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*60 Years*

*Atoms for Peace and Development*

# Status of TENDL

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**WPEC Meeting, May 18-19 2017, NEA, Paris**

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# TALYS-based evaluated nuclear data library

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## TENDL-2015

By A.J. Koning<sup>1</sup>, [D. Rochman](#)<sup>2</sup>, J. Kopecky<sup>3</sup>, J.Ch. Sublet<sup>4</sup>, M. Fleming<sup>4</sup>, E. Bauge<sup>7</sup>, S. Hilaire<sup>7</sup>, P. Romain<sup>7</sup>, B. Morillon<sup>7</sup>, H. Duarte<sup>7</sup>, S.C van der Marck<sup>6</sup>, [S. Pomp](#)<sup>5</sup>, [H. Sjostrand](#)<sup>5</sup>, [R. Forrest](#)<sup>1</sup>, H. Henriksson<sup>8</sup>, O. Cabellos<sup>9</sup>, S. Goriely<sup>10</sup>, J. Leppanen<sup>11</sup>, H. Leeb<sup>12</sup>, A. Plompen<sup>13</sup>, and R. Mills<sup>14</sup>

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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<sup>SM</sup>

### Random files

[1. Random fission yields](#)

[2. Random thermal scattering](#)

### Sub-library files

[1. neutron](#)

[Proton 2.](#)

[Deuteron 3.](#)

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### TENDL-2015: (release date: 18 January 2016)

Last update: 2 May 2016

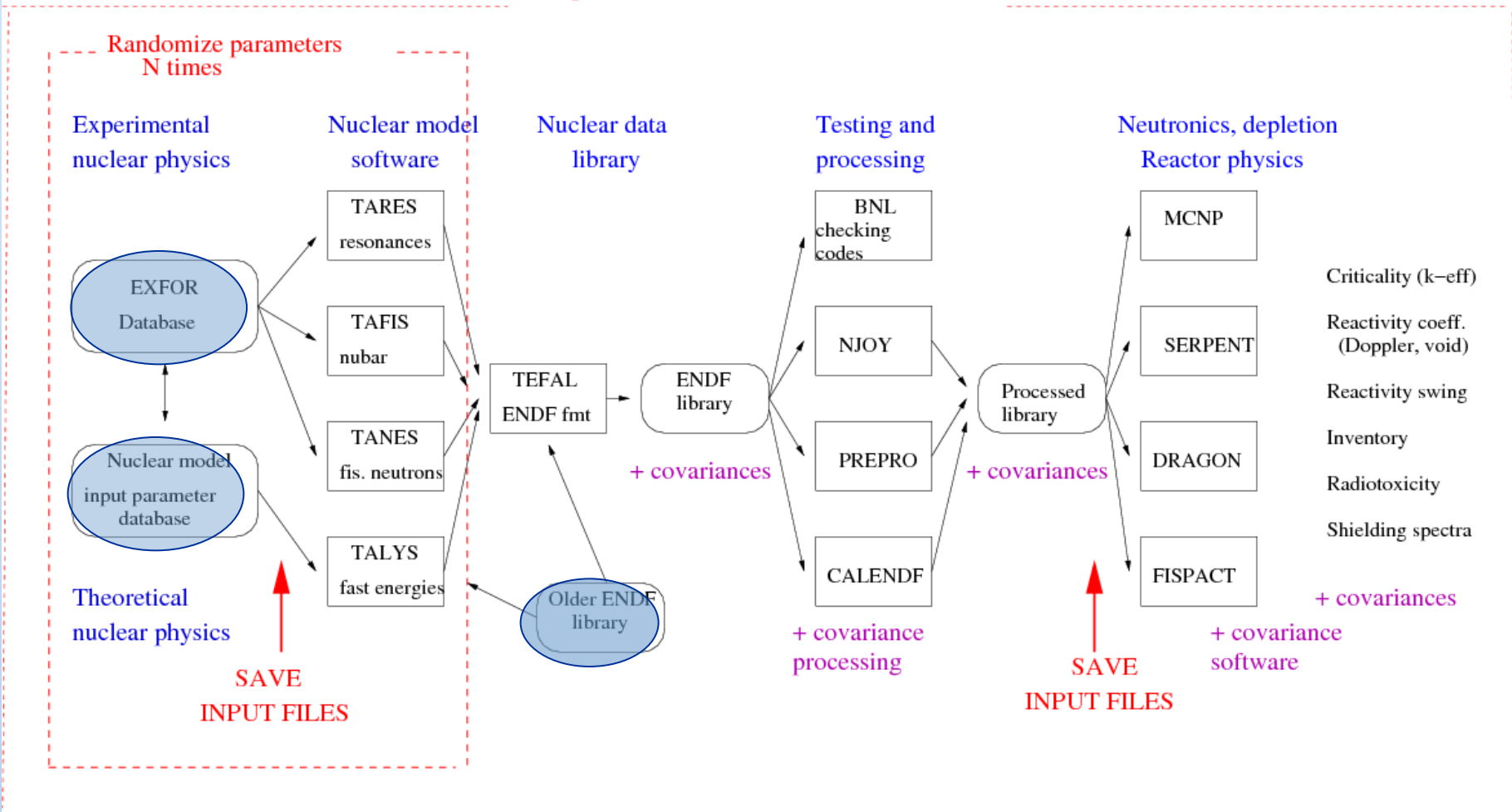
TENDL is a nuclear data library which provides the output of the TALYS nuclear model code system for direct use in both basic physics and applications. The 8<sup>th</sup> version is TENDL-2015, which is based on both default and adjusted TALYS calculations and data from other sources (previous releases can be found here: [2008](#), [2009](#), [2010](#), [2011](#), [2012](#), [2013](#), and [2014](#)).



60 Years

# TENDL nuclear data library

Loop over nuclides : TENDL



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

# TENDL nuclear data library: overview 1

- TENDL is in fact a by-product of a series of codes,
- This is one fundamental difference with other libraries (no manual work),
- It allows to perform „TMC“ for Total Monte Carlo (uncertainty propagation)
- Goal: improve simulations (C/E) for any application,

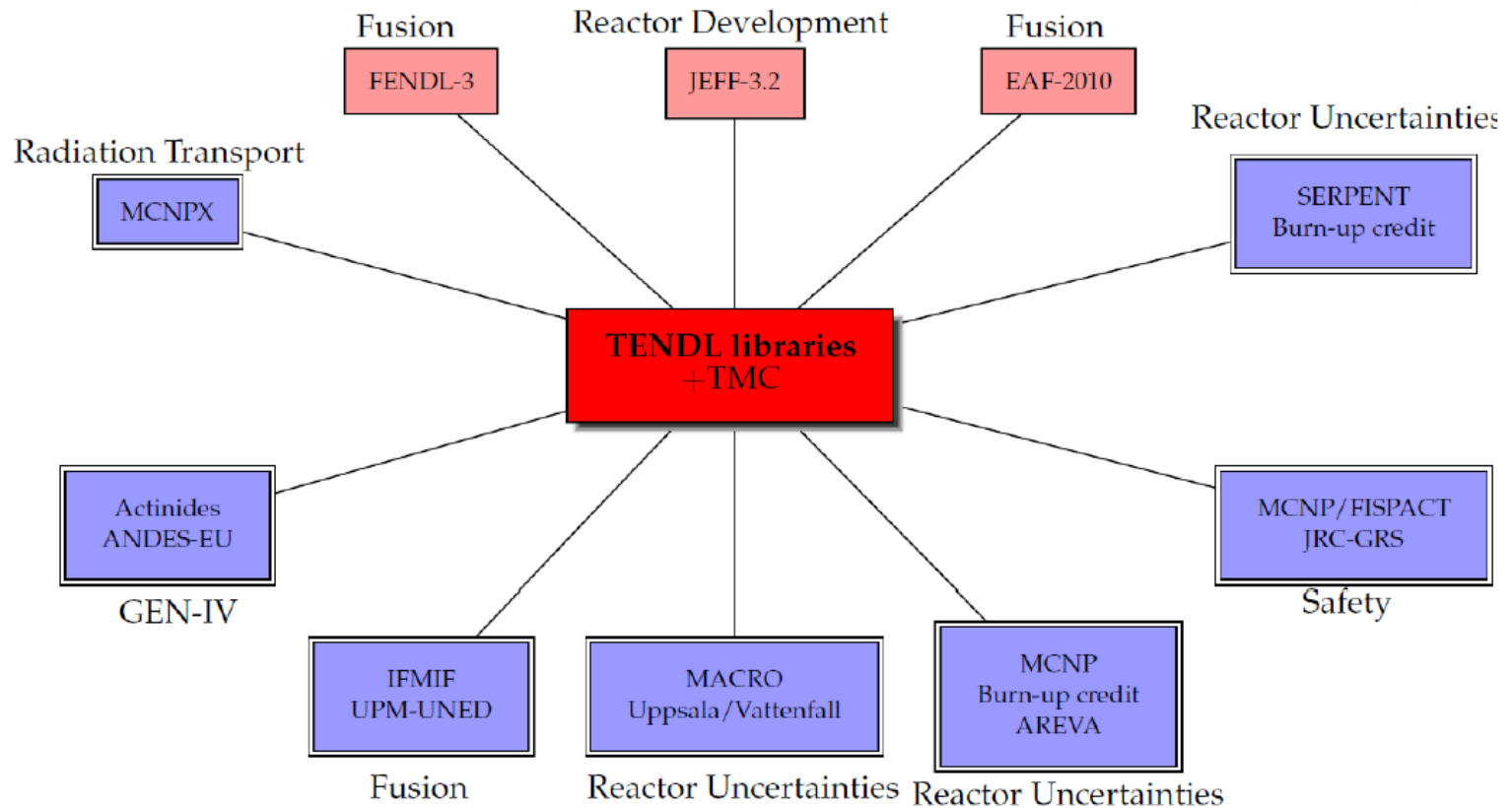
$$\chi^2 = 0 \text{ or } 1$$

- Methods: reproductibility & completeness, development of a portable system
- Background: theoretical calculations (TALYS) with experimental inputs, with original resonance evaluations,
- Impact:
  - TENDL-2008 to 2015 (2800 isotopes),
  - Neutrons, protons, deuterons, tritons, He3, alpha and gamma induced,
  - all isotopes, all cross sections with covariances, 0-200 MeV,
  - more than 300 isotopes in the NEA JEFF-3.3,
  - more than 450 publications using TENDL

$$\chi^2 = \frac{1}{n} \sum_{i=1}^n \left( \frac{C_i - E_i}{\Delta E_i} \right)^2$$

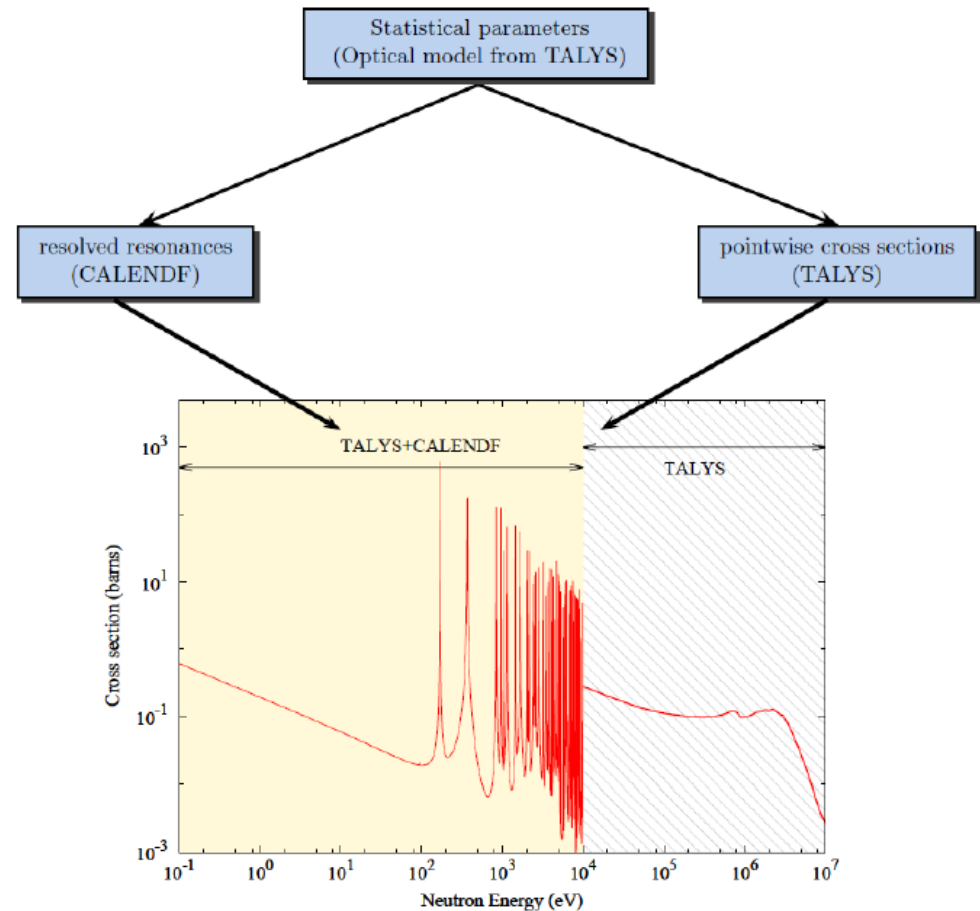
# TENDL nuclear data library: overview 2

- Fully implemented in FISPACT-II, part of GEANT, commercial codes...,
- Used in fission, fusion applications, medical isotope productions



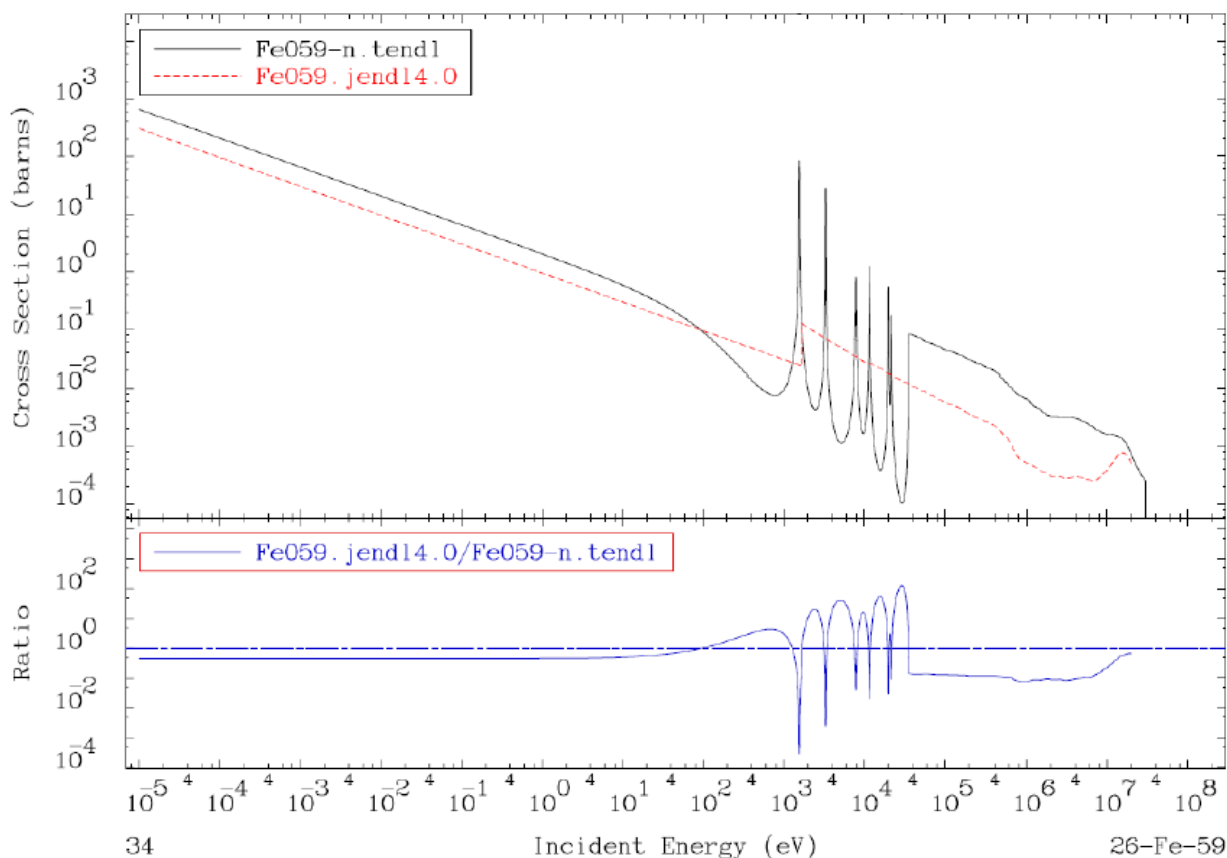
- In TENDL, all 2800 isotopes have unique resonances
  - Only about **10 %** of the resonances are measured,
  - The rest comes from the HFR method (statistical resonances),

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



HFR: When no measured resonances: consistency from 0 to 200 MeV

- A single OMP,
- A single  $\gamma$ -strength function,
- A single level density model,
- All using SAMMY retro-active method,
- All with MF-33 from 0 to 200 MeV,



# Thermal and fast range: Fission products etc.

- Consistently use the latest resonance parameter information (Rochman's TARES code + Atlas)
- Fast range: Adjustment of average radiative width and GDR gamma parameters in TALYS
- Consistently apply to entire nuclide chart
- Don't stop till other libraries are outperformed

# Thermal capture cross sections

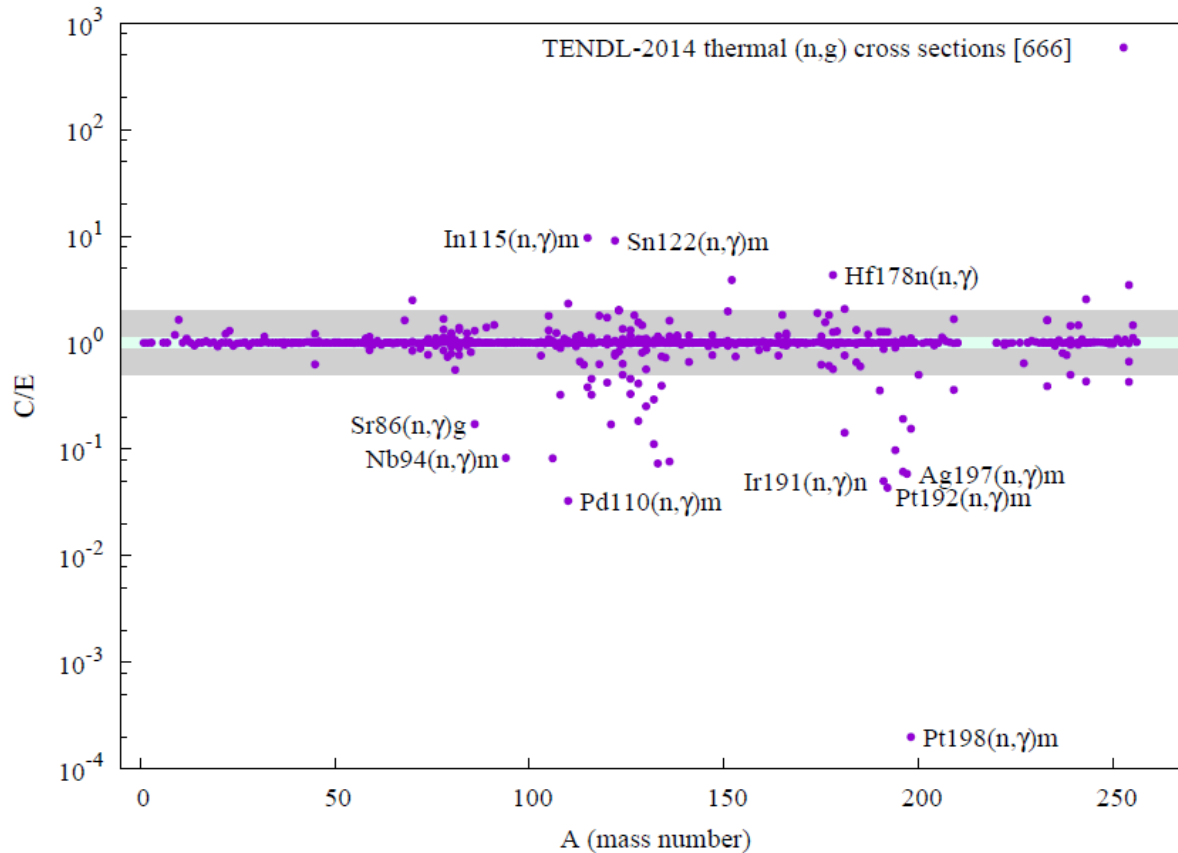


Figure 4: Distribution of TENDL-2014 (n,γ) thermal cross section C/E values against number of nucleons  $A$ . The bands represent regions of  $\frac{1}{2} < C/E < 2$  and  $|C-E|/E < 10\%$ .

Fleming et al, Probing experimental & systematic trends of the neutron-induced TENDL-2014 nuclear data library, UKAEA-R(15)30

# MACS comparison with other libraries

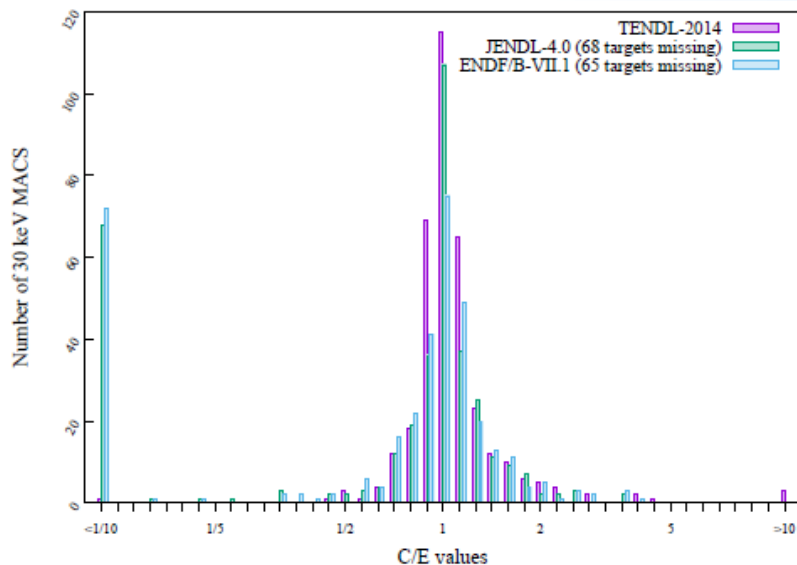
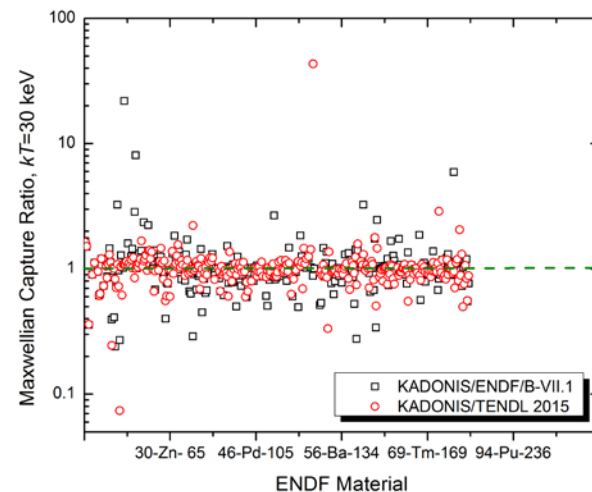


Figure 8: Comparison of C/E distributions overall all 357 KADoNiS 30 keV cross sections with TENDL-2014, JENDL-4.0 and ENDF/B-VII.1 values calculated with maxwav. C/E values for missing nuclides in JENDL-4.0 and ENDF/B-VII.1 are tallied in the  $<1/10$  bin.

Boris Pritychenko: mini-CSEWG 2017

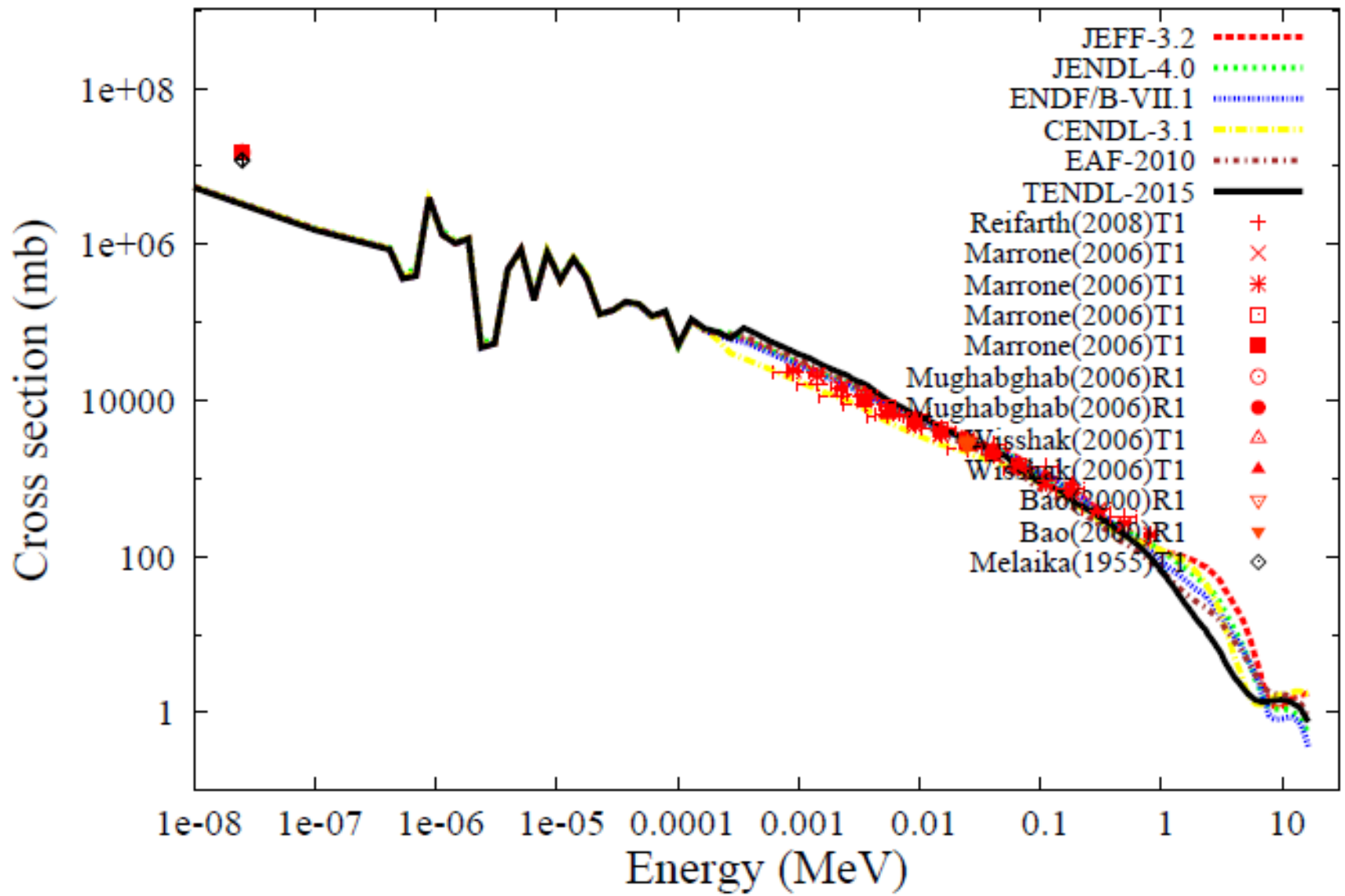
“ENDF/B-VII.1 is definitely better for Sr, Te, Sm and Hg. No difference for major actinides. In other cases TENDL 2015 is often better.”

[Sublet and Fleming, Maxwellian-averaged neutron-induced cross sections for  \$kT=1\$  keV to 100 keV, KADoNiS, TENDL-2014, ENDF/B-VII.1 and JENDL-4.0u nuclear data libraries UKAEA-R\(15\)29](#)





# $^{151}\text{Sm}(n,g)^{152}\text{Sm}$



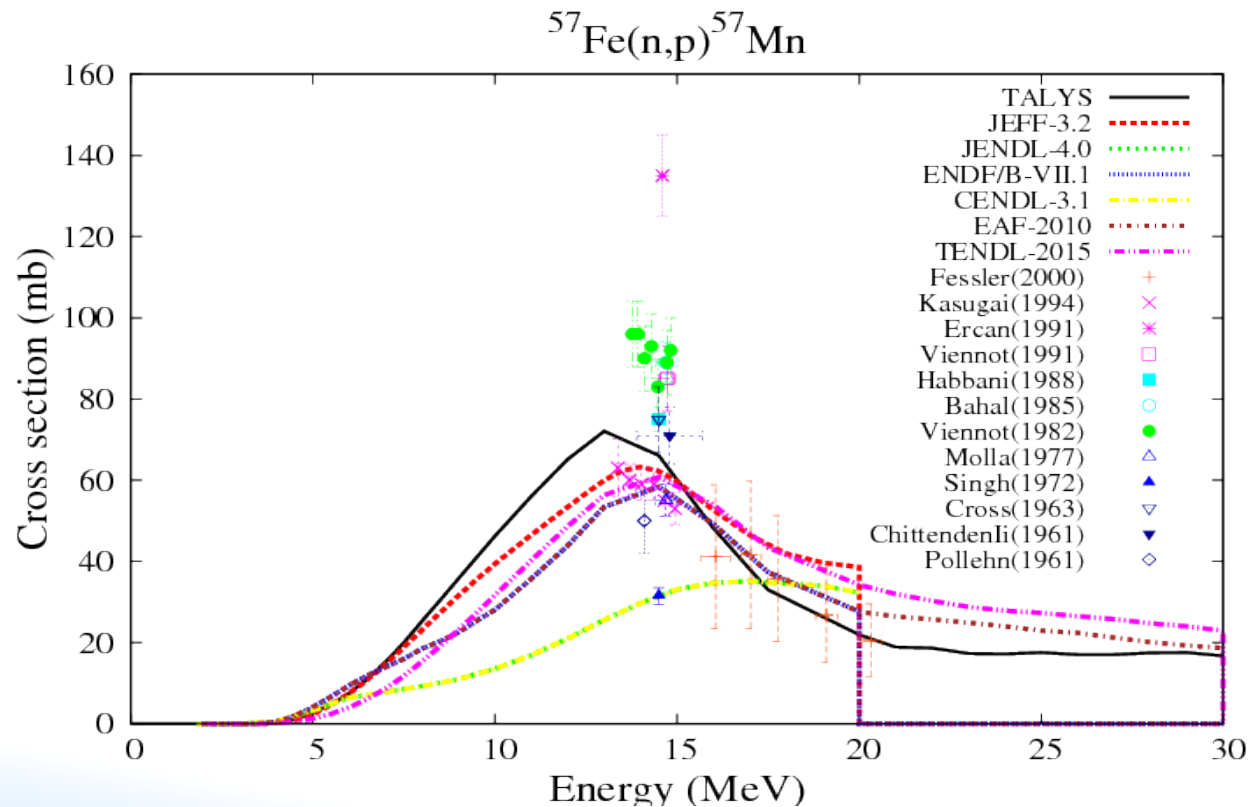
# Improvements of activation cross sections for fusion

- Dzysiuk and Koning F4E-GRT-168.02 Task 5.3 Progress Report, May 2016. Improve 42 important activation cross sections for TENDL.

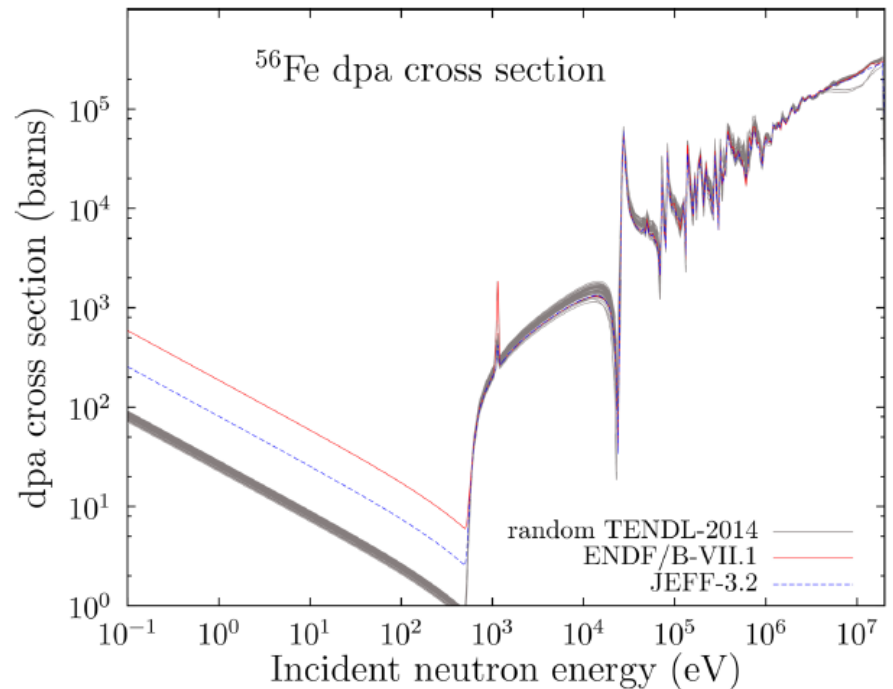
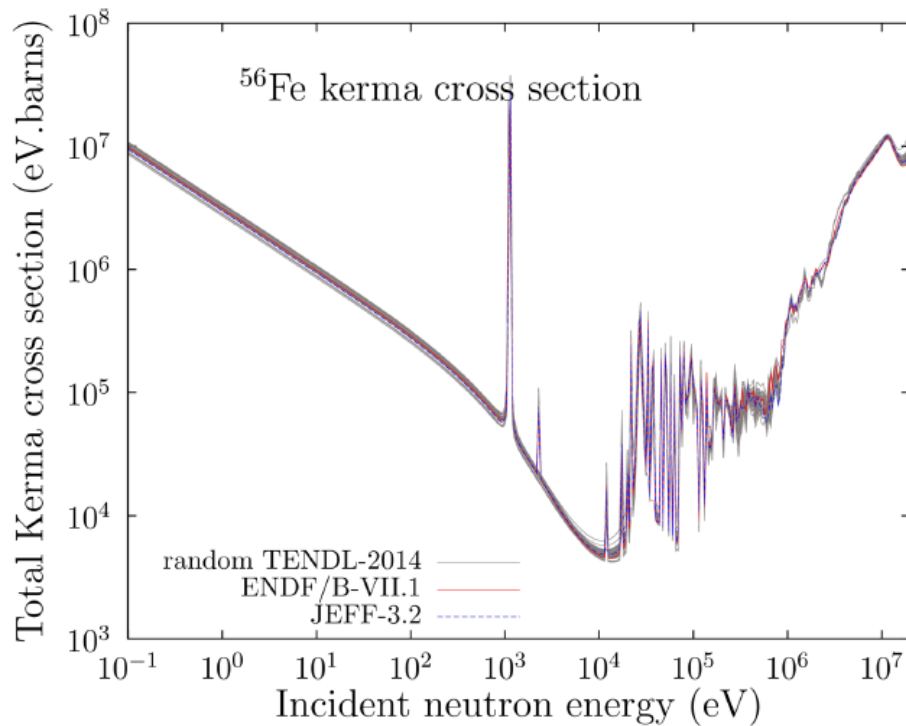
|    | Reaction                                | Spectrum     | $\sigma(b)$ | C/E (EAF) | C/E (TENDL 2012) | C/E (TENDL 2014) | C/E (TENDL 2017**) |
|----|---|--------------|-------------|-----------|------------------|------------------|--------------------|
| 1  | $^{16}\text{O}(n,p)\text{N}^{16}$       | fns_5min     | 3.23E-02    | 1.016     | 1.040            | 1.060            | 1.009*             |
| 2  | $^{23}\text{Na}(n,p)\text{Ne}^{23}$     | fns_5min     | 3.03E-02    | 1.190     | 1.189            | 1.190            | 1.163              |
| 3  | $^{24}\text{Mg}(n,p)\text{Na}^{24}$     | fns_5min     | 1.57E-01    | 1.165     | 1.000            | –                | 0.984*             |
|    |   | cf252_flux_1 | 1.94E-03    | 1.347     | 1.238            | –                | 1.107*             |
|    |   | cf252_flux_1 | 2.01E-03    | 1.300     | 1.283            | –                | 1.068*             |
| 4  | $^{32}\text{S}(n,t)\text{P}^{30}$       | d-Be         | 4.13E-03    | 0.608     | 0.655            | 2.770            | 1.032              |
| 5  | $^{34}\text{S}(n,\alpha)\text{Si}^{31}$ | fns_5min     | 0.1160      | 1.019     | 1.019            | 0.940            | 1.001              |
| 6  | $^{34}\text{S}(n,p)\text{P}^{34}$       | fns_5min     | 0.0723      | 0.971     | 0.996            | 3.700            | 1.000              |
| 7  | $^{37}\text{Cl}(n,p)\text{S}^{37}$      | fns_5min     | 0.0179      | 1.368     | 0.871            | 0.970            | 0.971              |
| 8  | $^{37}\text{Cl}(n,\alpha)\text{P}^{34}$ | fns_5min     | 0.0275      | 0.980     | 1.305            | 0.940            | 1.011              |
| 9  | $^{40}\text{Ca}(n,t)\text{K}^{38}$      | d-Be         | 4.94E-03    | 0.338     | 0.571            | –                | 1.007              |
| 10 | $^{41}\text{K}(n,p)\text{Ar}^{41}$      | fns_5min     | 3.63E-02    | 1.176     | 1.205            | –                | 1.132              |

# Improvements of activation cross sections for fusion

- Improve best set of TALYS parameters by carefully weighting experimental data



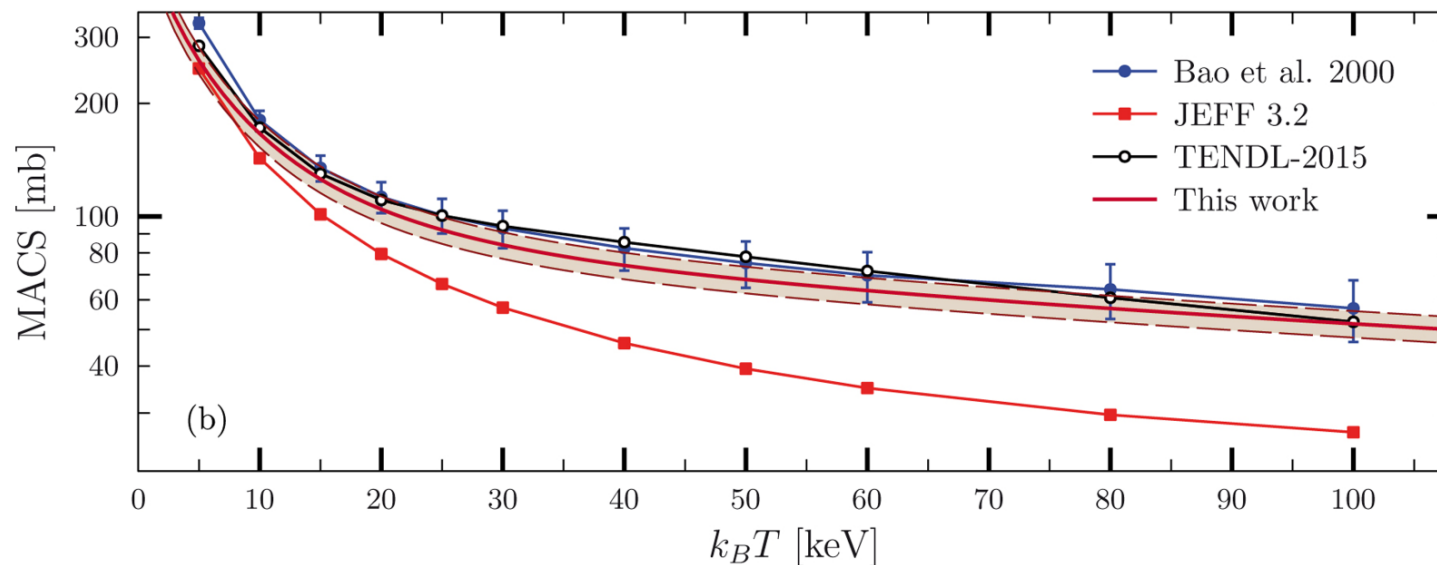
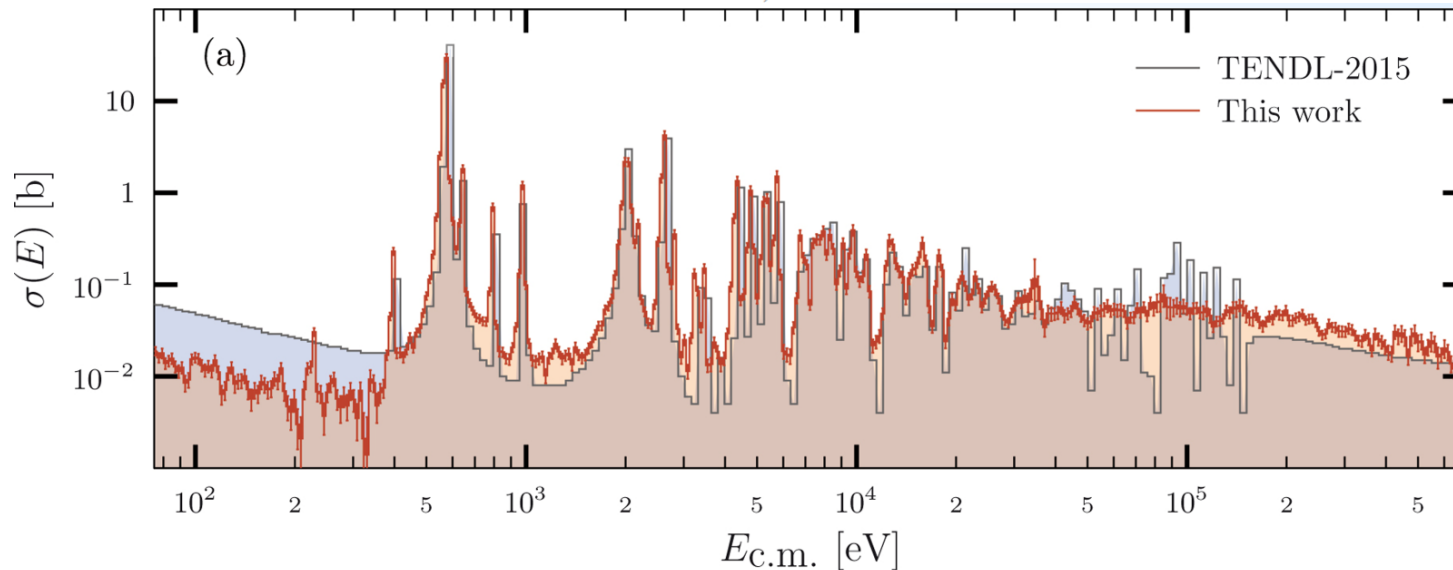
- Example for  $^{56}\text{Fe}$  with a few hundreds of random files:
  - the kerma and dpa can be obtained from a NJOY/HEATR processing.



- But energy-balance kerma may differ from kinematics limit kerma, if the file is not complete (often the case)

**$^{63}\text{Cu}(n, \gamma)$  cross section measured via 25 keV activation and time of flight**

M. Weigand,<sup>1,\*</sup> C. Beinrucker,<sup>1</sup> A. Couture,<sup>2</sup> S. Fiebiger,<sup>1</sup> M. Fonseca,<sup>3,4</sup> K. Göbel,<sup>1</sup> M. Heftrich,<sup>1</sup> T. Heftrich,<sup>1</sup> M. Jandel,<sup>2</sup>  
 F. Käppeler,<sup>5</sup> A. Krása,<sup>6</sup> C. Lederer,<sup>1,7</sup> H. Y. Lee,<sup>2</sup> R. Plag,<sup>1</sup> A. Plompen,<sup>6</sup> R. Reifarh,<sup>1</sup> S. Schmidt,<sup>1</sup>  
 K. Sonnabend,<sup>1</sup> and J. L. Ullmann<sup>2</sup>



- Neutrons
  - More optimized FPs, especially capture
  - Adoption of CIELO evaluations
  - More optimized activation xs for fusion
  - Larger automated validation schemes
  - Covariance data in resonance range go into MF33
- Photons:
  - Individual evaluations to improve IAEA photonuclear library, in synch with running CRP
- Alpha particles
  - Adoption of experimental (alpha,n), and JENDL-A, on light nuclides for safeguards

# Future

- TALYS-2.0 under development
  - Rewrite in Fortran-95 nearly done
  - TEFAL (ENDF formatter) nearly included
  - TASMAN (uncertainties, covariances, TMC) will be included
- Open source release of T6/TENDL/TALYS package so every country, collaboration etc. can make their own XENDL library or contribute to TENDL



(insert name)



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*Thank you!*

