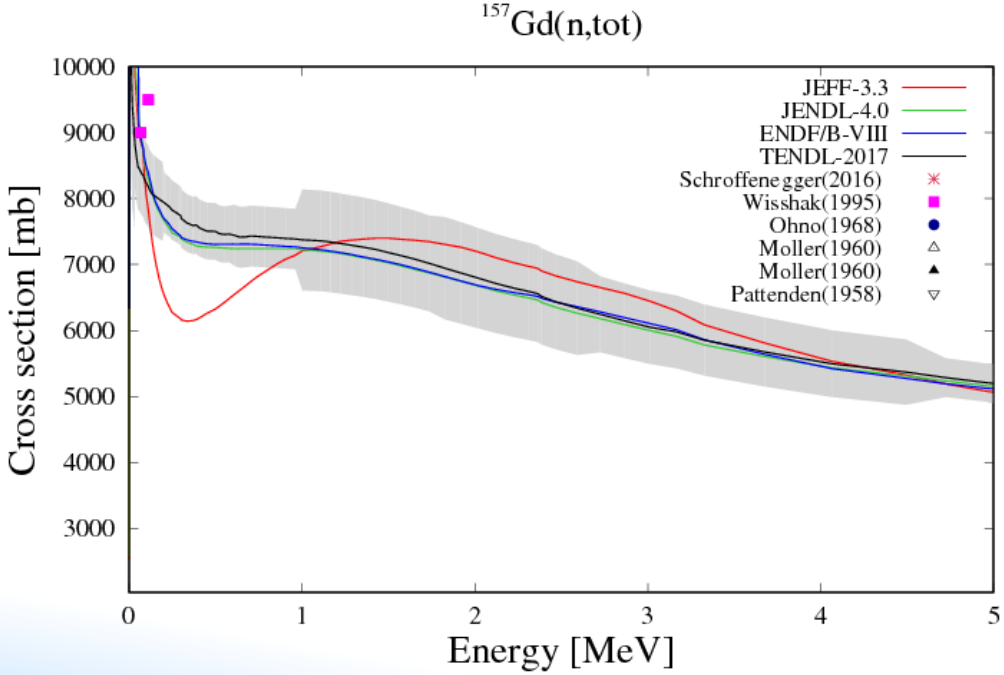

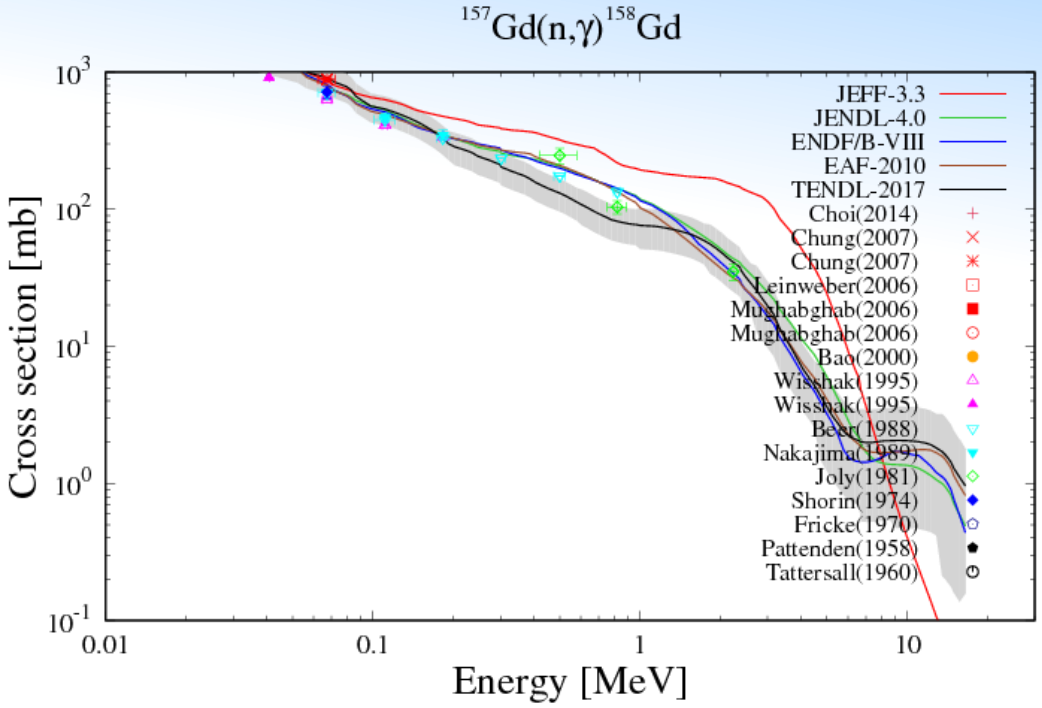

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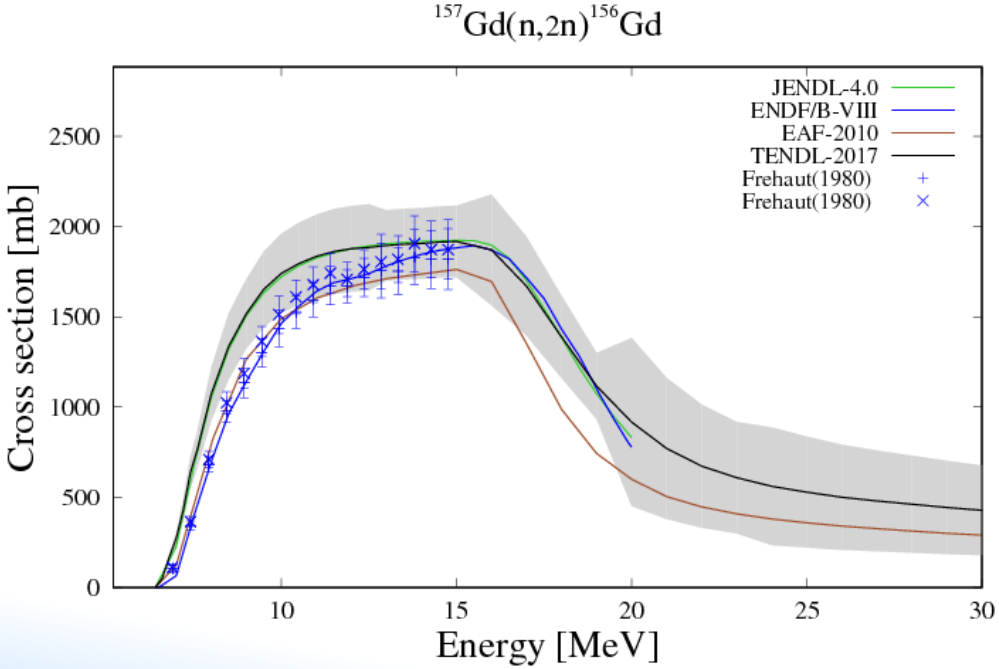
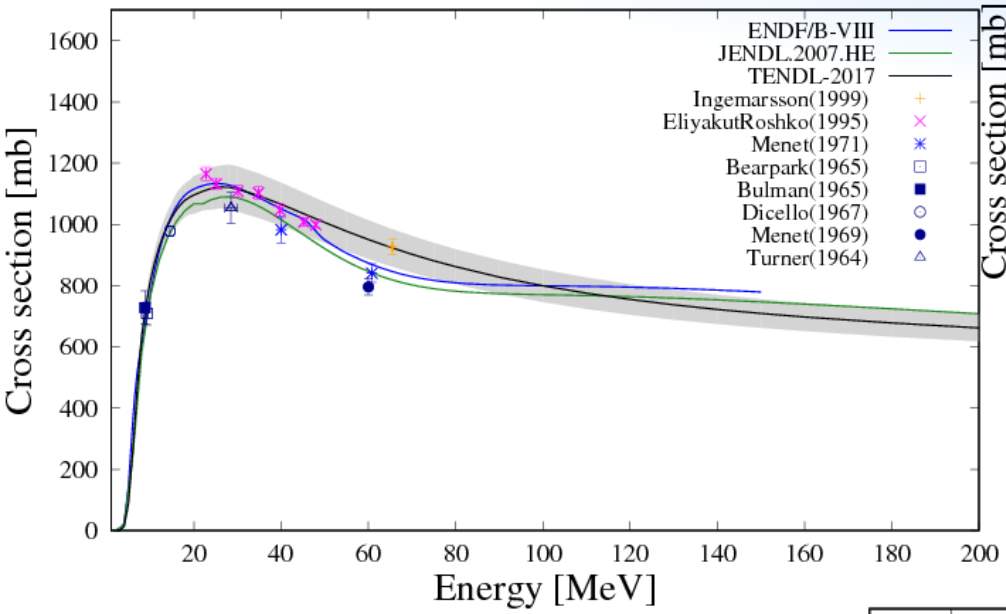
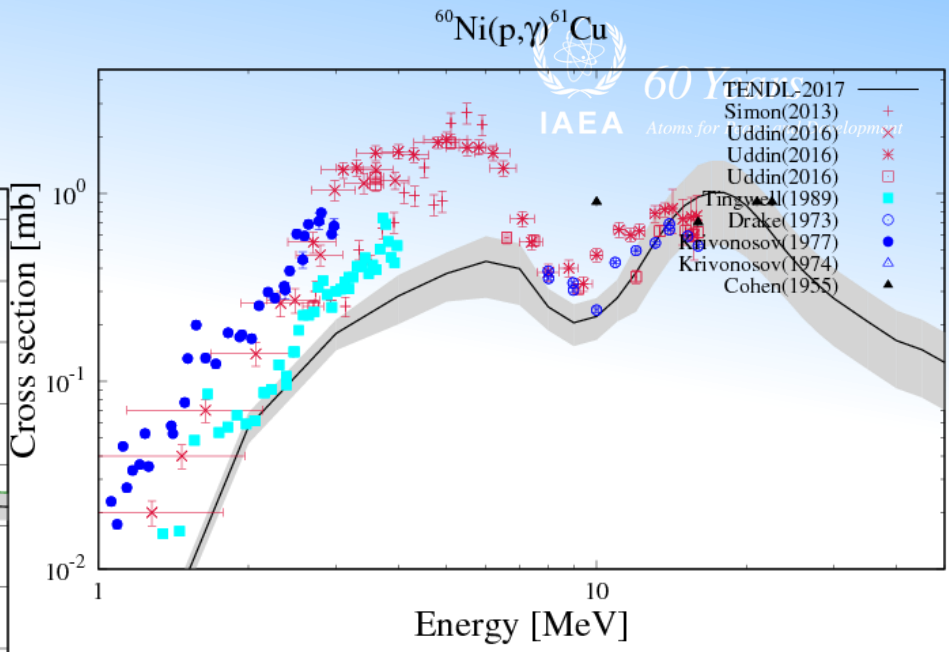
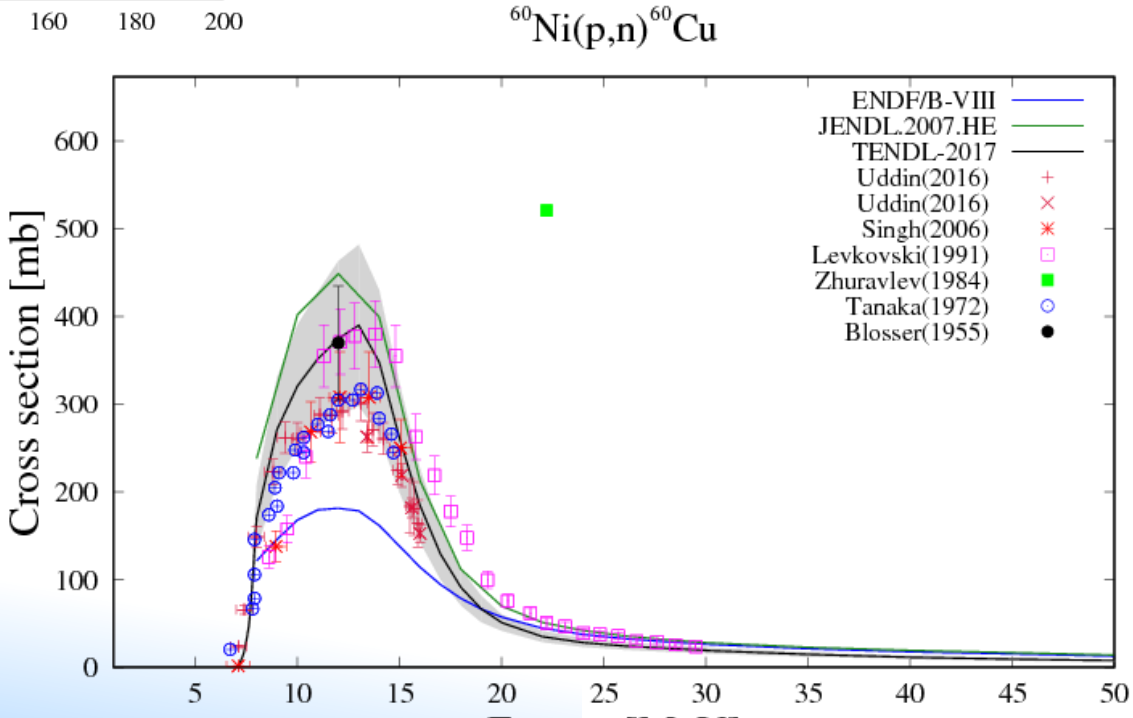


Protons

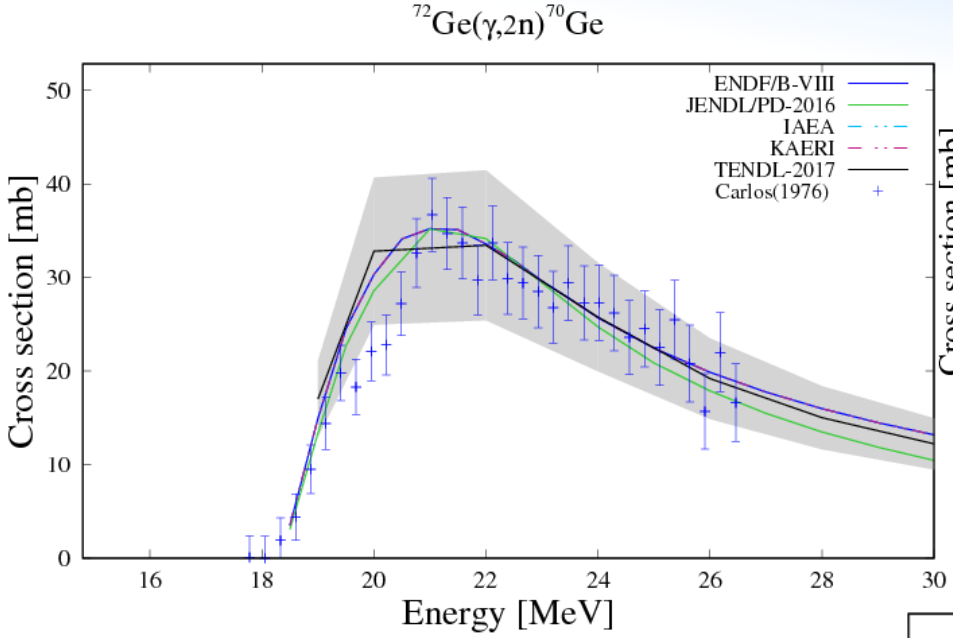


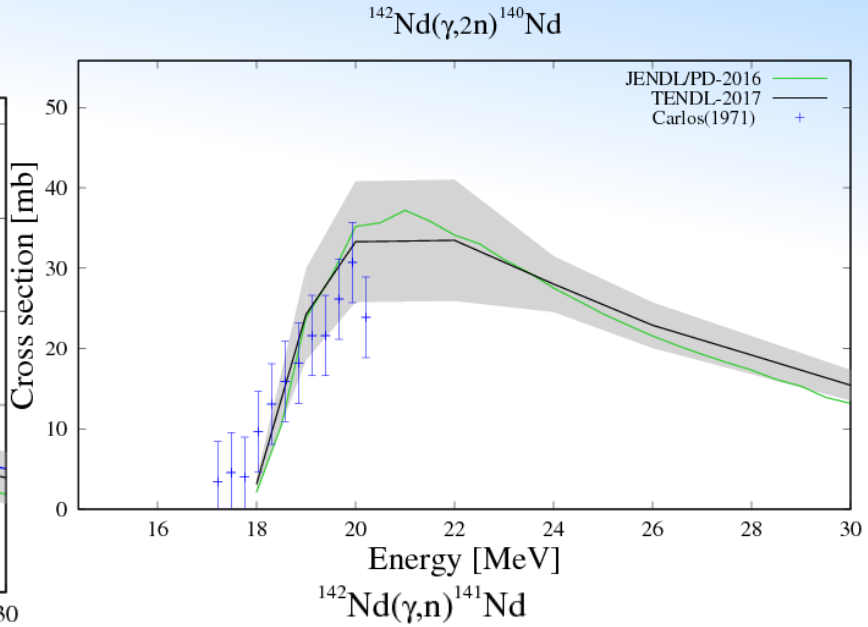




Plots for **all** particles, target nuclides, reaction channels and nuclear data libraries available at ftp://ftp.nrg.eu/pub/www/talys/plots

Photonuclear





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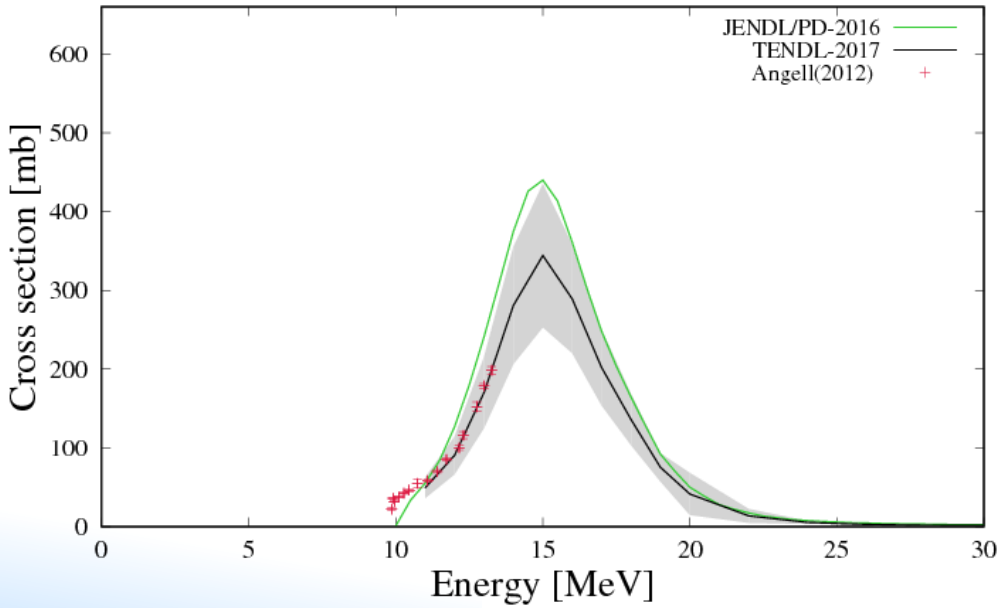
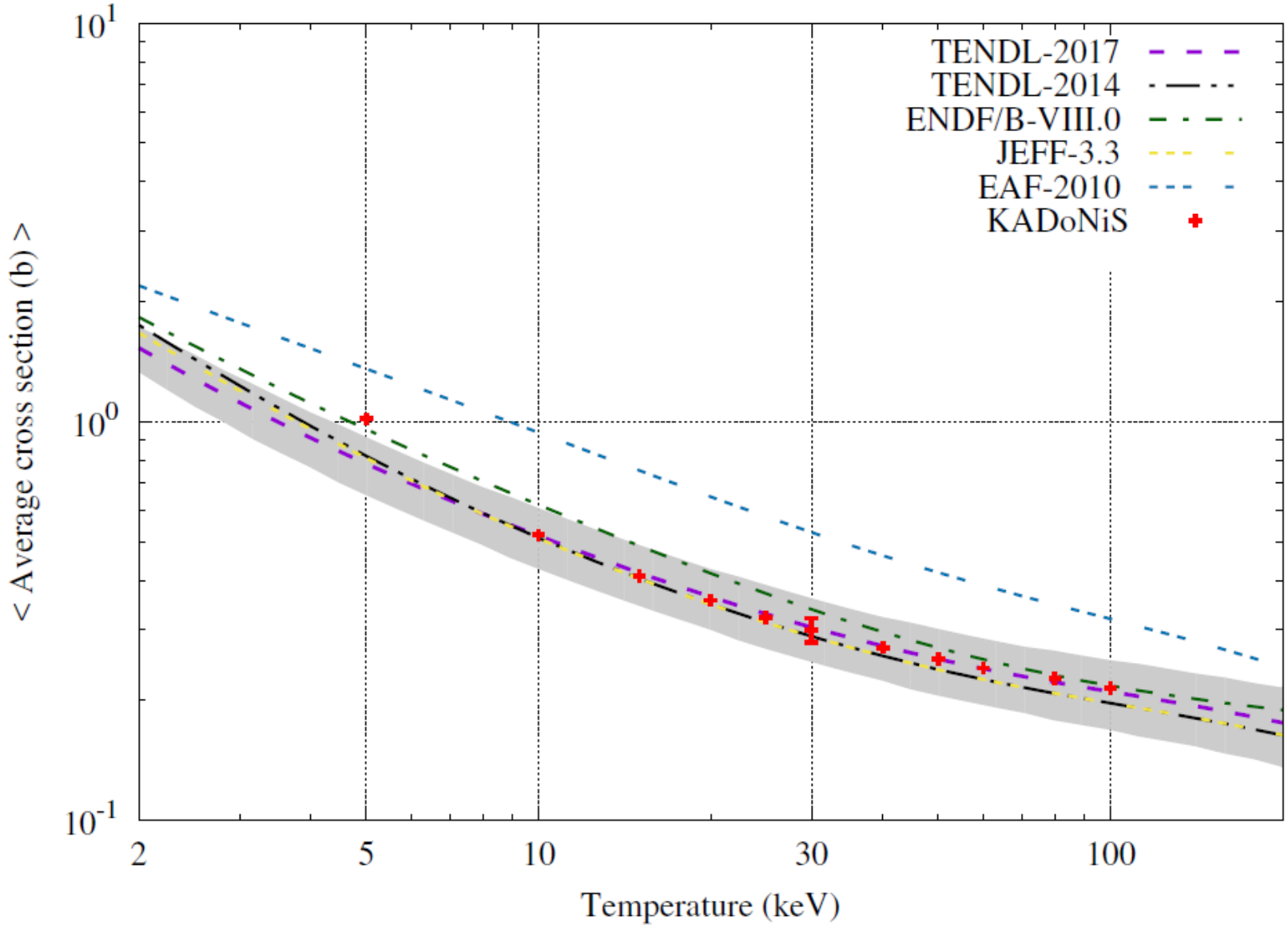
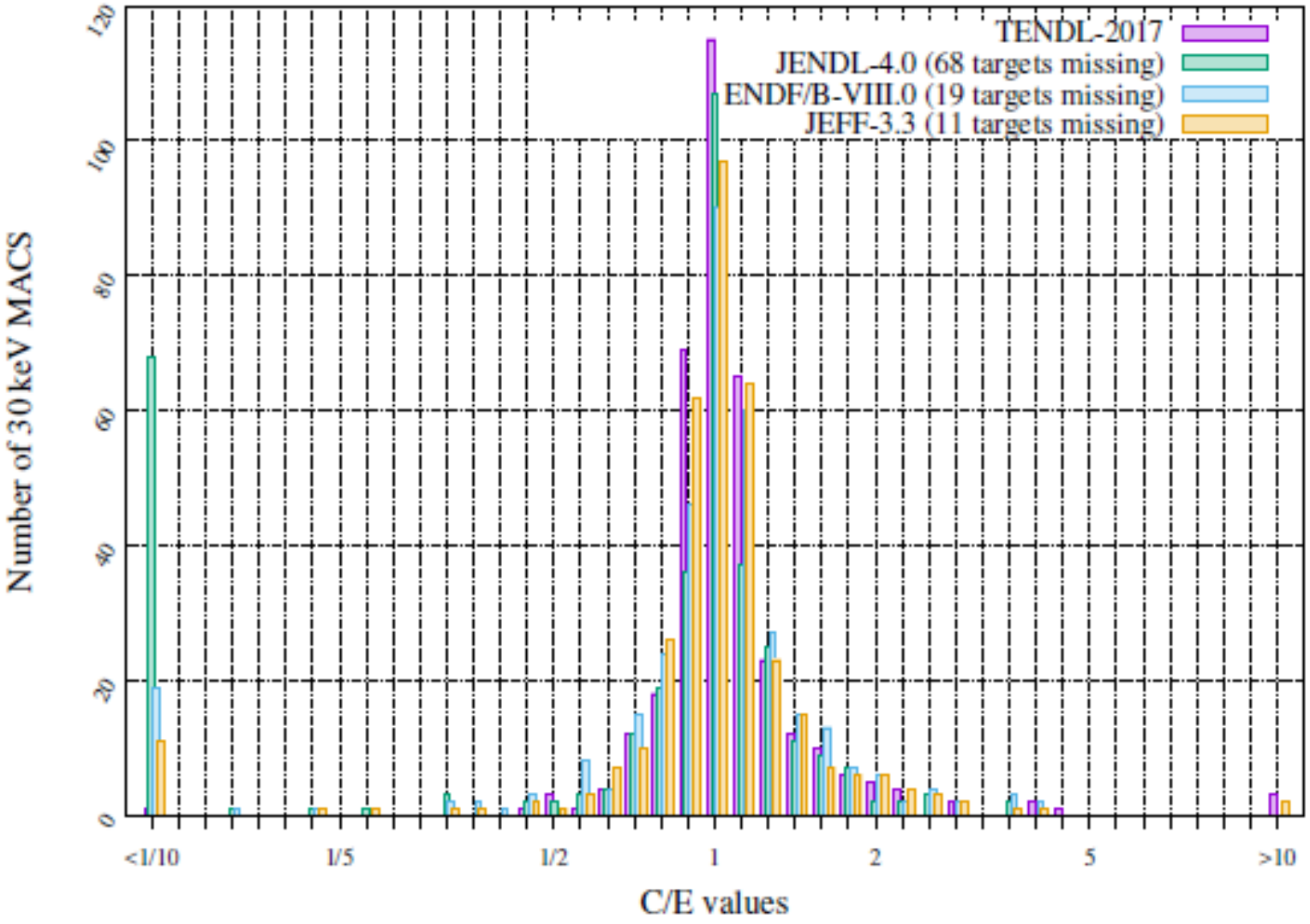


Maxwellian Averaged cross sections: Ce-136



Neutron capture: global 30 keV comparison



TENDL approach

Requires things which are also useful for the other approaches:

- Revision of the thermal, MACS, RI databases (partly derived from EXFOR) (tbd)
- Systematic evaluation of EXFOR that is quantified and reproducible, unlike an ENDF table (tbd)
- Direct availability of all historical nuclear data in an efficient form

The ‘libraries/’ database (need better name)

Transform the most important ENDF libraries and EXFOR into simple accessible x-y(-dy) tables.

All created by a program called ENDFTABLES

Benefits:

- Cut in the middle: Reading and interpreting an ENDF-6/EXFOR library is done in separate step
- ENDF and EXFOR can be used efficiently by non-ENDF people
- Very efficient for plotting
- Reproducible use in adoption of data into other data libraries
- Automatic EXFOR quality scoring procedures
- Medical isotope production
- Collection of all EXFOR vs library plots
- Etc.

‘Libraries/’

- Huge: about 200 Gb untarred, 8 million files
- ftp://ftp.nrg.eu/pub/www/talys/libraries
- get libraries*tar; tar zxf libraries*tar

```
n/Fe054/jendl4.0/tables/angle/
n/Fe054/jendl4.0/tables/damage/
n/Fe054/jendl4.0/tables/info/
n/Fe054/jendl4.0/tables/resonance/
n/Fe054/jendl4.0/tables/xs/
```

Cross sections

If we take the xs/ directory as the first example, we see the subdirectory looks as follows

```
n/Fe054/jendl4.0/tables/xs/n-Fe054-MT001-G069.jendl4.0
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```
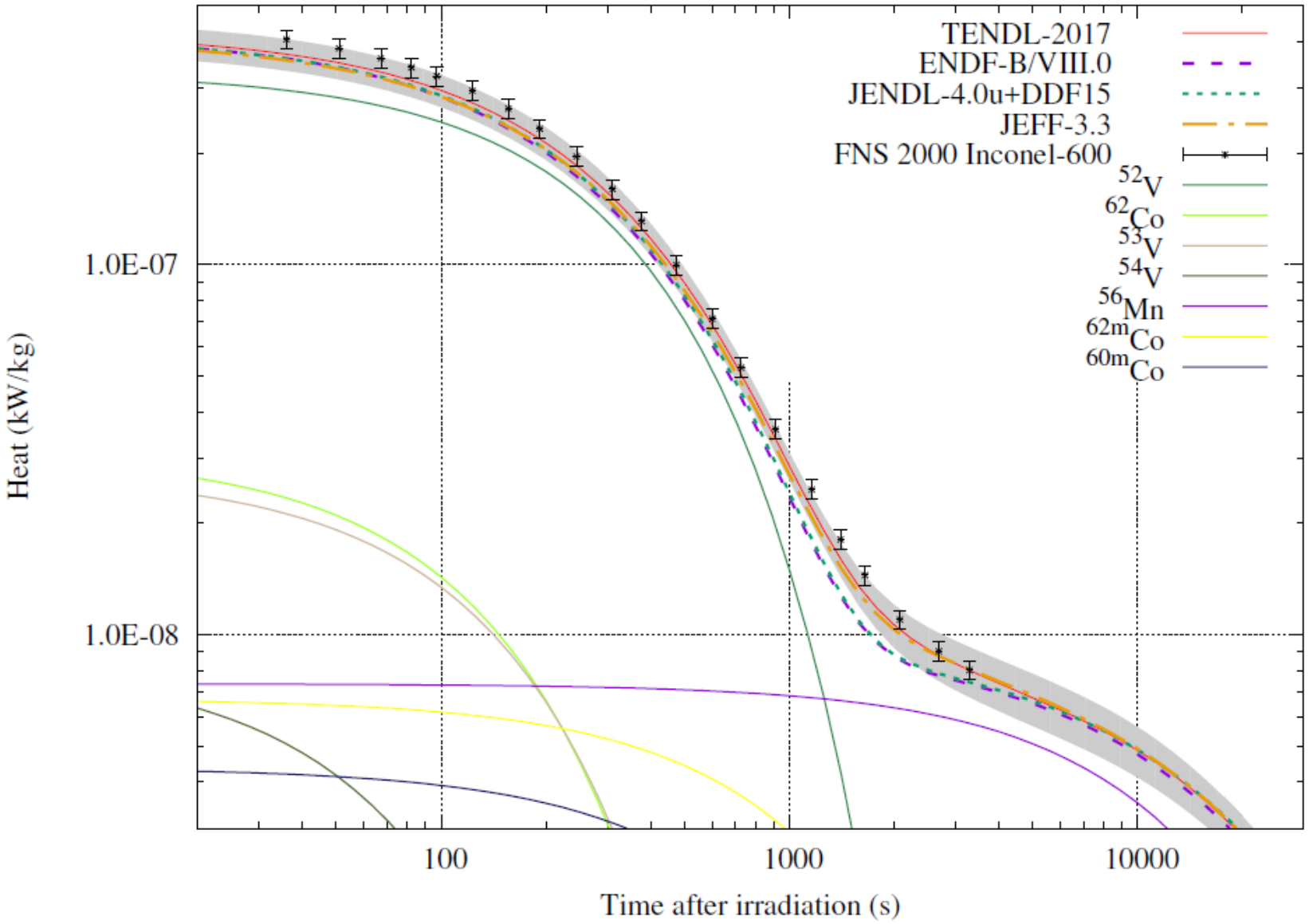
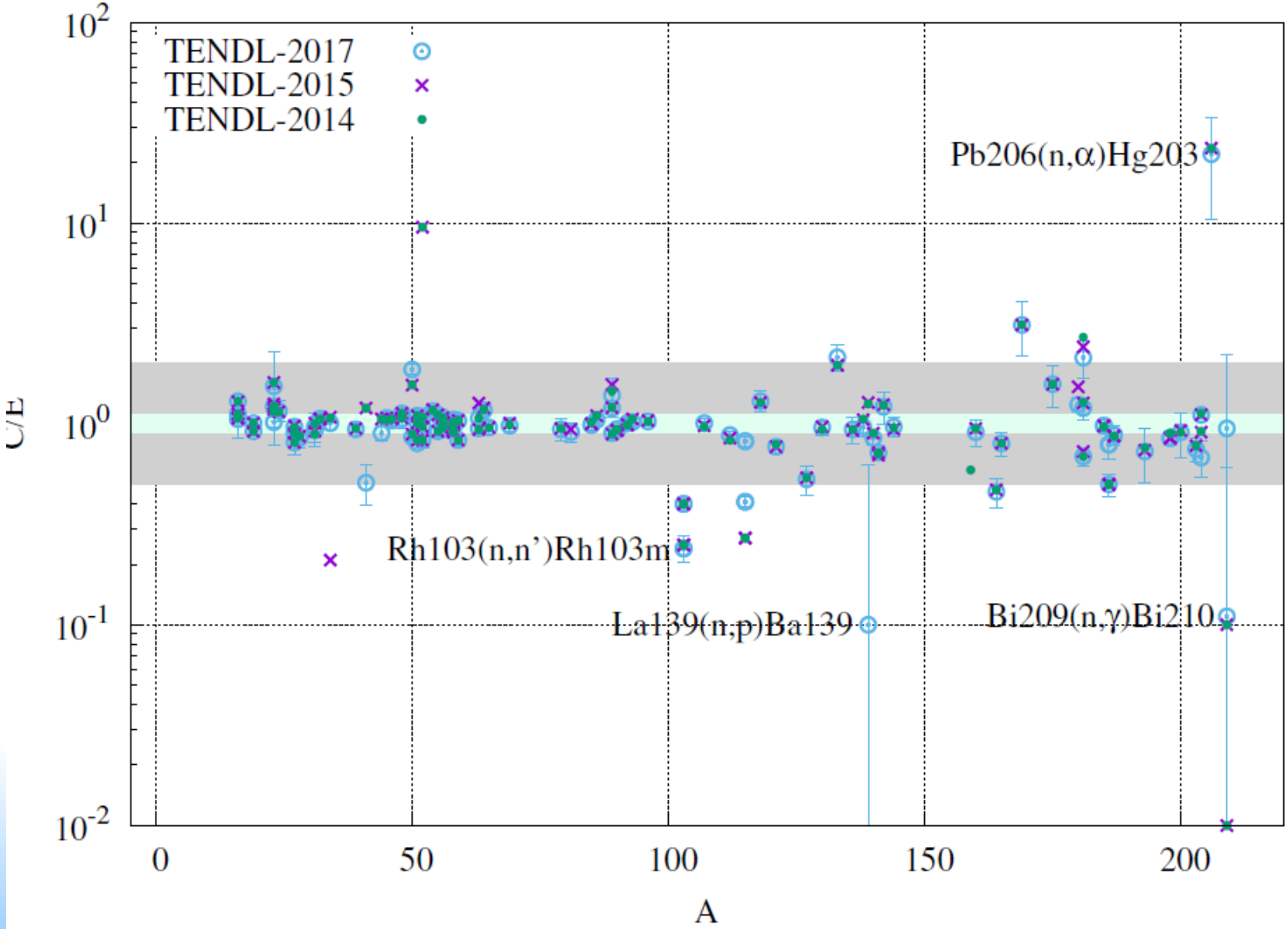

Fusion decay heat

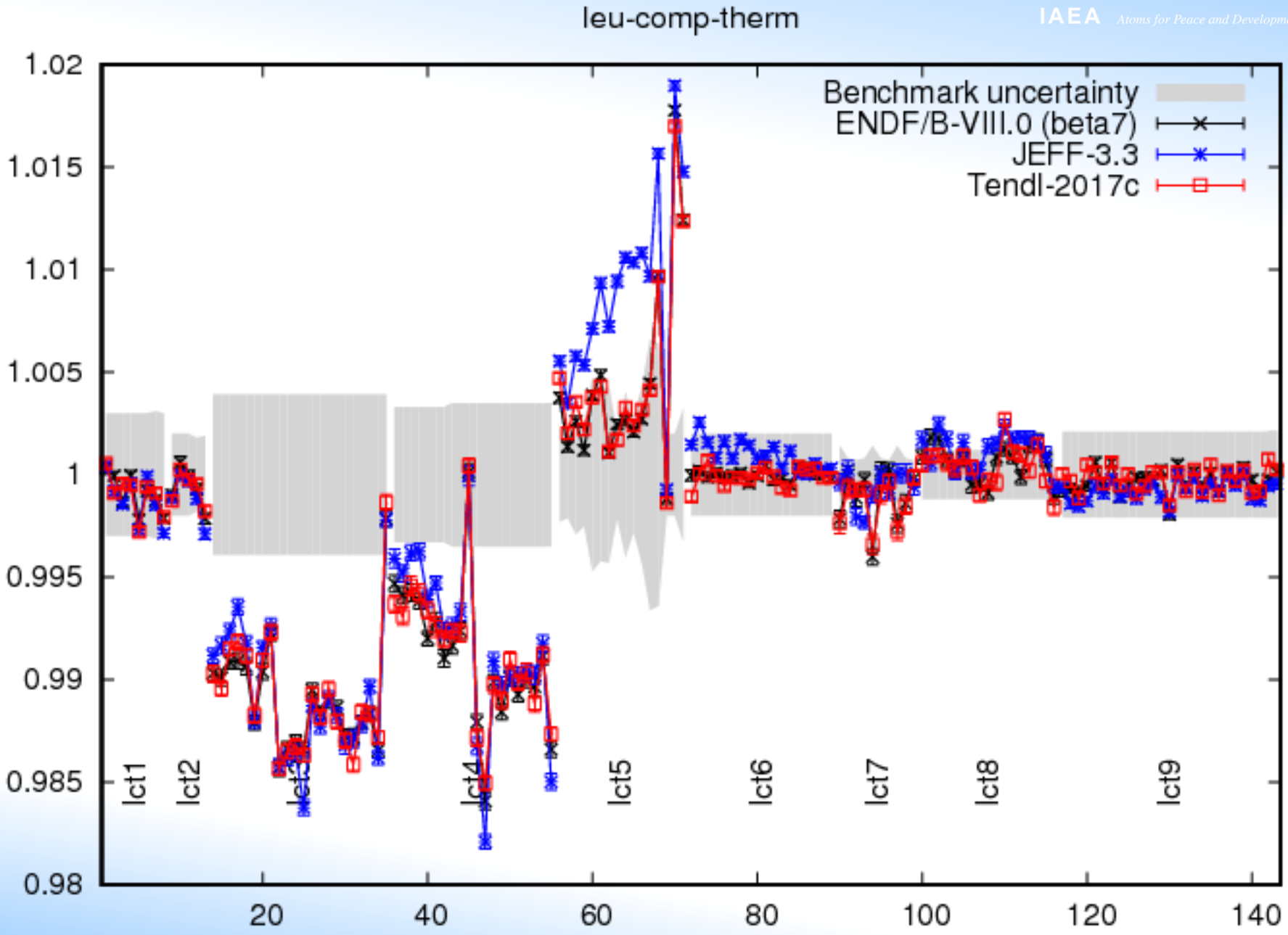


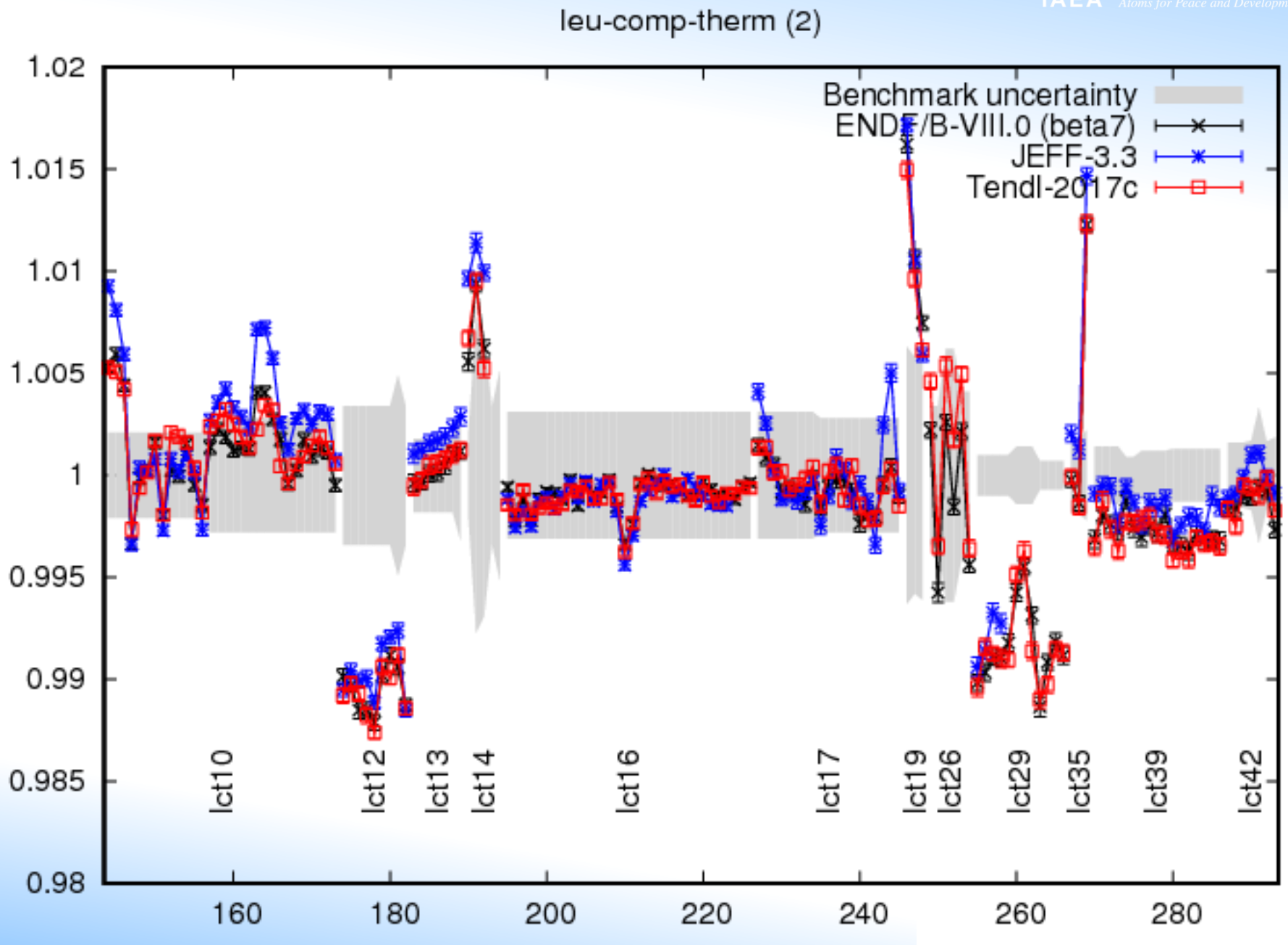
Fusion decay heat: global comparison

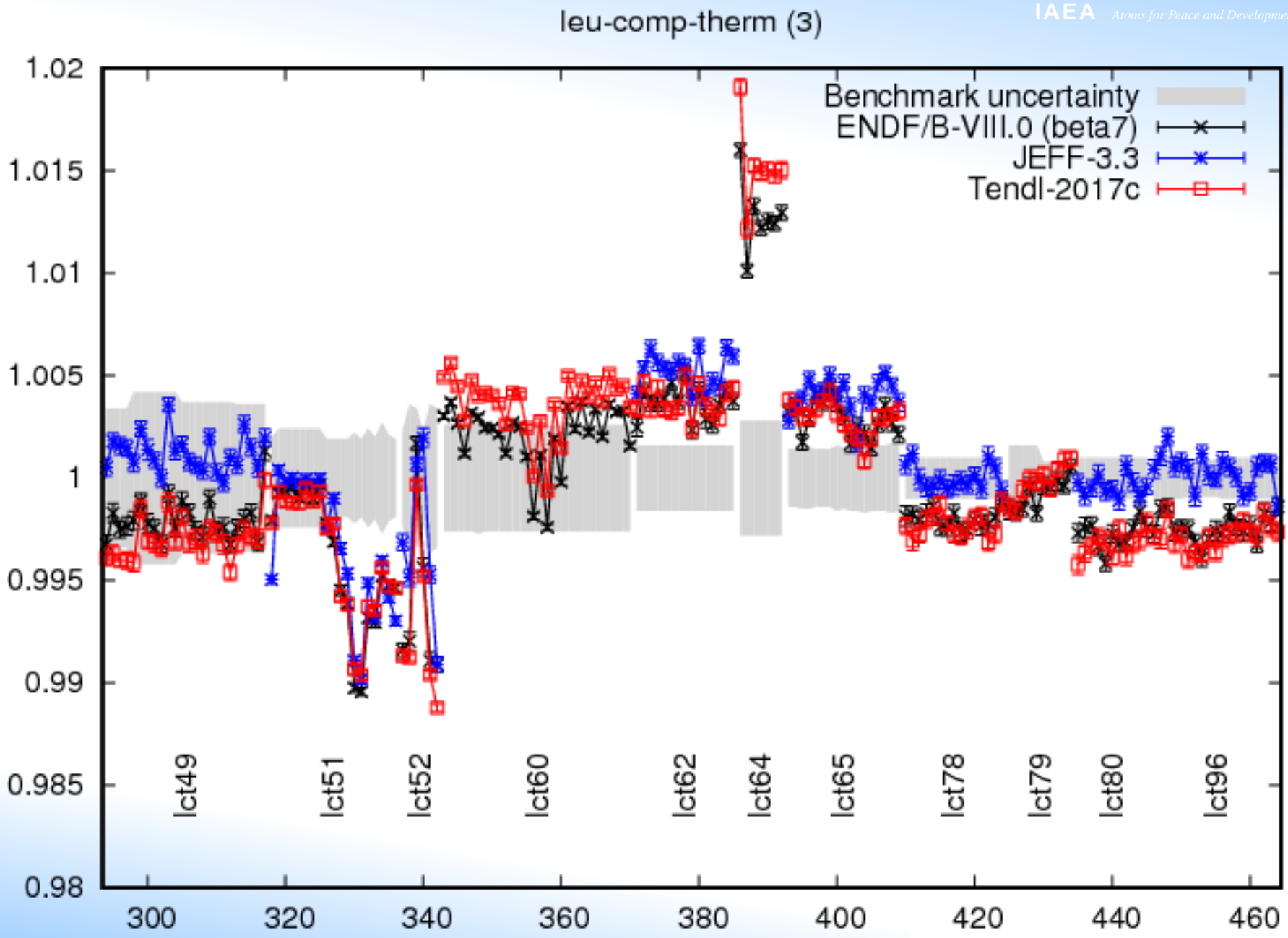


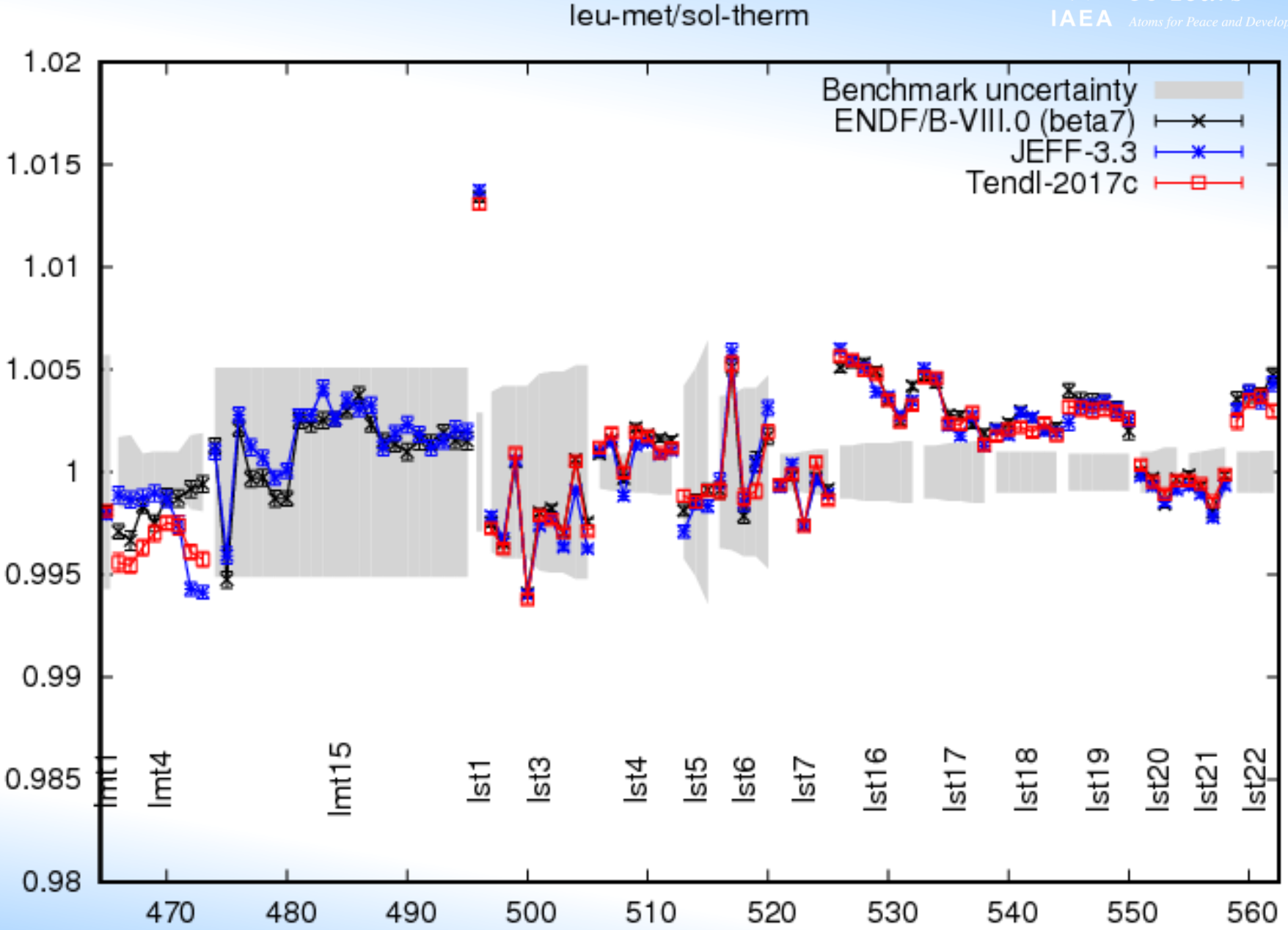
Criticality benchmarking by NRG (Steven van der Marck)

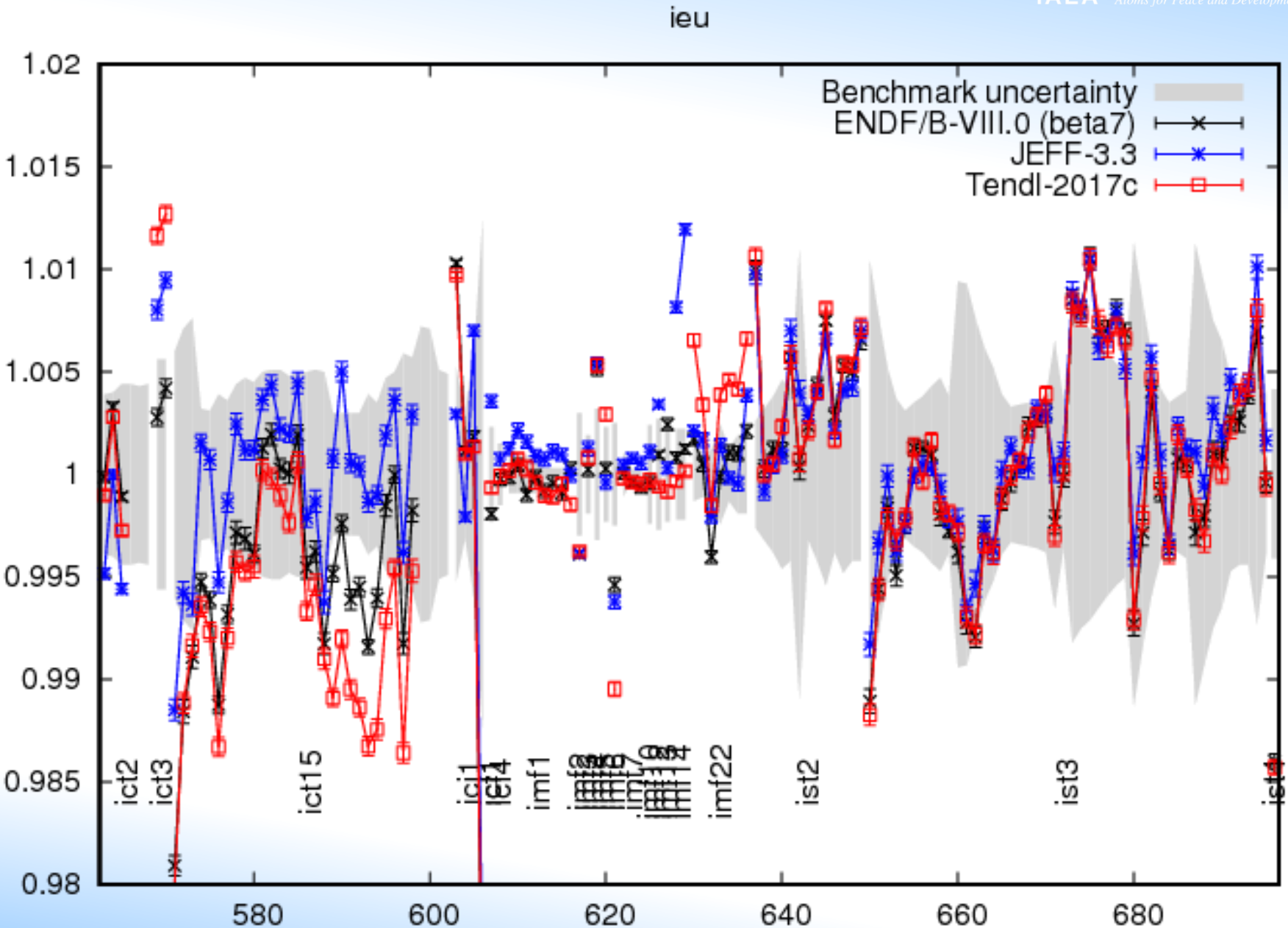
- Remember: TENDL-2017 neutron library adopts ^{1}H – ^{19}F, ^{232}Th, ^{233,235,238}U,^{239}Pu from ENDF/B-VIII
- This will thus test all other non-fissile materials for performance in criticality
- MCNP for ~2550 ICSBEP cases
- Observations: Improvement needed for Ni in fast range, Cu and Pb

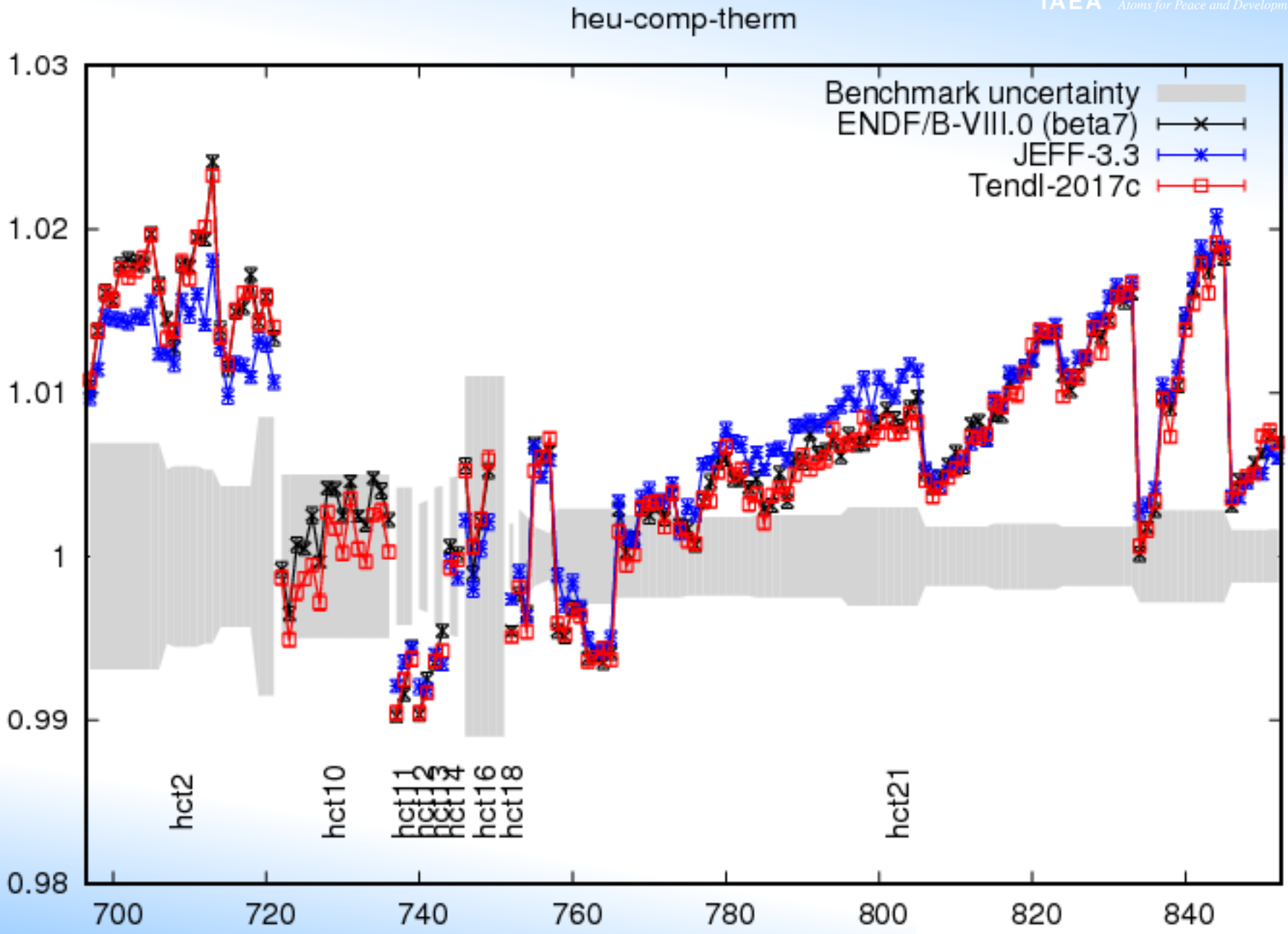


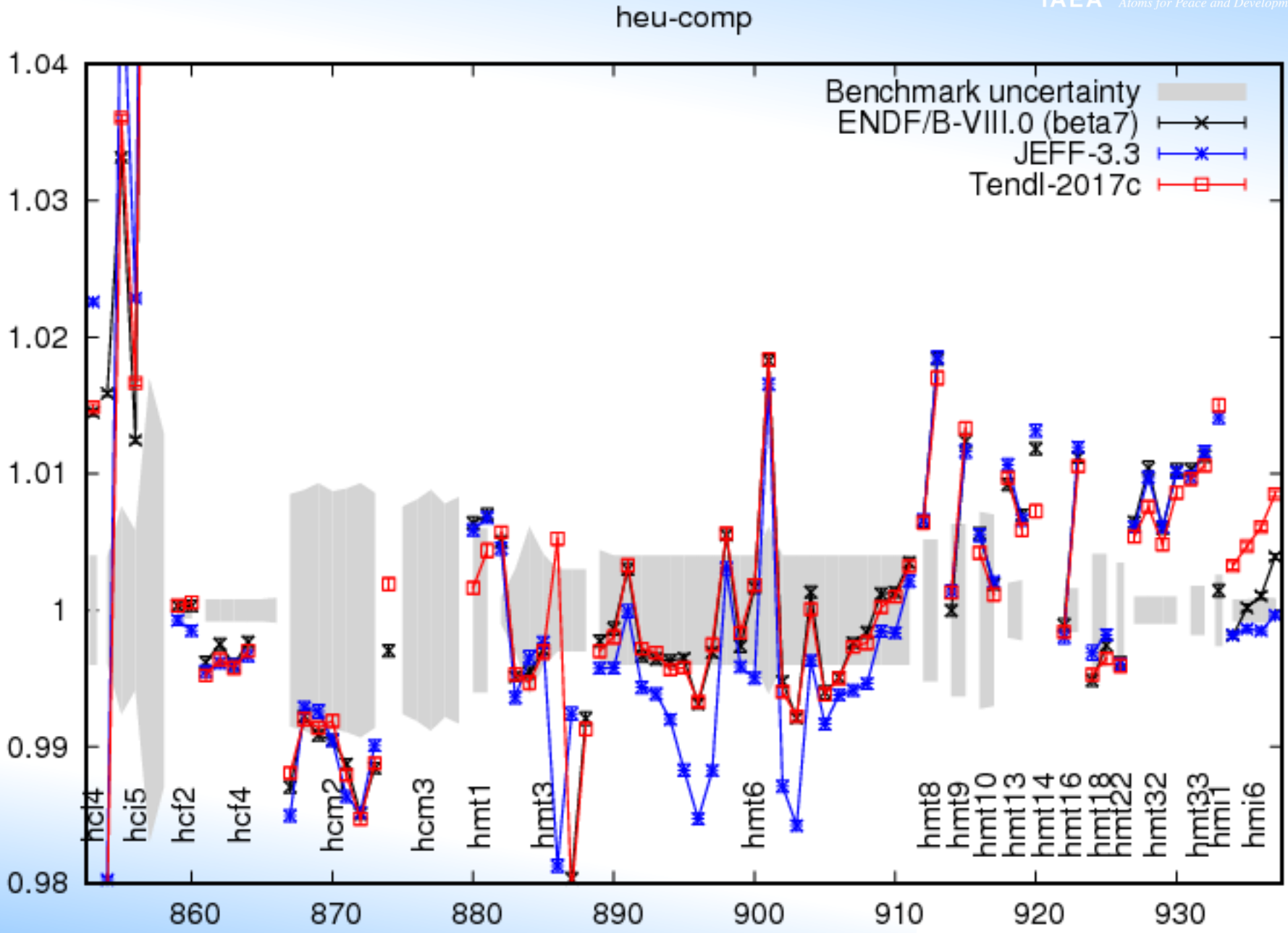







ieu
Benchmark uncertainty
ENDF/B-VIII.0 (beta7)
JEFF-3.3
Tendl-2017c
1.02
1.015
1.01
1.005
1
0.995
0.99
0.985
0.98
580
600
620
640
660
680
ict2
ict3
ict15
ici1
imf1
imf22
ist2
ist3




heu-comp
Benchmark uncertainty
ENDF/B-VIII.0 (beta7)
JEFF-3.3
Tendl-2017c
1.04
1.03
1.02
1.01
1
0.99
0.98
860
870
880
890
900
910
920
930
hci4
hci5
hcf2
hcf4
hcm2
hcm3
hmt1
hmt3
hmt6
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hmt13
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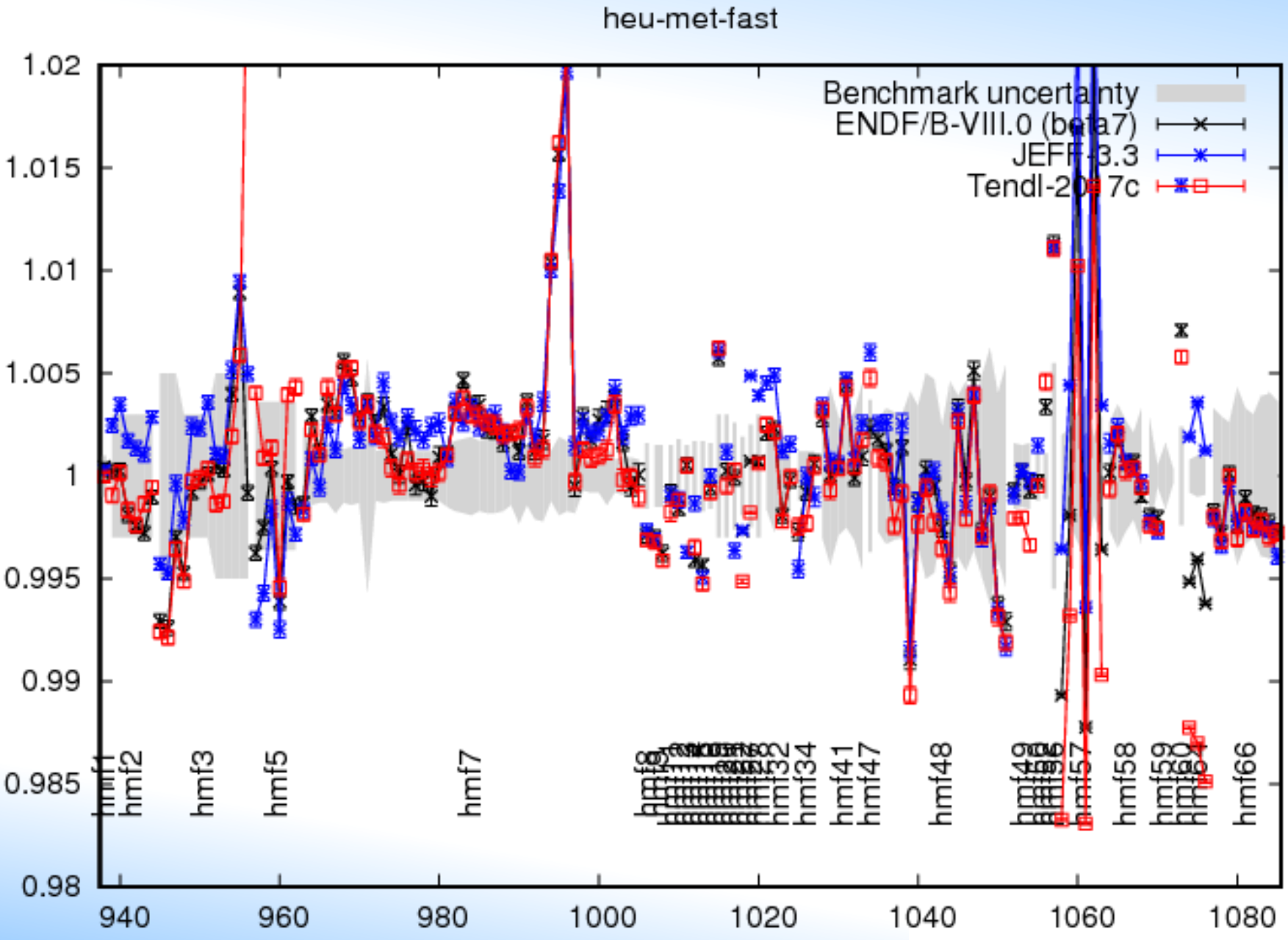
hmt18
hmt22
hmt32
hmt33
hmi1
hmi6


heu-met-fast
Benchmark uncertainty
ENDF/B-VIII.0 (beta7)
JEFF-3.3
Tendl-2017c
1.02
1.015
1.01
1.005
1
0.995
0.99
0.985
0.98
940
960
980
1000
1020
1040
1060
1080
hmf1
hmf2
hmf3
hmf5
hmf7
hmf8
hmf32
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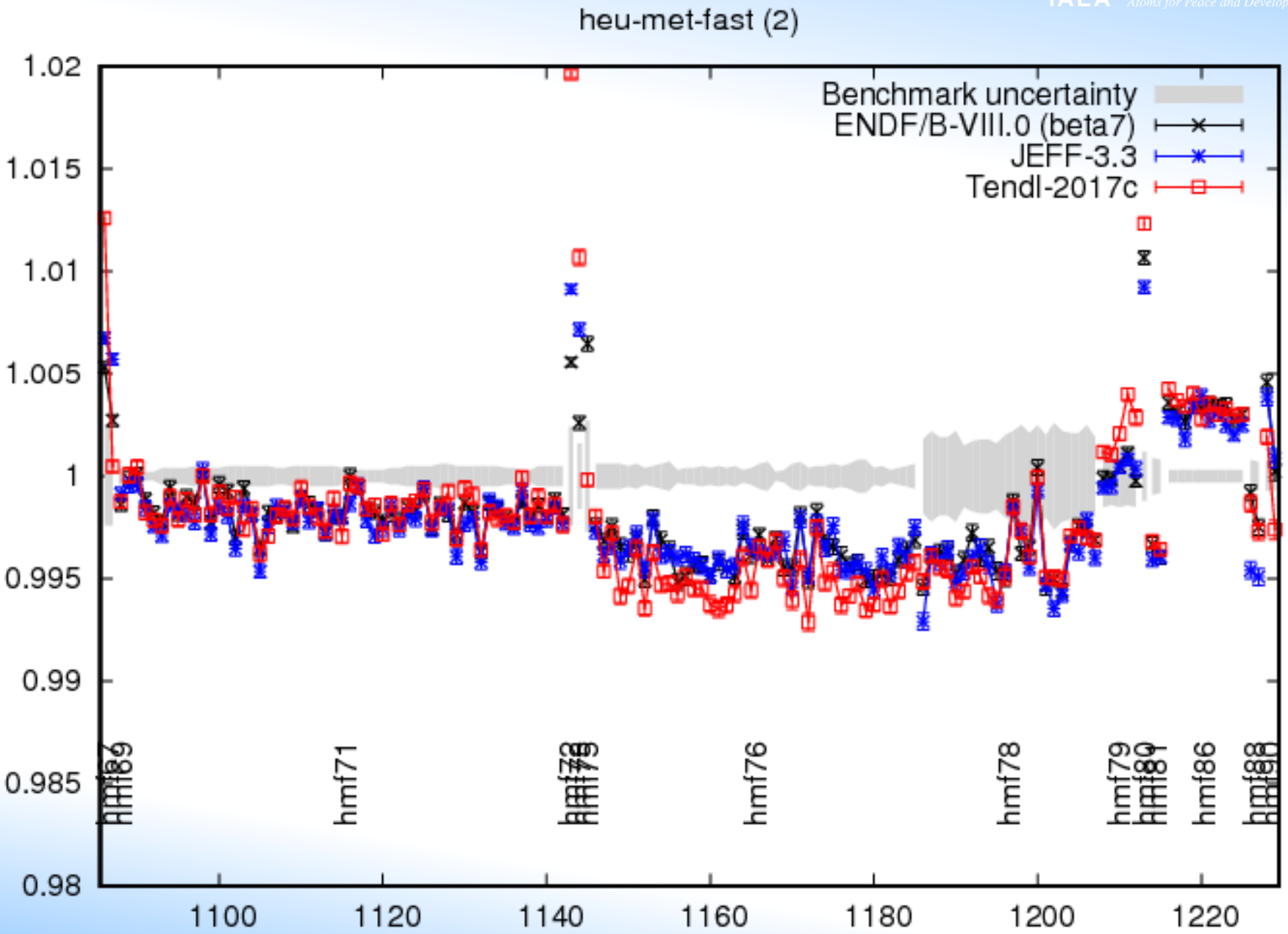
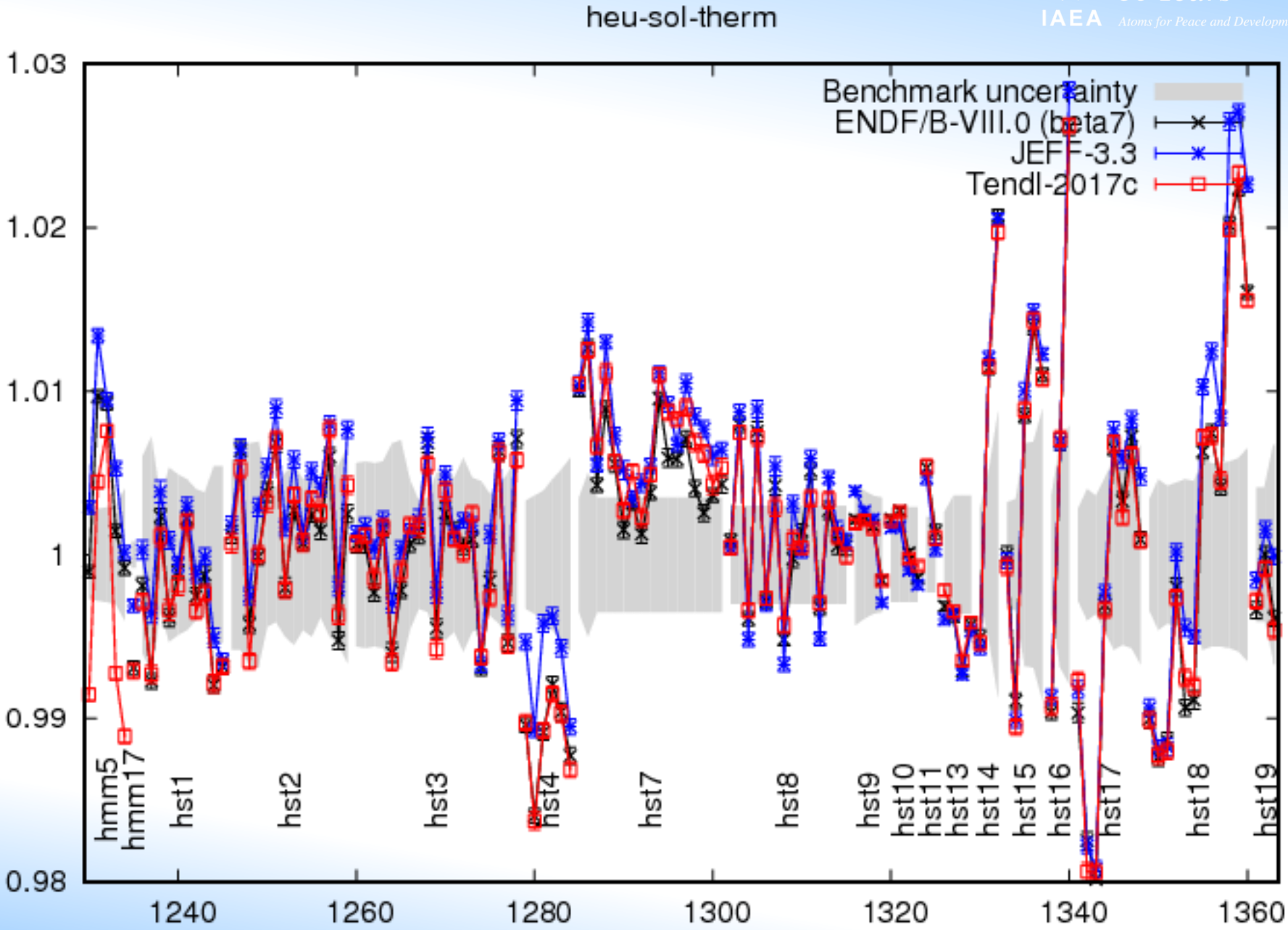
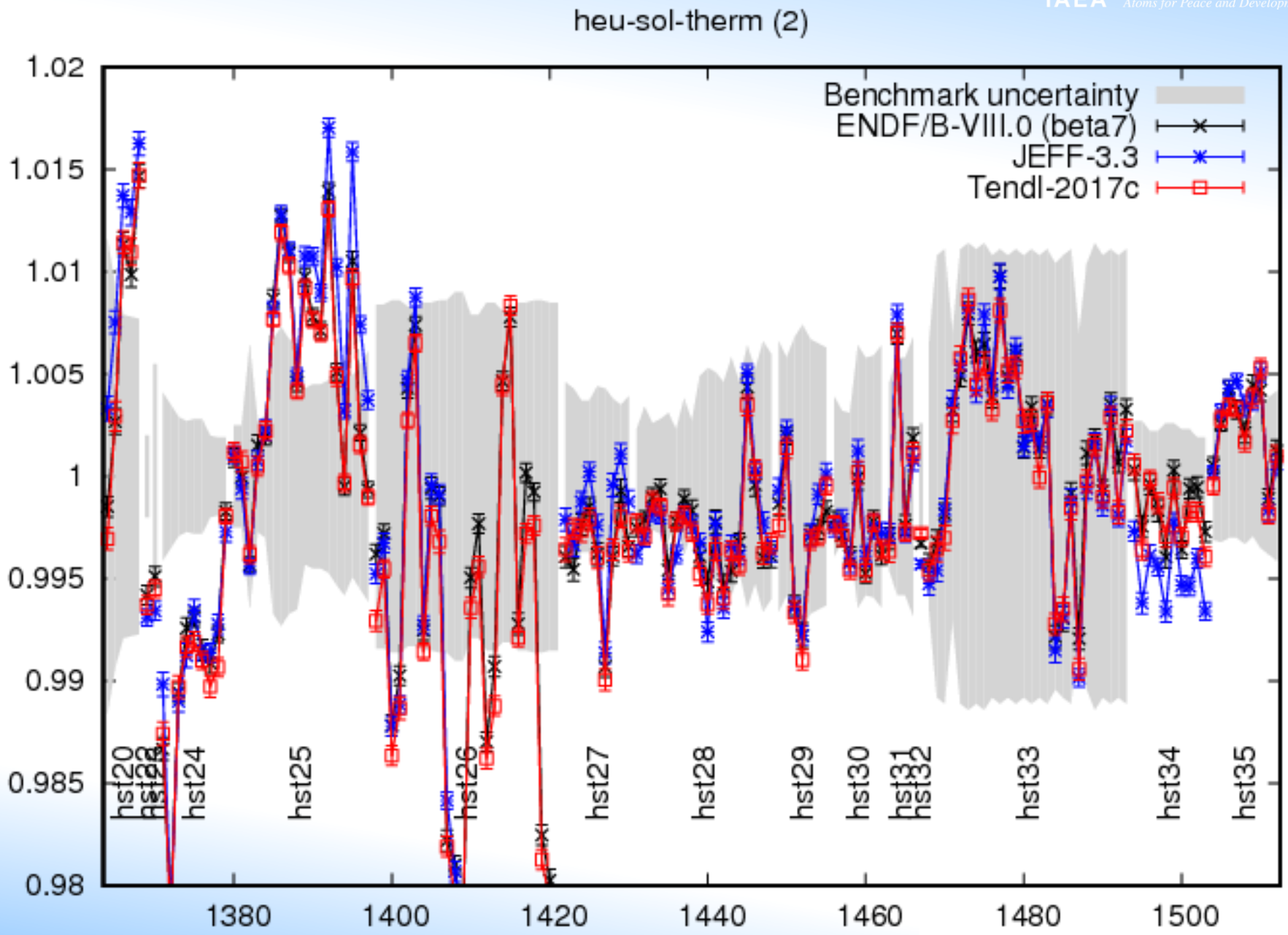
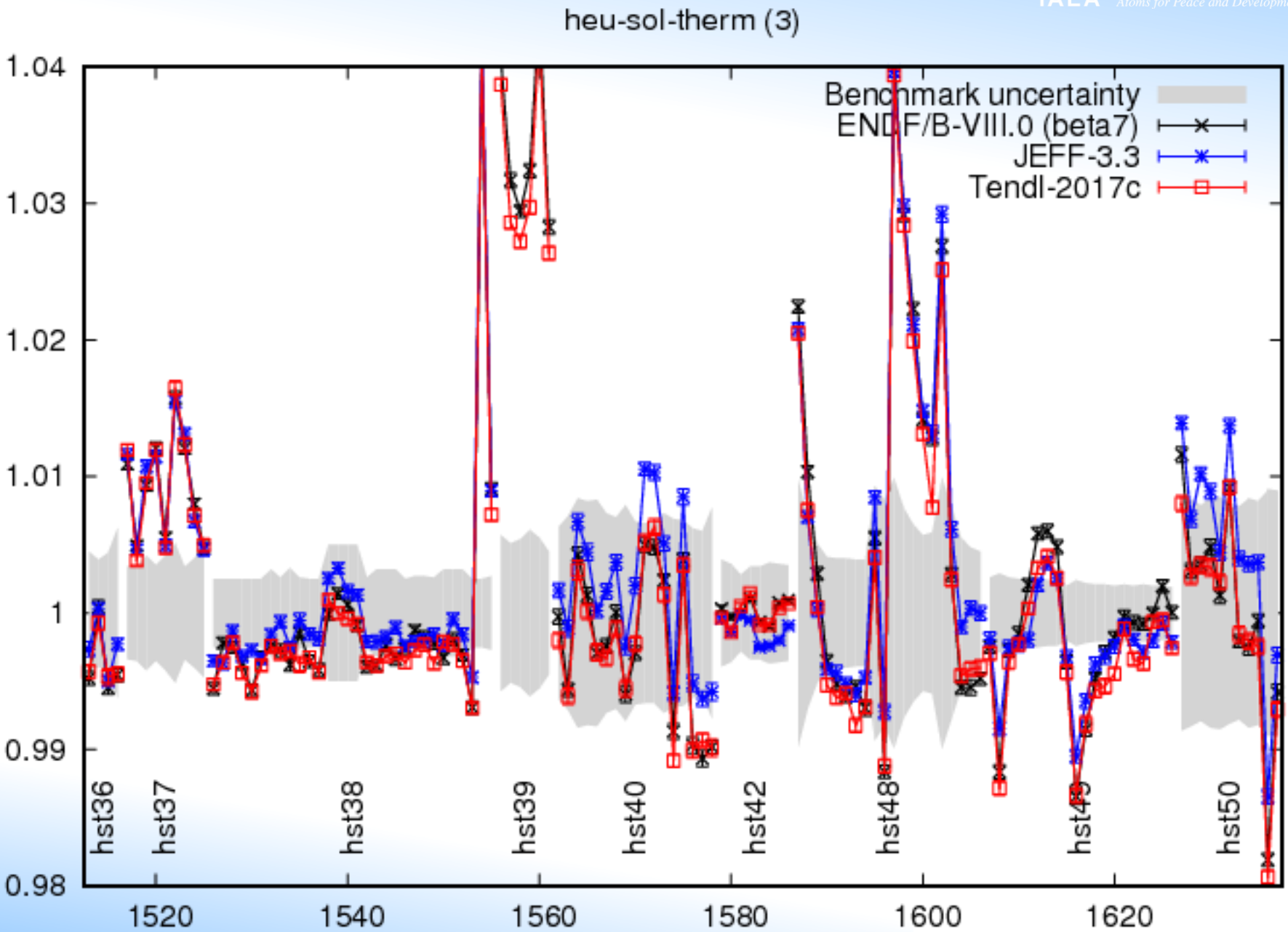
hmf48
hmf49
hmf57
hmf58
hmf59
hmf66


heu-met-fast (2)
Benchmark uncertainty
ENDF/B-VIII.0 (beta7)
JEFF-3.3
Tendl-2017c
1.02
1.015
1.01
1.005
1
0.995
0.99
0.985
0.98
1100
1120
1140
1160
1180
1200
1220
hmf71
hmf76
hmf78
hmf86






heu-sol-therm (3)
Benchmark uncertainty
ENDF/B-VIII.0 (beta7)
JEFF-3.3
Tendl-2017c
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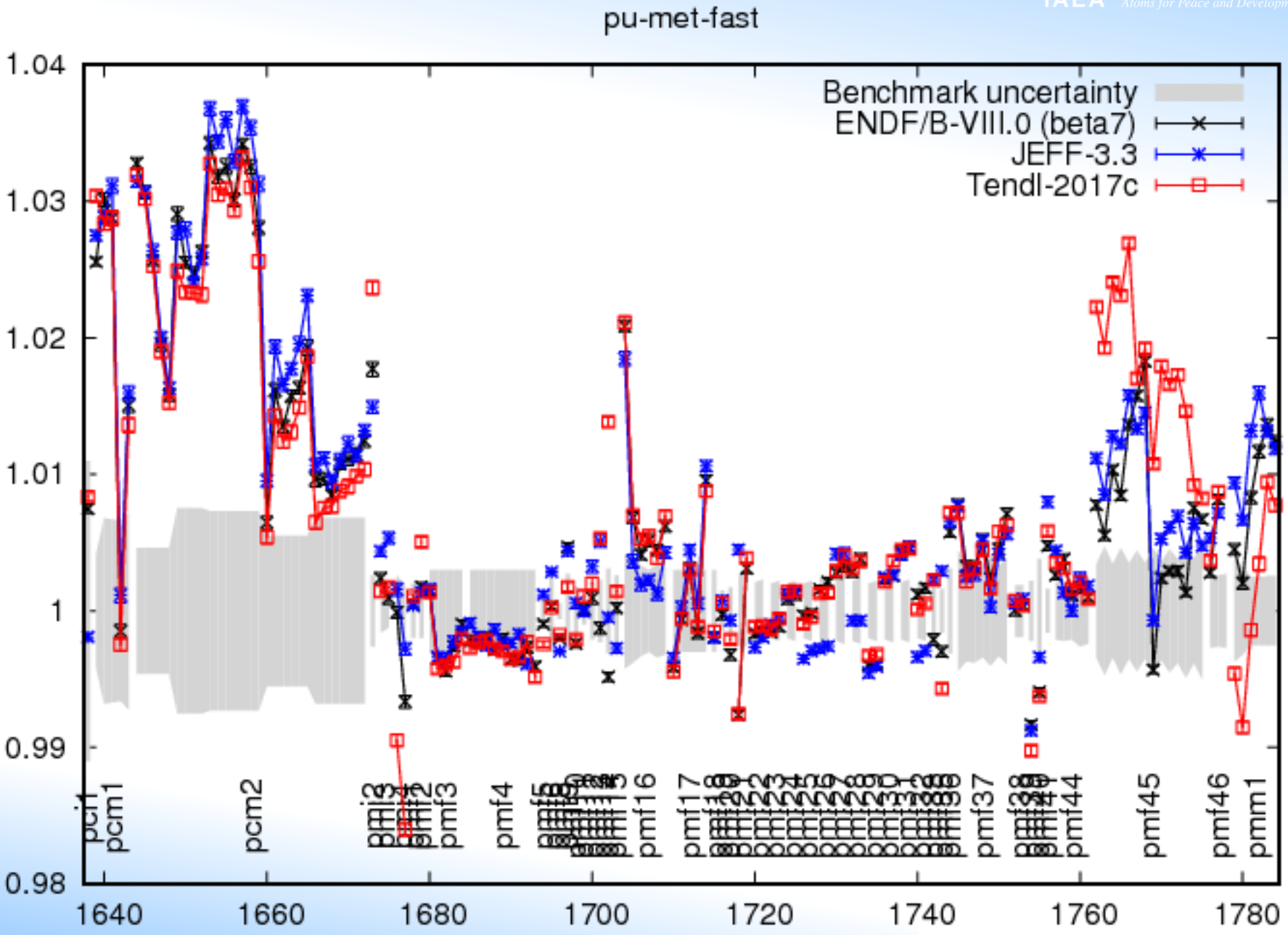
1.03
1.02
1.01
1
0.99
0.98
hst36
hst37
hst38
hst39
hst40
hst42
hst48
hst49
hst50
1520
1540
1560
1580
1600
1620


pu-met-fast
Benchmark uncertainty
ENDF/B-VIII.0 (beta7)
JEFF-3.3
Tendl-2017c
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1.03
1.02
1.01
1
0.99
0.98
1640
1660
1680
1700
1720
1740
1760
1780
pcr
pcm1
pcm2
pmf3
pmf4
pmf16
pmf17
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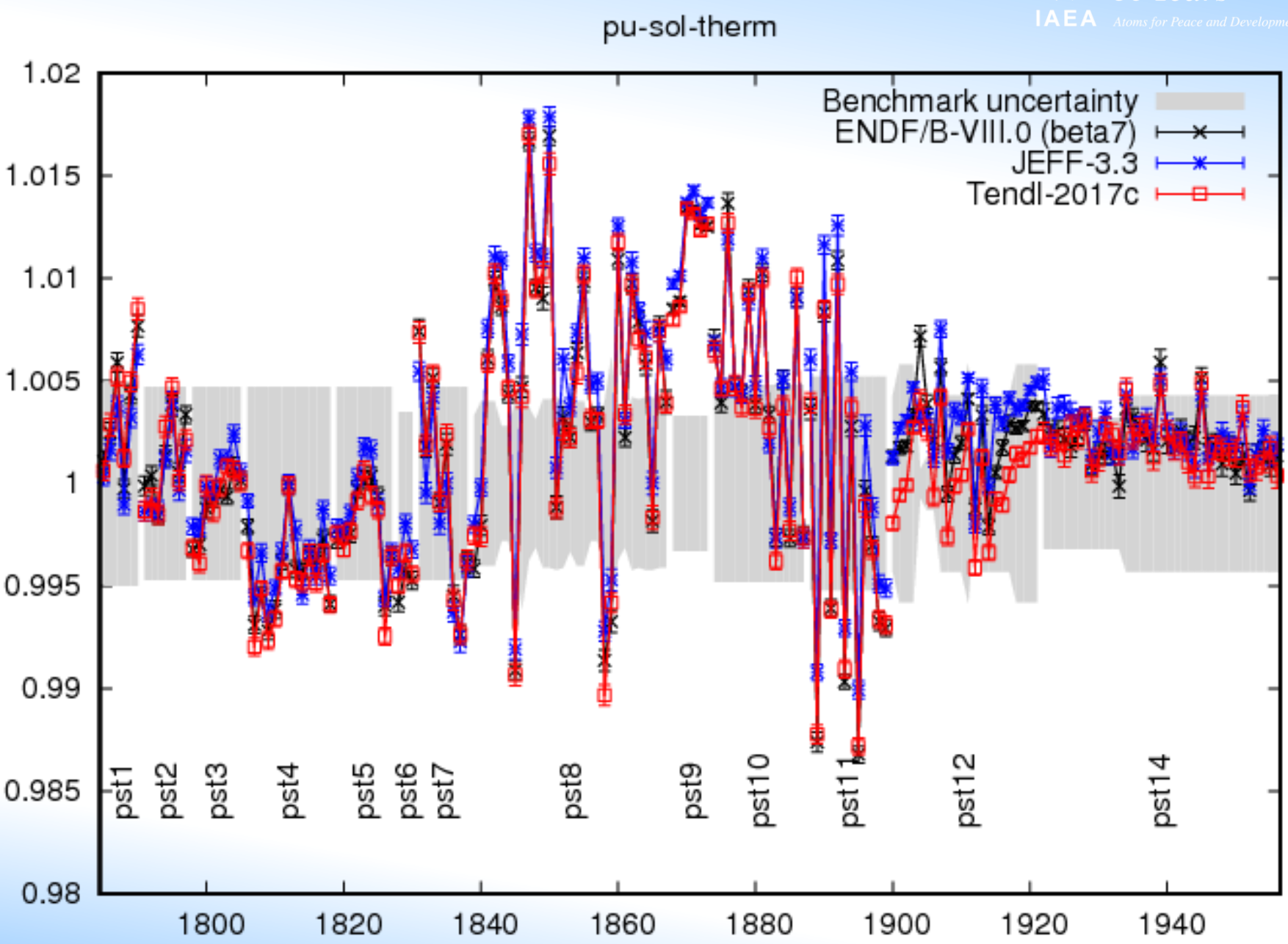
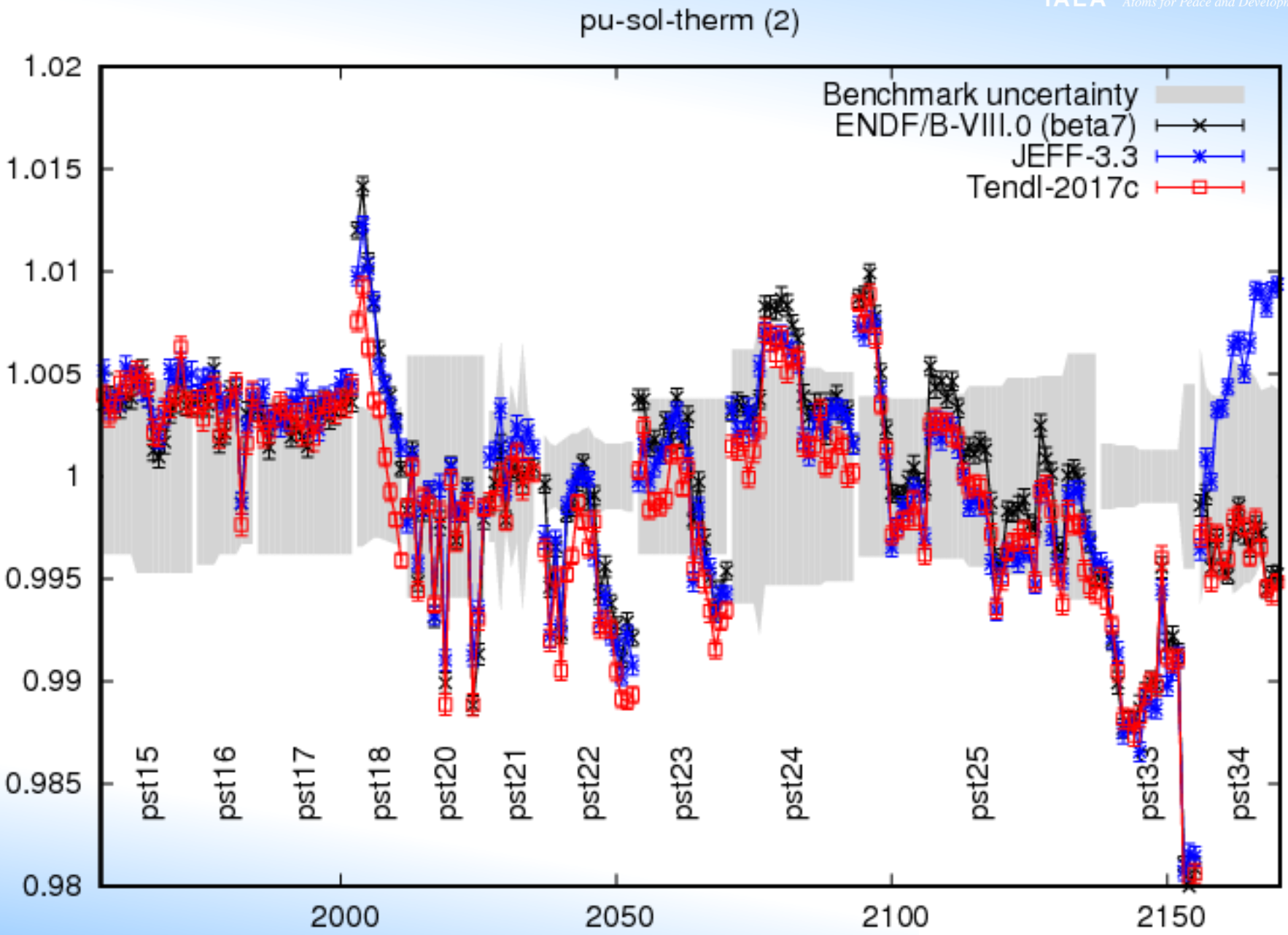
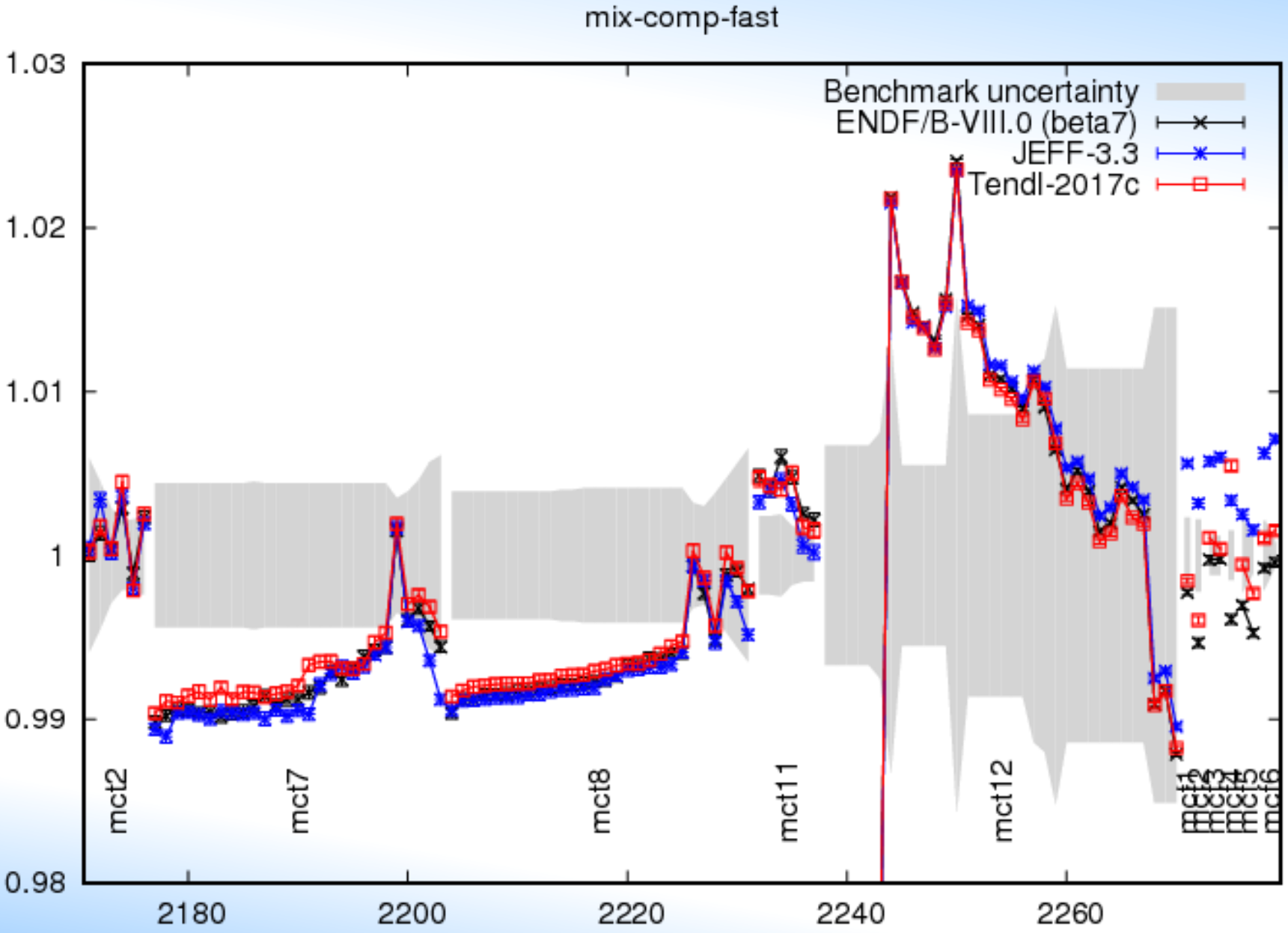
pmf45
pmf46
pmm1






mix-comp-fast
Benchmark uncertainty
ENDF/B-VIII.0 (beta7)
JEFF-3.3
Tendl-2017c
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1.02
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0.98
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2220
2240
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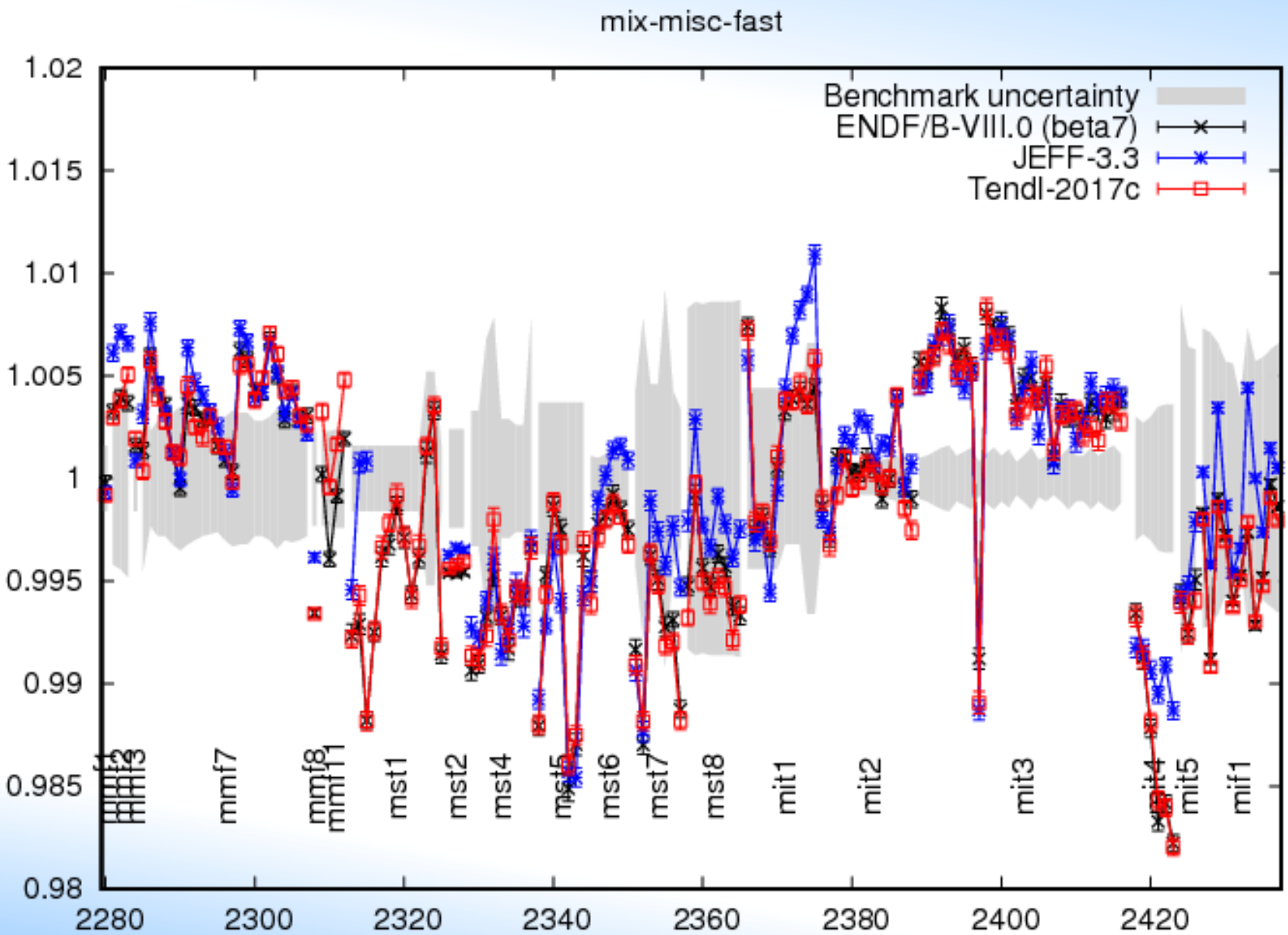
mct2
mct7
mct8
mct11
mct12


mix-misc-fast
Benchmark uncertainty
ENDF/B-VIII.0 (beta7)
JEFF-3.3
Tendl-2017c
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1.01
1.005
1
0.995
0.99
0.985
0.98
2280
2300
2320
2340
2360
2380
2400
2420
mmf7
mmf8
mmf11
mst1
mst2
mst4
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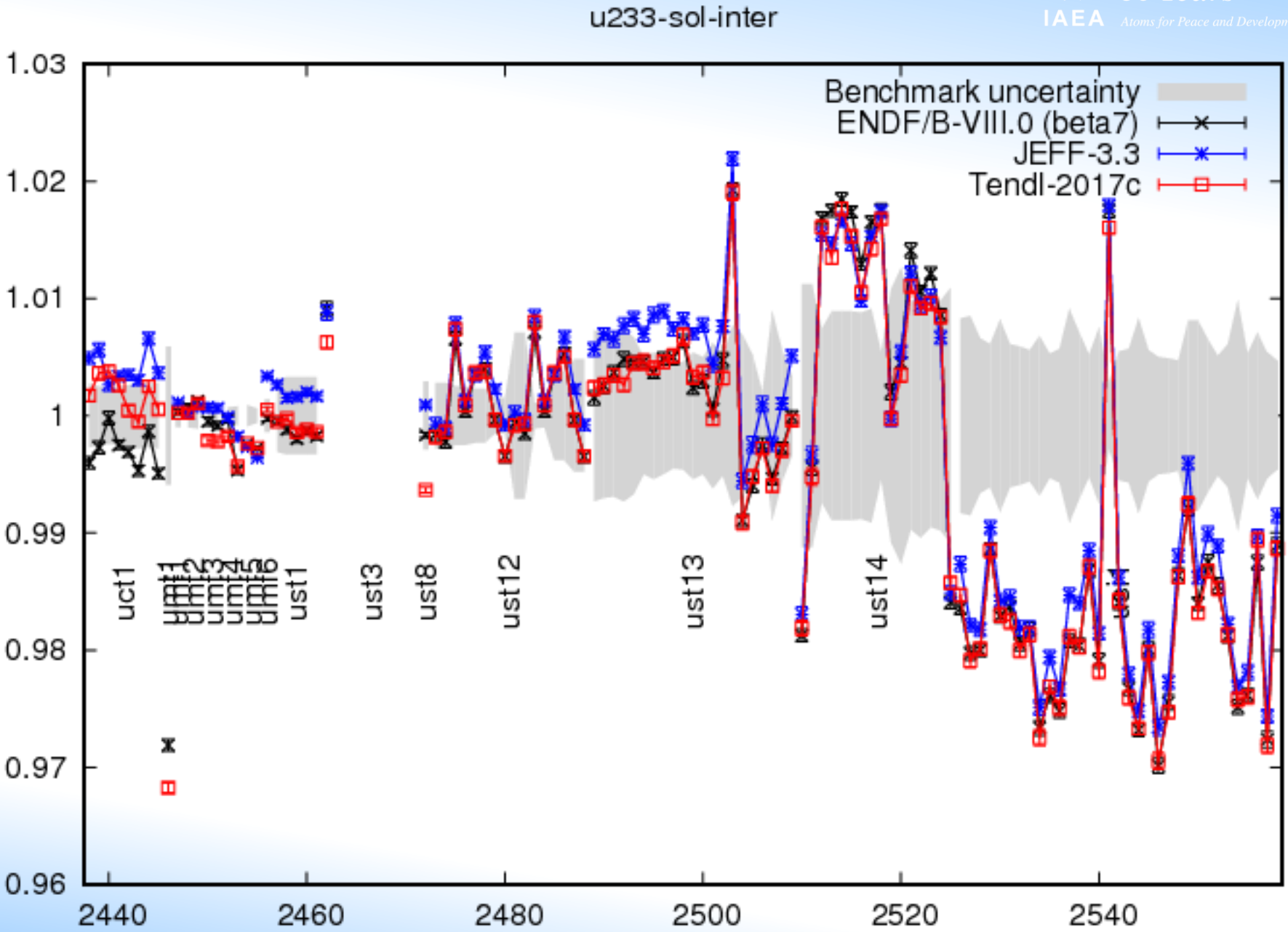
mst8
mit1
mit2
mit3
mit4
mit5
mif1



Next TALYS: 2018-2019

- TALYS-2.0
  - Full Fortran-95
  - TEFAL code included:
    - Complete ENDF formatting
    - Allows TALYS users to create ENDF data libraries
  - TASMAN code included:
    - Uncertainties, covariances, sensitivity profiles, Bayesian Monte Carlo, Total Monte Carlo
    - Allows TALYS users to perform uncertainty analyses, random nuclear data libraries and covariance evaluations
  - Resonance parameters via external database
  - Opens up TENDL-like production to all users

Next TENDL: 2018

- Produced with TALYS-2.0
- Correct remaining deficiencies:
  - (n,p) and (n,alpha) resonances for low-energy positive Q-value reactions
  - Isomeric ratio for thermal (n,gamma) reactions
- Systematic validation scheme:
  - CCFE: Integral activation measurements, decay heat, radiation damage, etc. (Gilbert et al.)
  - NRG: van der Marck criticality (ICSBEP) and shielding (SINBAD) benchmarking suite
  - PSI: EXFOR, thermal, MACS and resonance validation, library optimization with the “Petten method”, FPY (Rochman)
  - IAEA: “EASY-database”, processing, all non-criticality validation (Sublet), criticality (Trkov), differential (Koning) validation
  - Try to minimize the turnaround time. Ideally: integral testing during evaluation
- TENDL paper in Nuclear Data Sheets, January 2019.

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Atoms for Peace and Development

Thank you!