Wonder 2026: 7th edition of the International Workshop On Nuclear Data Evaluation for Reactor Applications

WONDER 2026

# Assessment of evaluated nuclear data consistency using integral damage and heating cross sections


**Shengli Chen**, Tianxiang Wang

Sino-French Institute of Nuclear Engineering & Technology,

Sun Yat-sen University, China



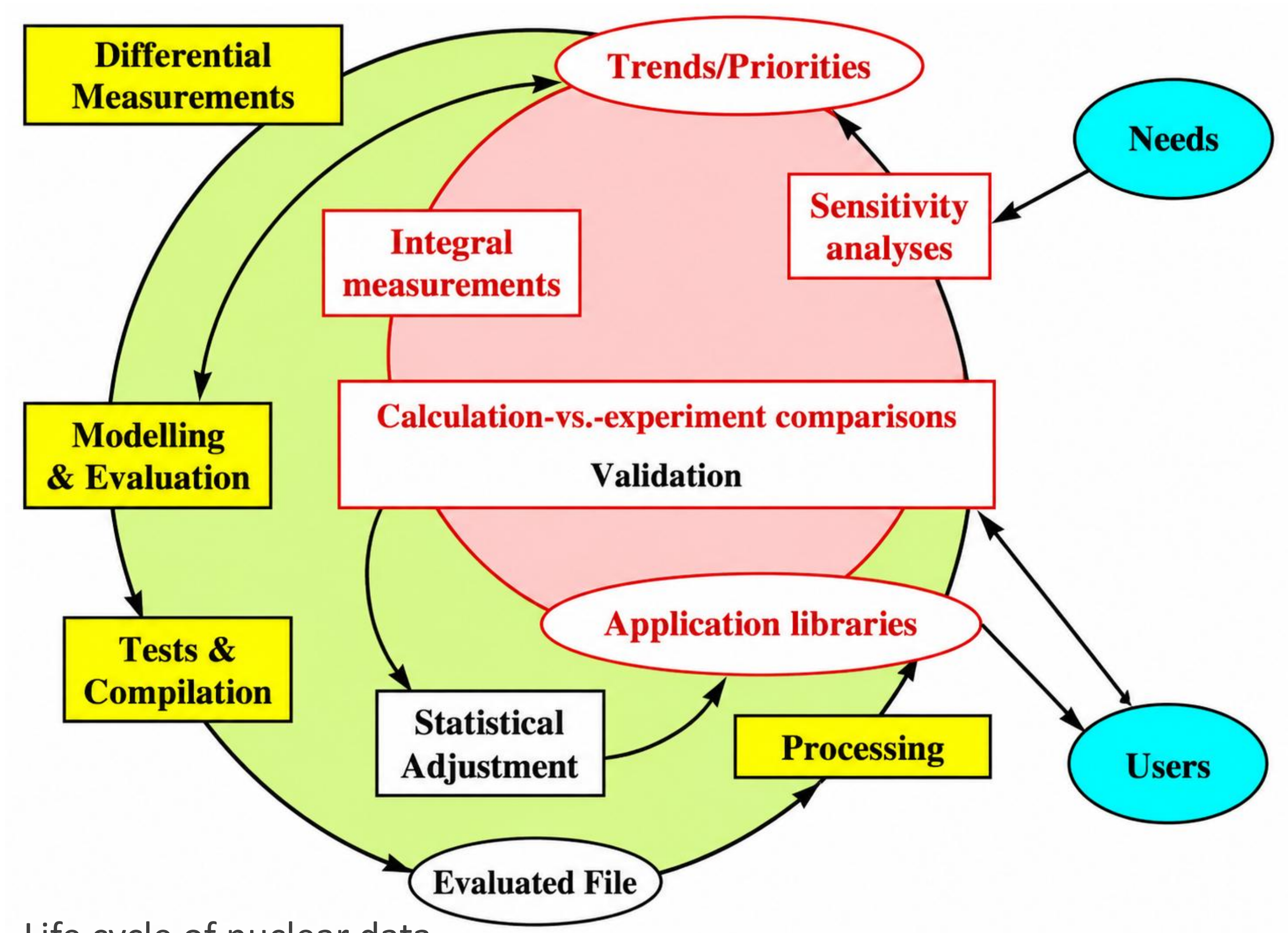
July 3, 2026

Aix-en-Provence, France

# Outline

- Introduction
- Complementary validation
- Integral consistency verification
- Conclusions

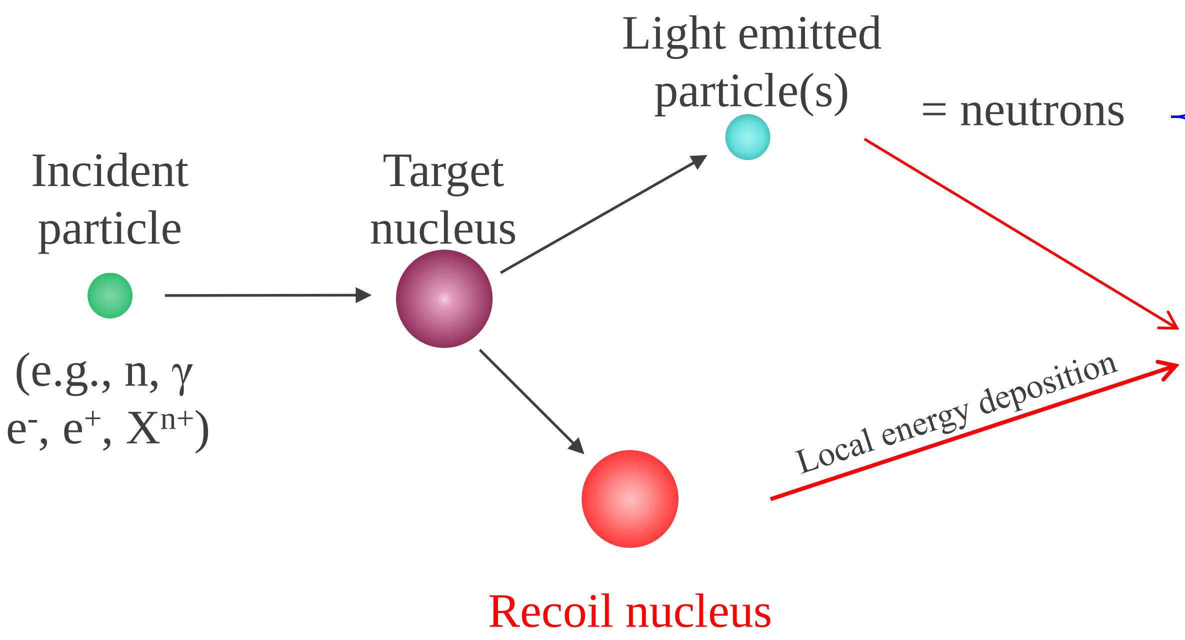
# Development and applications of nuclear data




Life cycle of nuclear data development @Koning

- **Reactor physics**
- **Shielding**
- Nuclear heating
- Radiation damage
- Medical applications
- Neutrino
- …

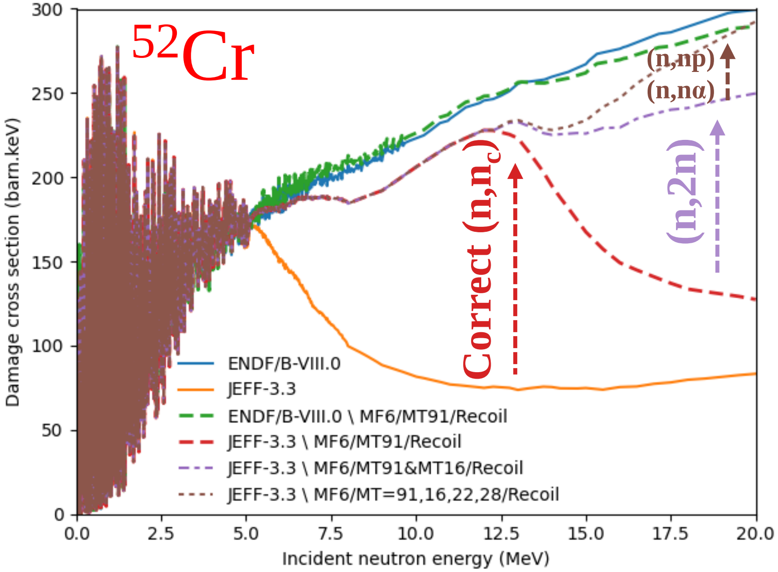
# Nuclear heating and damage applications




- **Reactor physics**
- **Shielding**
- Nuclear heating
- Radiation damage
- Medical applications
- Neutrino
- …

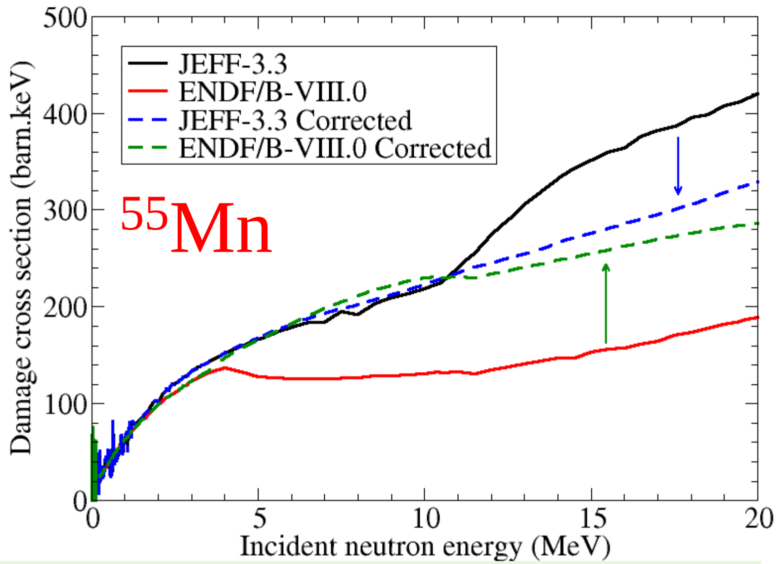
Not included in routine V&V

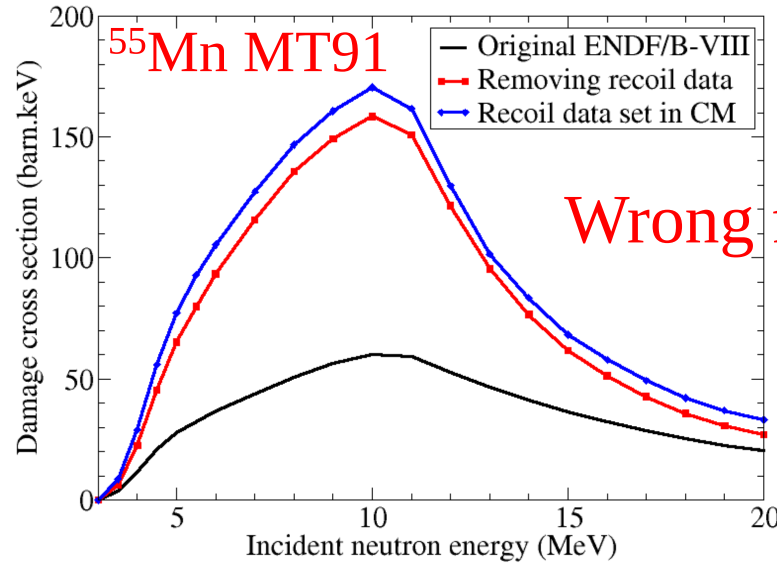
# Issues in some evaluations (1)




```
2.405200+4 5.149432+1          0          1          1       22431 6 91  347
         2          2                                          2431 6 91  348
4.793311+6 1.000000+0 1.500000+8 1.000000+0                    2431 6 91  349
0.000000+0 0.000000+0          1          1          1      182431 6 91  350
        18          2                                          2431 6 91  351
0.000000+0 4.793311+6          0          0          4       22431 6 91  352
0.000000+0 1.000000+0 1.000000+0 0.000000+0                    2431 6 91  353
0.000000+0 5.000000+6          0          0          4       22431 6 91  354
0.000000+0 1.000000+0 1.000000+0 0.000000+0                    2431 6 91  355
0.000000+0 6.000000+6          0          0          4       22431 6 91  356
0.000000+0 1.000000+0 1.000000+0 0.000000+0                    2431 6 91  357
0.000000+0 7.000000+6          0          0          4       22431 6 91  358
0.000000+0 1.000000+0 1.000000+0 0.000000+0                    2431 6 91  359
```

**Incorrect recoil data!**

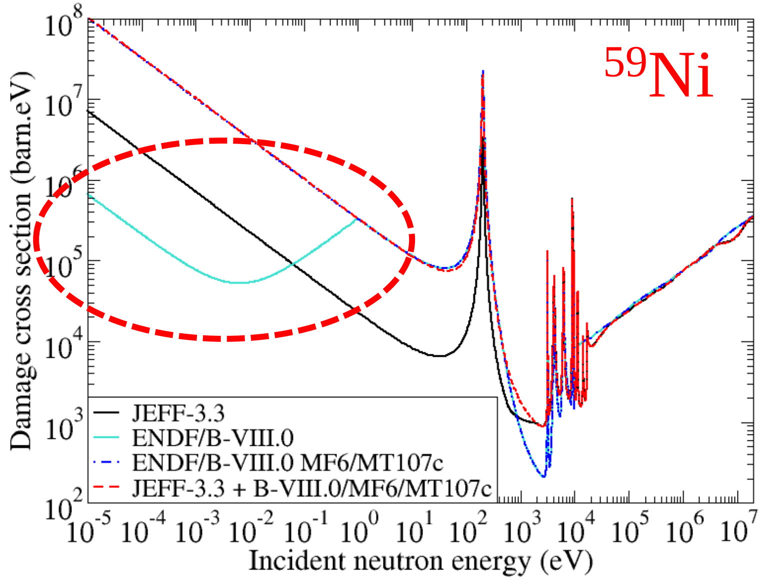


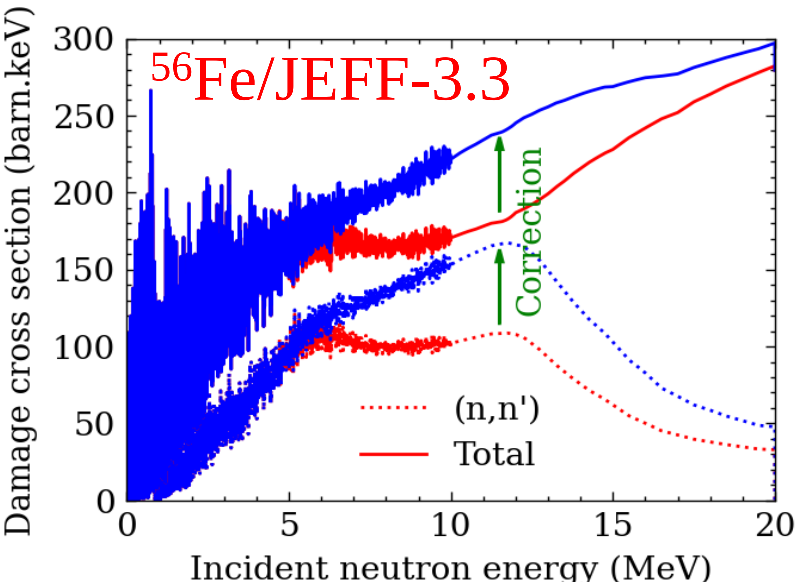



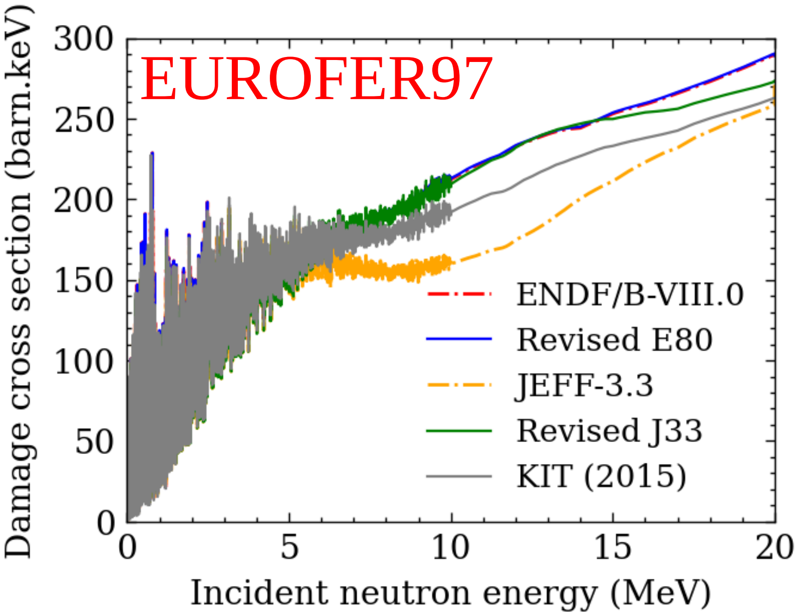

**Wrong frame**

Chen and Bernard, *J. Nucl. Mater.*, **562**: 153610, 2022

# Issues in some evaluations (2)



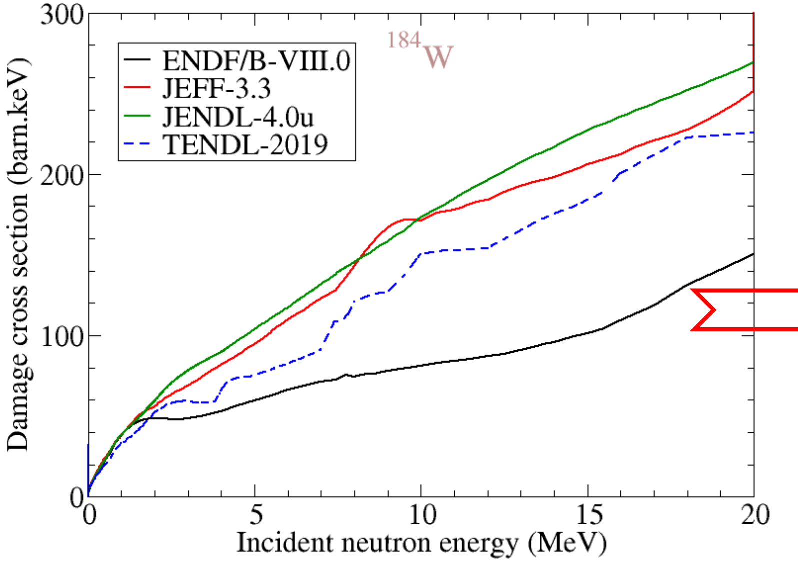



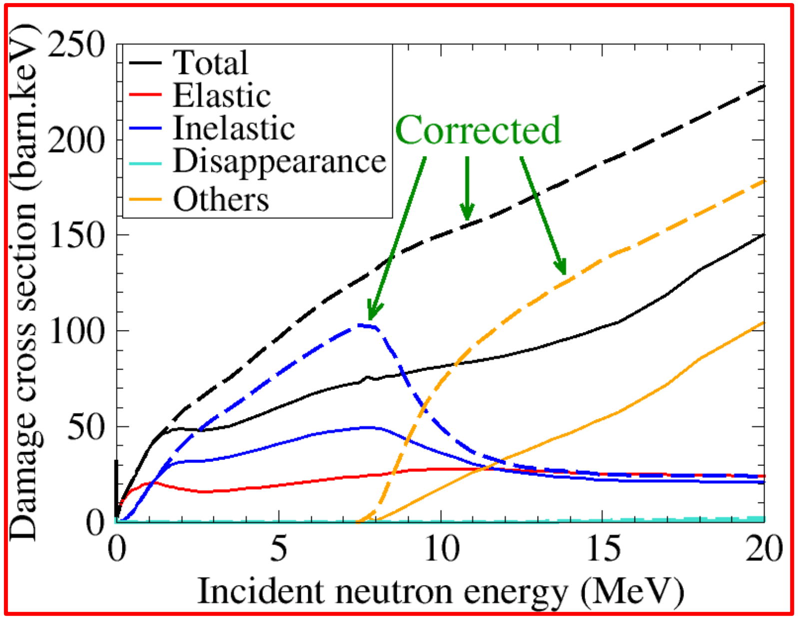


Chen and Bernard, *J. Nucl. Mater.*, **562**: 153610, 2022

Chen, *Nucl. Mater. Energy*, **33**: 101284, 2022

# Issues in some evaluations (3): W




Displacements per Atom (DPA) rates / JEFF-3.1.1 calculation ($^{nat}$W)

| Spectrum | JEFF-3.3 | JENDL-4.0u | ENDF/B-VIII.0 | Modif. MF6 | Max. Diff. |
|---|---|---|---|---|---|
| **First wall** | 1.009 | 1.072 | **0.647** | 0.958 | 66→11% |

The reference system flag LCT was corrected from LCT=3 to LCT=2 in MF6 for Mn-55, W-180, W-182, W-183, W- 184, W-186 and Th-232. It implies that the recoil distributions are now given in the center of the mass system (CM). Before, they were erroneously flagged in the laboratory system (LAB).

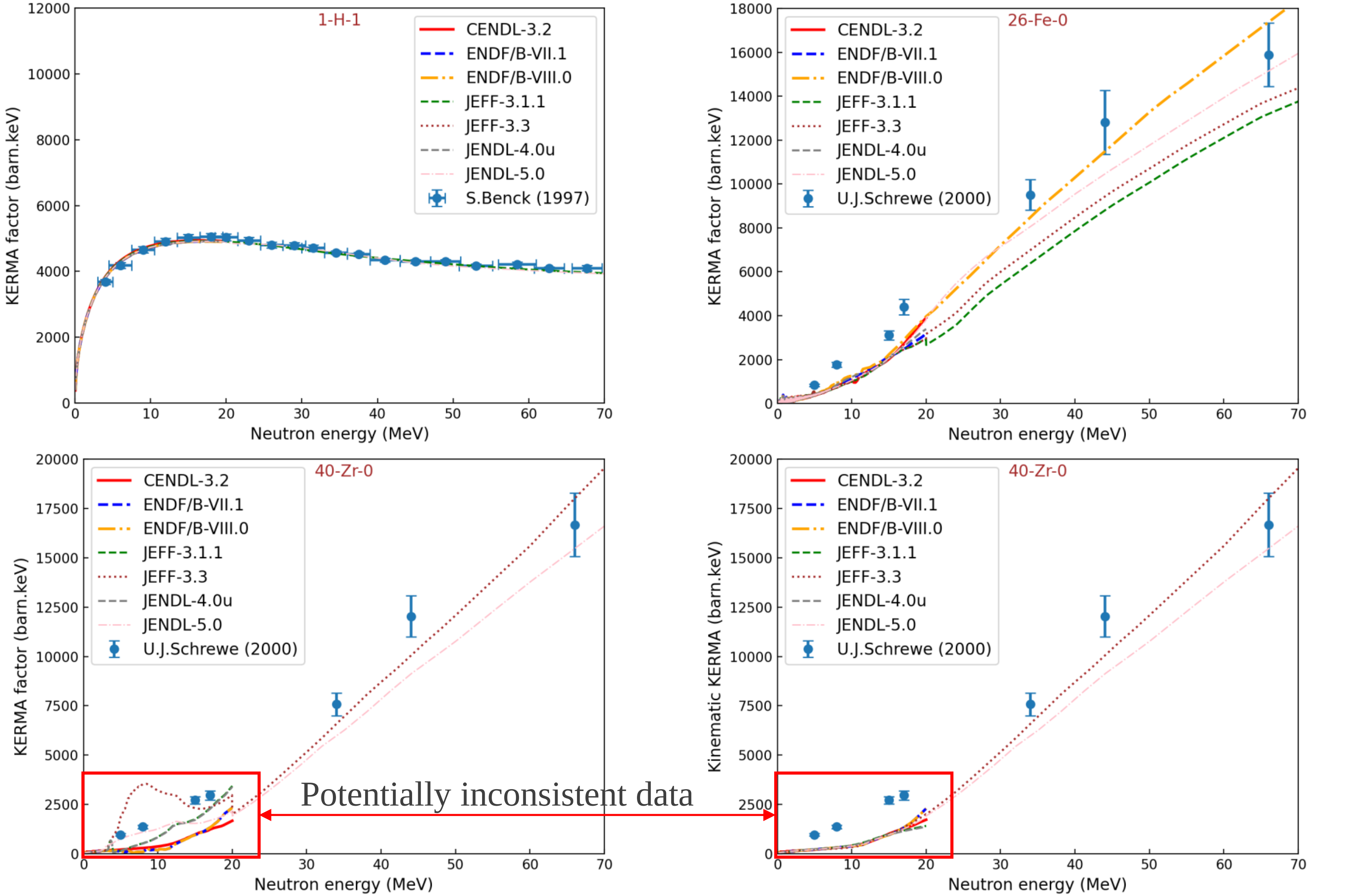
Daniel López Aldama, Georg Schnabel. Updating the fusion library FENDL-3.2b to FENDL-3.2c, IAEA INDC(NDS)-0905, 2024

Chen *et al.*, *Fusion Eng. Des.*, **171**: 112594, 2021
Chen and Bernard, *J. Nucl. Mater.*, **562**: 153610, 2022

# Outline

- Introduction
- **Complementary validation**
- Integral consistency verification
- Conclusions

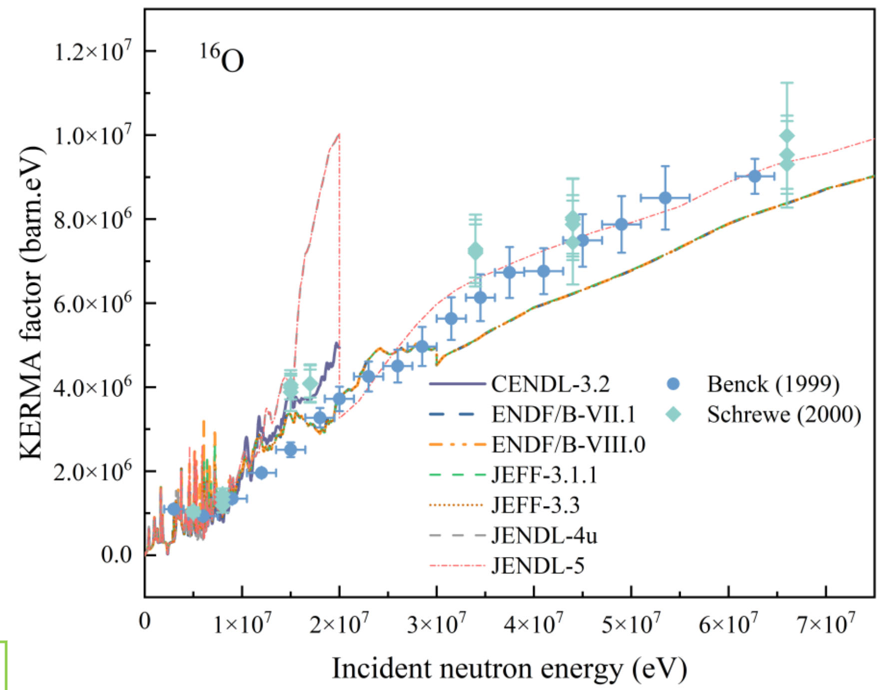
# Direct validation against experimental KERMA



# Direct validation against experimental KERMA

Nuclides with experimental KERMA factor(s)

| Nuclide | | |
|---|---|---|
| $^{1}H$ | C | Mg |
| Si | $^{14}N$ | $^{16}O$ |
| $^{27}Al$ | Fe | Zr |



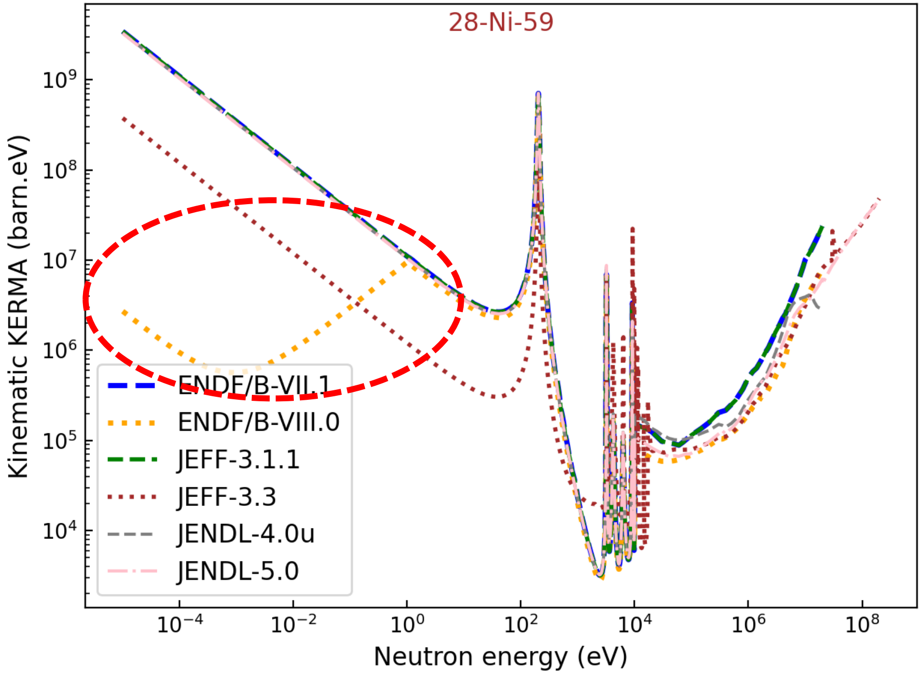

Number of evaluated nuclear data files

| | Latest version | Last updated | Nuclides |
|---|---|---|---|
| China | CENDL-3.2 | 2020 | **272** |
| USA | ENDF/B-VIII.1 | 2024 | **558** |
| Europe | JEFF-4.0 | 2025 | **593** |
| Japan | JENDL-5 | 2021 | **795** |
| Russia | BROND-3.1 | 2016 | **372** |

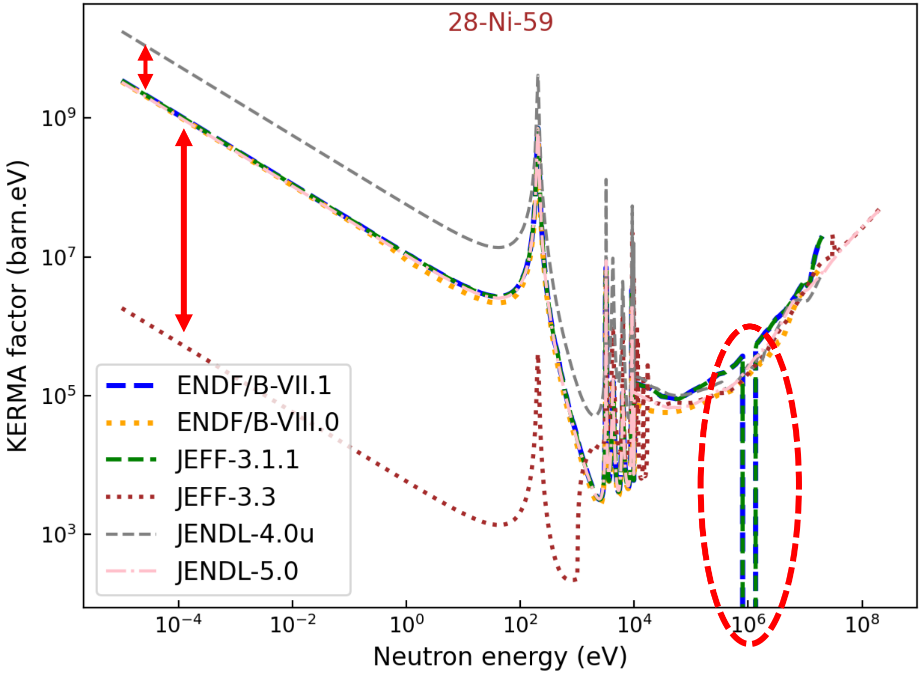
**Limited experimental data**

**→ library-to-library comparison for isotope-by-isotope consistency assessment**

# Library-to-library comparison: $^{59}$Ni KERMA




Kinematic KERMA




Energy-balance KERMA

**Compare 2 KERMA factors and DPA cross sections in <u>different energy regions</u>**

# Isotope-by-isotope comparison: thermal region

## 1. Euclidean distance

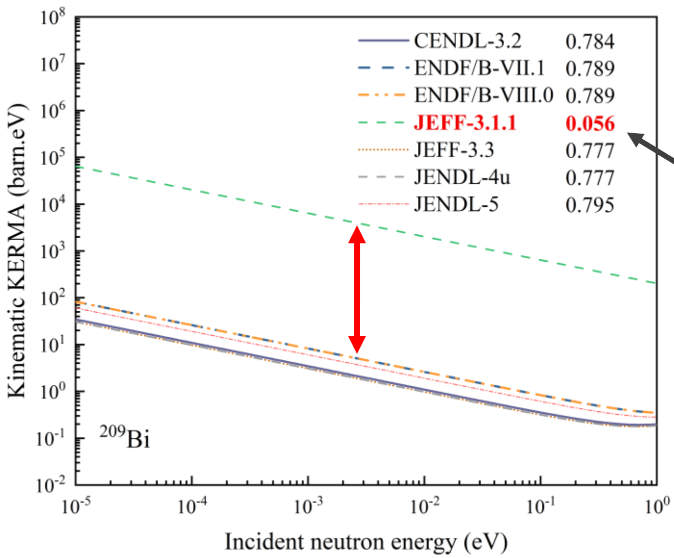
$X = \{x_1, x_2, \dots, x_N\}$

$Y = \{y_1, y_2, \dots, y_N\}$

$$d = \sqrt{\textstyle\sum_k (x_k - y_k)^2} \quad \rightarrow \quad \text{Similarity} = \left(1 - \frac{d}{d_{max}}\right) \quad \begin{aligned} &= 1 \text{ if } d = 0 \\ &= 0 \text{ if } d = d_{max} \end{aligned}$$

→ Similarity matrix $M[i,j]$ → $S(q) = \frac{1}{N-1}\sum_{j \neq q} M[q,j]$ Aggregation of similarity for library $q$

**Higher $S$ → better consistency with other libraries**




KERMA factor of $^{209}$Bi at thermal energies

| | CD32 | B71 | B80 | JF311 | JF33 | JD4u | JD5 |
|---|---|---|---|---|---|---|---|
| CD32 | 100.0% | 89.3% | 89.3% | 1.3% | 98.6% | 98.6% | 93.1% |
| B71 | 89.3% | 100.0% | 100.0% | 12.0% | 87.9% | 87.9% | 96.2% |
| B80 | 89.3% | 100.0% | 100.0% | 12.0% | 87.9% | 87.9% | 96.2% |
| JF311 | 1.3% | 12.0% | 12.0% | 100.0% | 0.0% | 0.0% | 8.2% |
| JF33 | 98.6% | 87.9% | 87.9% | 0.0% | 100.0% | 100.0% | 91.7% |
| JD4u | 98.6% | 98.6% | 87.9% | 0.0% | 100.0% | 100.0% | 91.7% |
| JD5 | 93.1% | 96.2% | 96.2% | 8.2% | 91.7% | 91.7% | 100.0% |

Corresponding constructed similarity matrix

Identifies JEFF-3.1.1 as the most deviated in the thermal region

# Isotope-by-isotope comparison: fast region

## Similarity measurement algorithms for sequential data

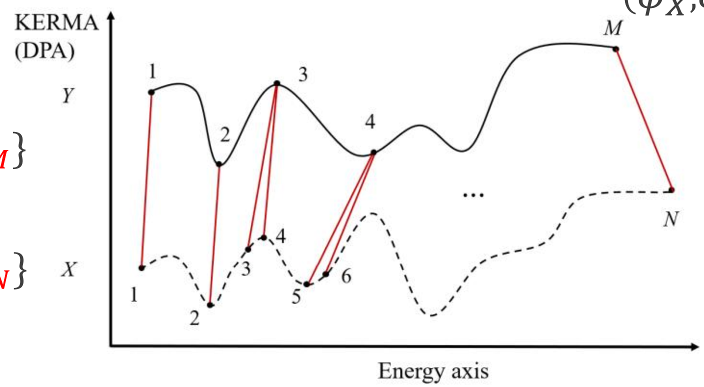
### 2. Dynamic Time Warping (DTW) algorithm

In nuclear engineering: mainly applied to fault diagnosis of nuclear power systems

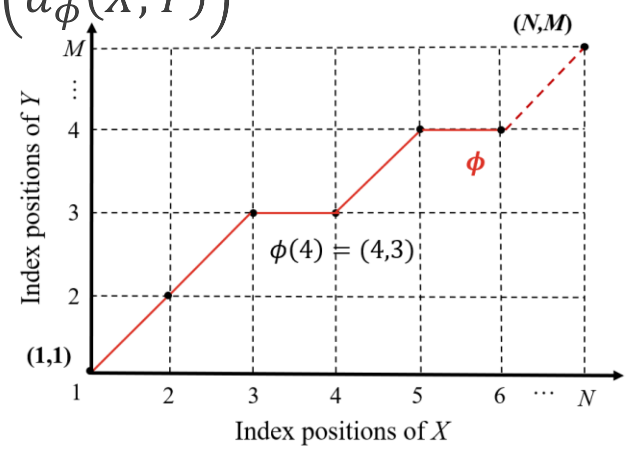
$$d(X,Y) = \min_{(\phi_X,\phi_Y)\in\phi} \left( d_\phi(X,Y) \right)$$

$Y = \{y_1, y_2, \ldots, y_M\}$

$X = \{x_1, x_2, \ldots, x_N\}$

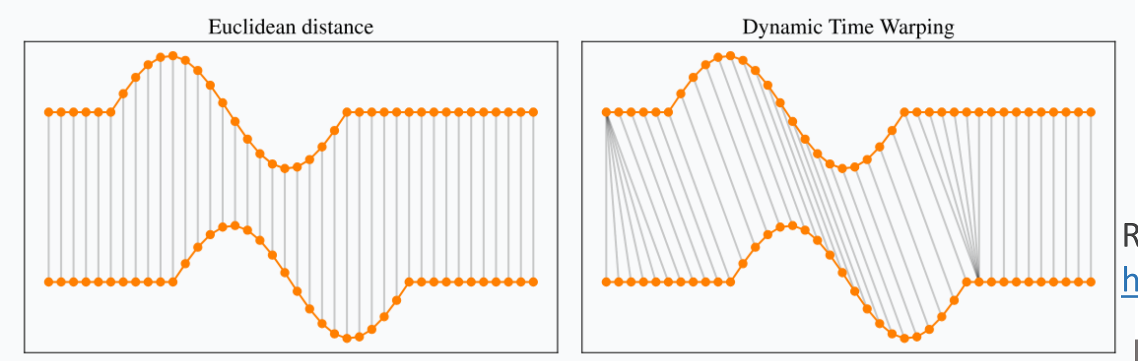



Point-to-point correspondence defined by the warping path



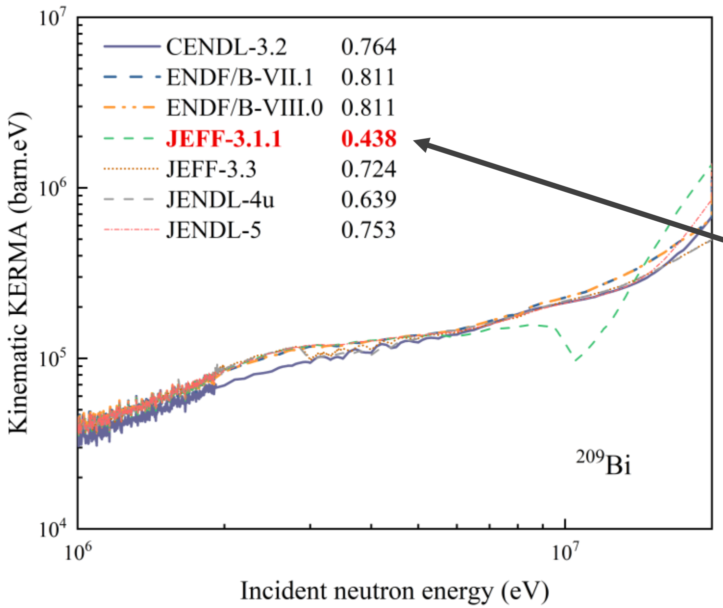

Schematic diagram of the warping path

- Stretching or compressing axis to better align the shapes of two sequences → robustness




Romain Tavenard, https://rtavenar.github.io/blog/dtw.html

# Isotope-by-isotope comparison: fast region




KERMA factors of $^{209}$Bi in high-energy region

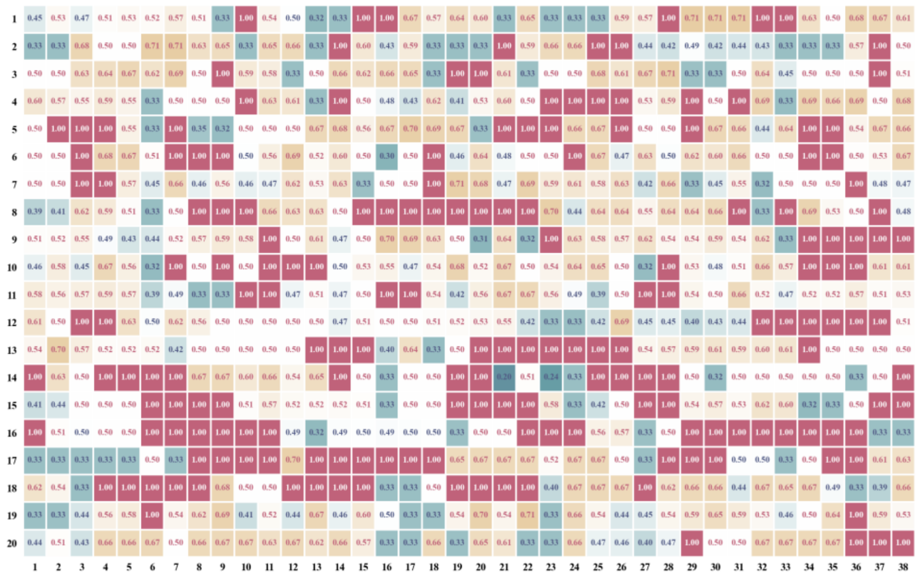
| | CD32 | B71 | B80 | JF311 | JF33 | JD4u | JD5 |
|---|---|---|---|---|---|---|---|
| CD32 | 100.0% | 83.8% | 83.8% | 38.4% | 87.3% | 81.9% | 83.0% |
| B71 | 83.8% | 100.0% | 100.0% | 62.0% | 81.9% | 75.0% | 83.7% |
| B80 | 83.8% | 100.0% | 100.0% | 62.0% | 81.9% | 75.0% | 83.7% |
| JF311 | 38.4% | 62.0% | 62.0% | 100.0% | 22.6% | 0.0% | 77.8% |
| JF33 | 87.3% | 81.9% | 81.9% | 22.6% | 100.0% | 94.2% | 66.5% |
| JD4u | 81.9% | 75.0% | 75.0% | 0.0% | 94.2% | 100.0% | 57.5% |
| JD5 | 83.0% | 83.7% | 83.7% | 77.8% | 66.5% | 57.5% | 100.0% |

Corresponding similarity matrix

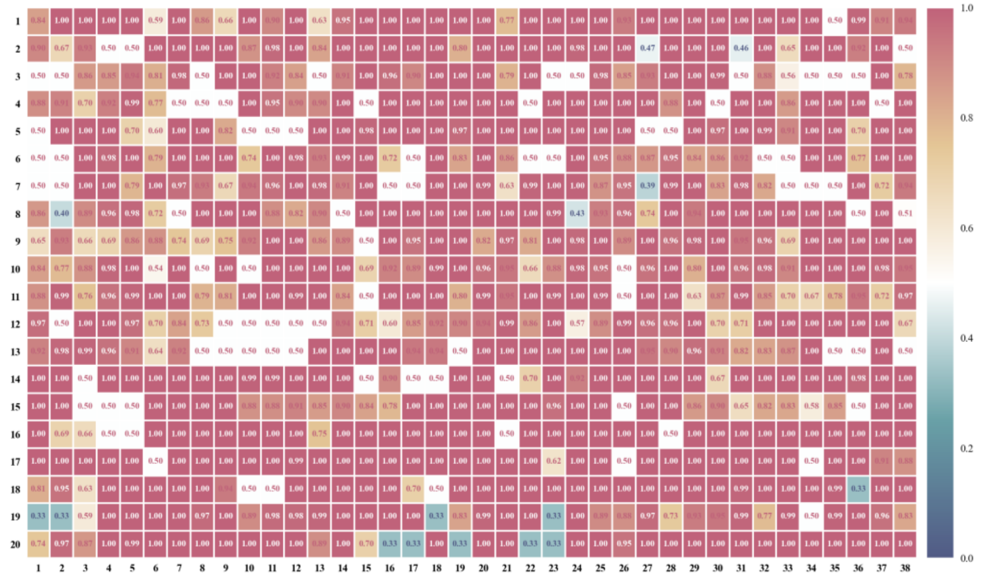
- **Similarity measurement → support refined verification for nuclear data (for ~all isotopes)**

# Isotope-by-isotope comparison for KERMA

Overall similarity of KERMA factors for the first 20*38 nuclides



Original 7 nuclear data libraries



After filtering …

- Significant improvements on the average overall similarity

→ More reliable KERMA factors and relevant ND

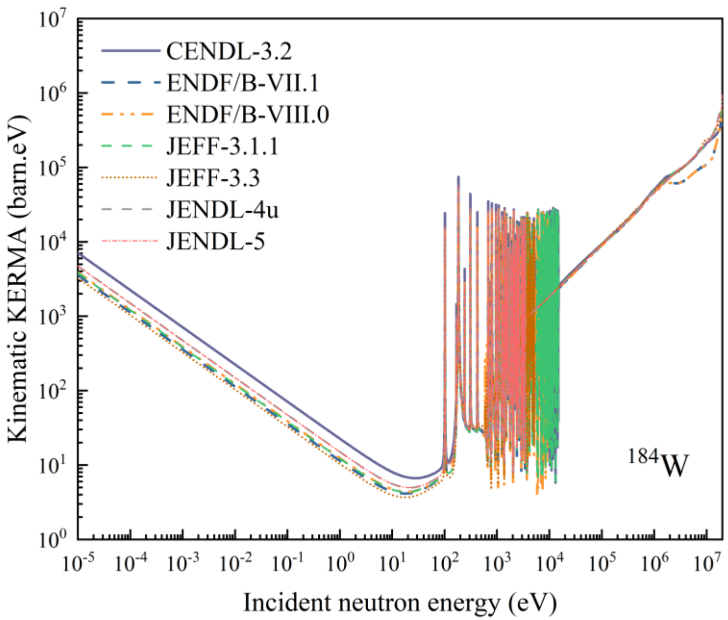
# Isotope-by-isotope comparison for DPA

$$KERMA(E) = \sigma(E)\int f(E,\boldsymbol{X})E_R(E,\boldsymbol{X})d\boldsymbol{X} + \cdots$$

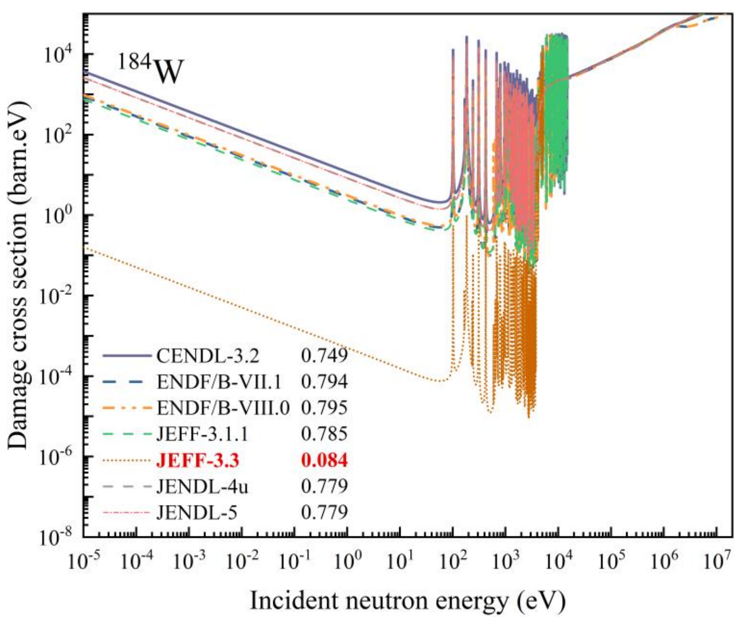
$$\sigma_D(E) = \sigma(E)\int f(E,\boldsymbol{X})E_D(E_R(E,\boldsymbol{X}))d\boldsymbol{X}$$

Discontinuous integrand

→ sensitive to recoil energies close to displacement thresholds




KERMA factor




DPA cross section

- DPA cross sections, complementary verification to that of KERMA factors

→ More reliable DPA cross sections and relevant ND

# Conclusions & outlook

- **Issues in KERMA & DPA calculations using nuclear data**
- **Isotope-by-isotope verification based on similarity of integral KERMA factors (*2) & DPA cross sections**
- **More reliable KERMA & DPA data after selection**
- **Feedback to nuclear data**
- **Further V & V with improved methods (e.g., AI) …**
- **Rapid consistency check of newly evaluated nuclear data**

# Thank you!


Shengli Chen

Associate Professor

Sino-French Institute of Nucl. Eng. Tech.,

Sun Yat-sen University

chenshli23@mail.sysu.edu.cn