Evaluation of Nuclear Data: The JEFF Project

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Figure 1. *Neutron transport Boltzmann equation*

$$\frac{1}{v}\frac{\partial \Psi}{\partial t} + \Omega \cdot \nabla \Psi + \Sigma_T \Psi = S + \int_E \int_\Omega \Psi(E', \Omega') \cdot \Sigma_s(E' \to E, \Omega' \to \Omega) dE' d\Omega'$$

$$S_{PF} = \sum_i N_i \int dE' \; \phi(E') \cdot \nu_i(E') \cdot \sigma_{F,i}(E') \cdot \chi_{F,i}(E', E)$$

$$S_{dn} = \sum_k \lambda_k \cdot C_k(r, t) \cdot \chi_{d,k}(E)$$

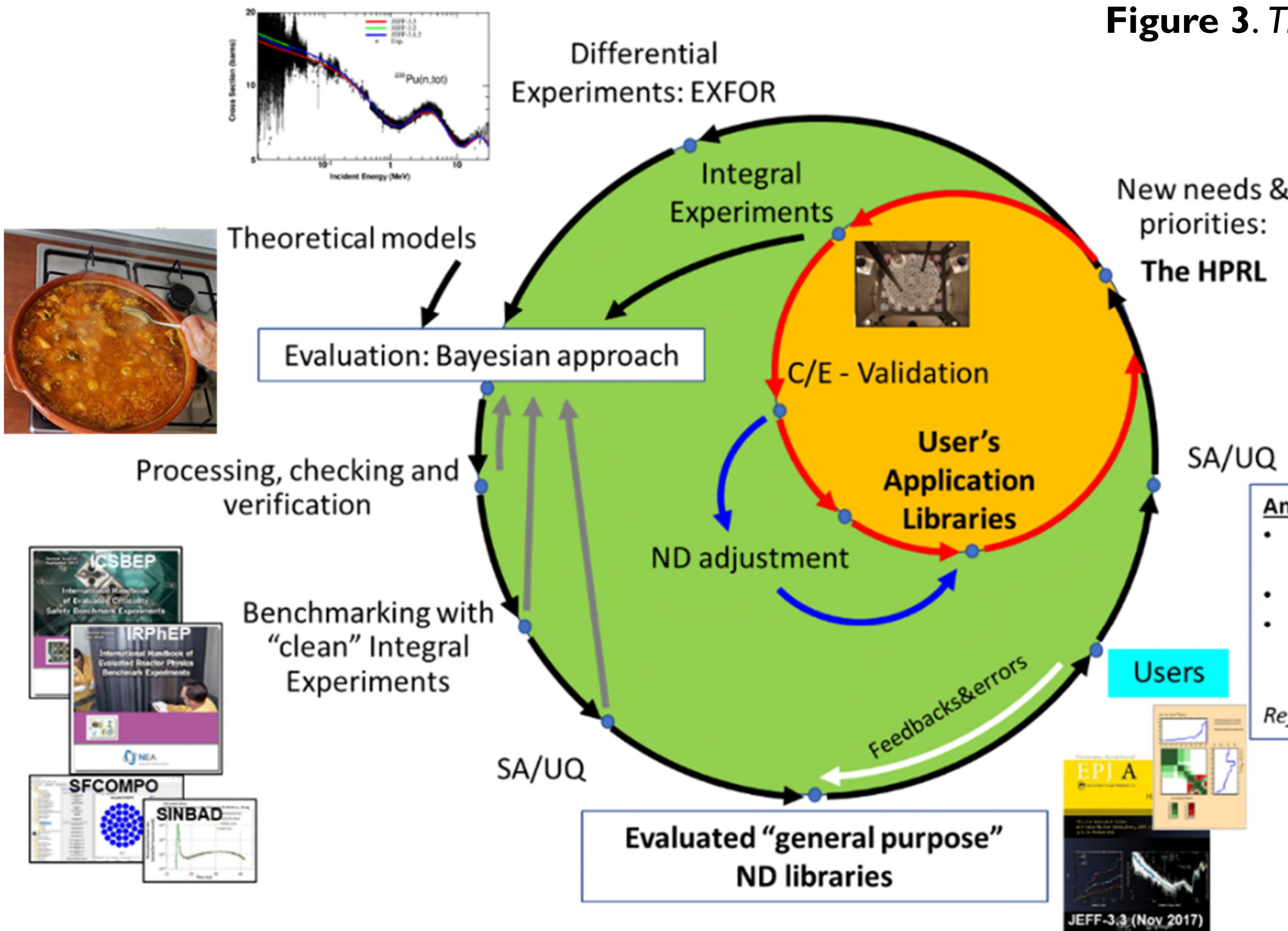
Figure 2. *Bateman transmutation equation*

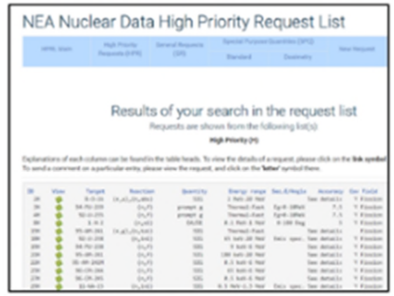
$$\frac{dN_i(t)}{dt} = -(\lambda_i + r_i) \cdot N_i(t) + \sum_{i \neq j} (\lambda_{j \to i} + r_{j \to i}) \cdot N_j(t) + PF_i$$

$$PF_i = \sum_h N_h \cdot \int_0^\infty dE \cdot \phi(E) \cdot \gamma_{h \to i}(E) \cdot \sigma_{f,h}(E)$$

The Nuclear Data Life-cycle

Figure 3. *The Nuclear data life cycle*

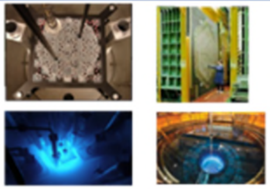




An example for MSRs: ^{35}**Cl(n,p)**

- Large differences between evaluated data
- Lack of uncertainties E> 1MeV
- Target Accuracy Requirements (Δkeff< 300pcm) gives a necessity for uncertainty reduction of 8%

Ref. WPEC/EGHPRL – May 2022



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The evaluation of ND: The Bayesian's Approach

Evaluated cross-sections and covariance matrices

<u>Experimental Input</u>

Inter and -intra experiment correlations

Experimental cross-sections

Bayesian Update

<u>Prior Knowledge</u>

Model Defects

Parameter Uncertainties

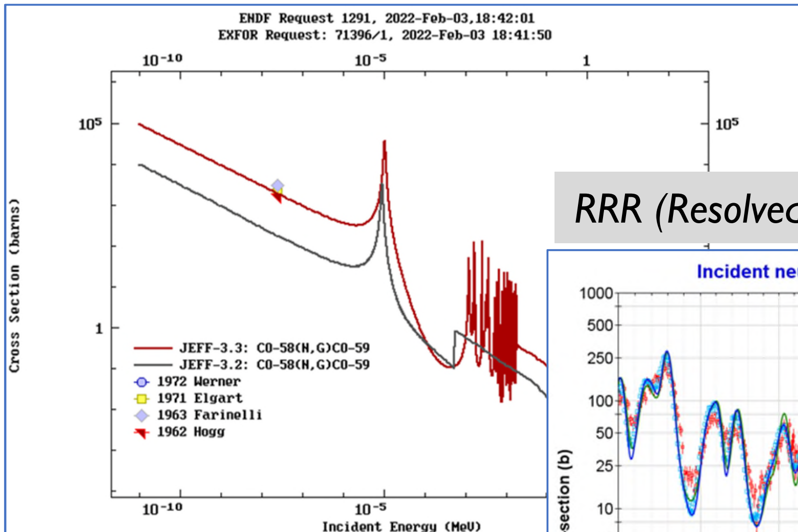
Model cross-sections

Ref. D. Neudecker, S. Gundacker, H. Leeb et al., ND2010
… and cooking rice-Paella's photos courtesy by M. Garasa

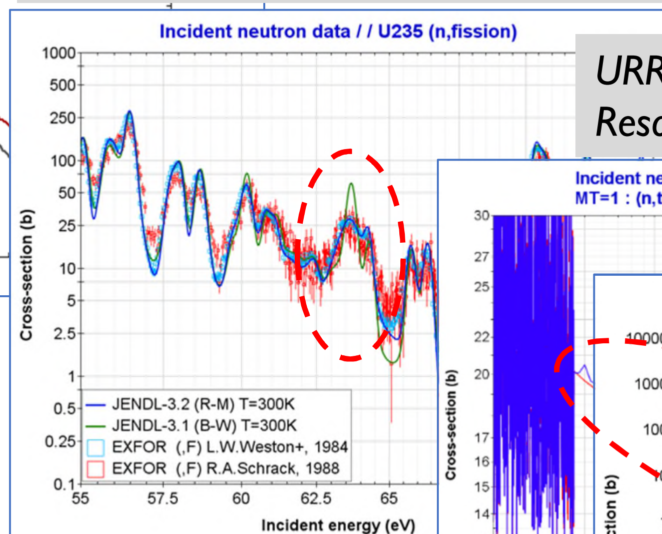
Figure 4. *Example of the Bayesian procedure to evaluate cross-section and covariances*

Evaluation of XSs in different energy

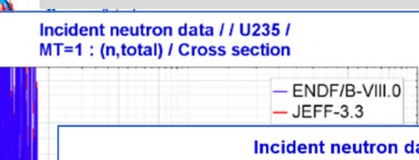
Thermal region



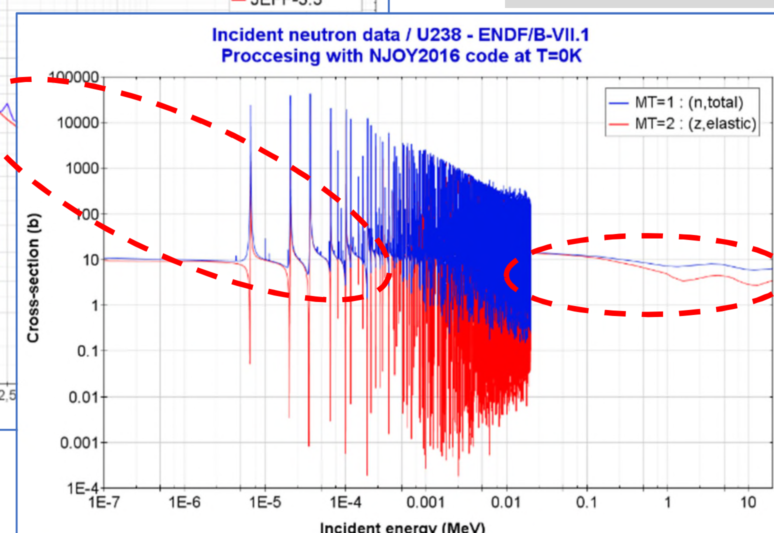
RRR (Resolved Resonance Region)



URR (Unresolved Resonance Region)



High energy – the continuum



International efforts on evaluation of ND Evaluations (n-induced)

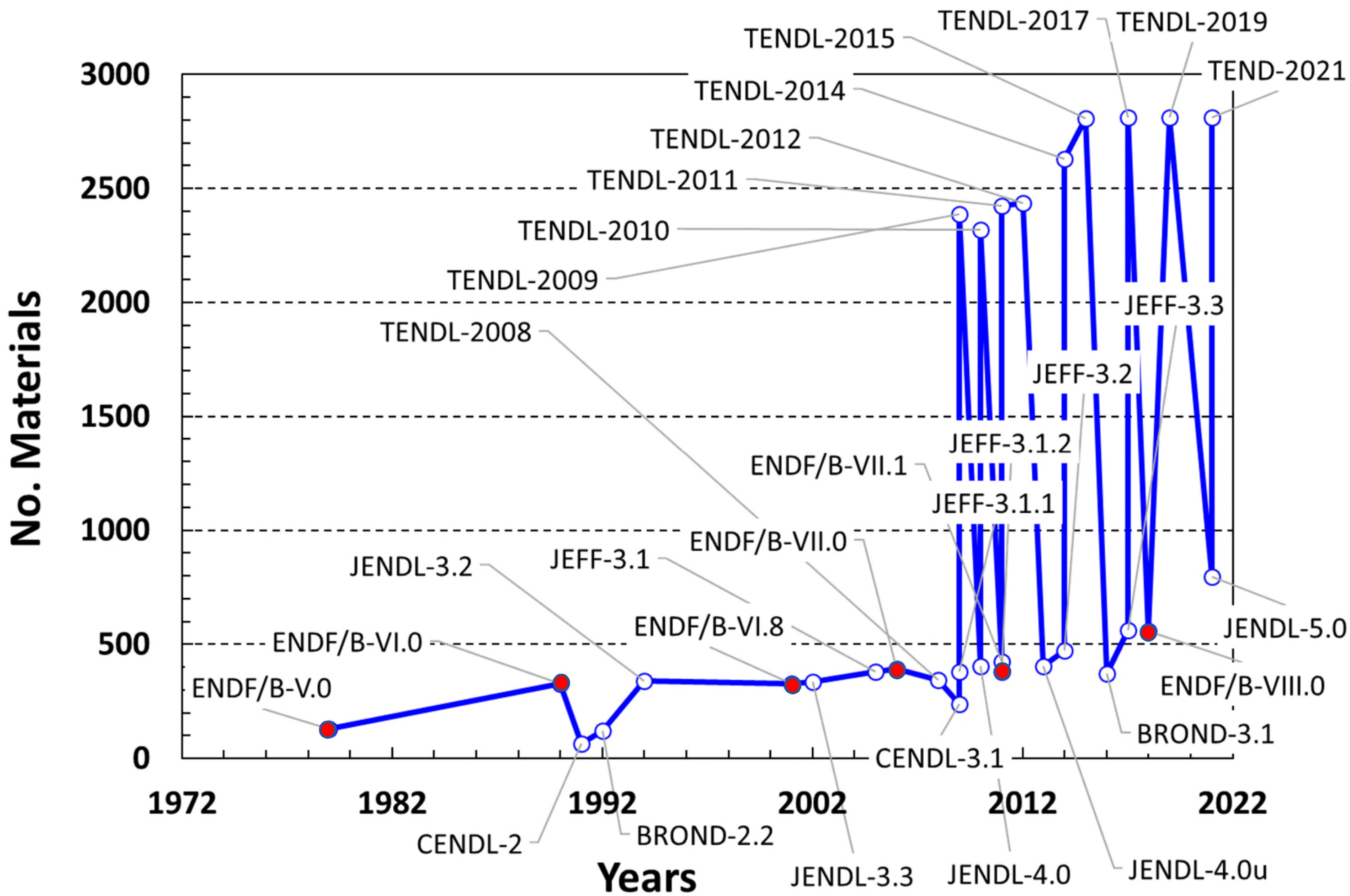


Figure 5. *Nuclear data libraries (n-induced) of today versus MAT*

The content and format in the Evaluated Nuclear Data Files

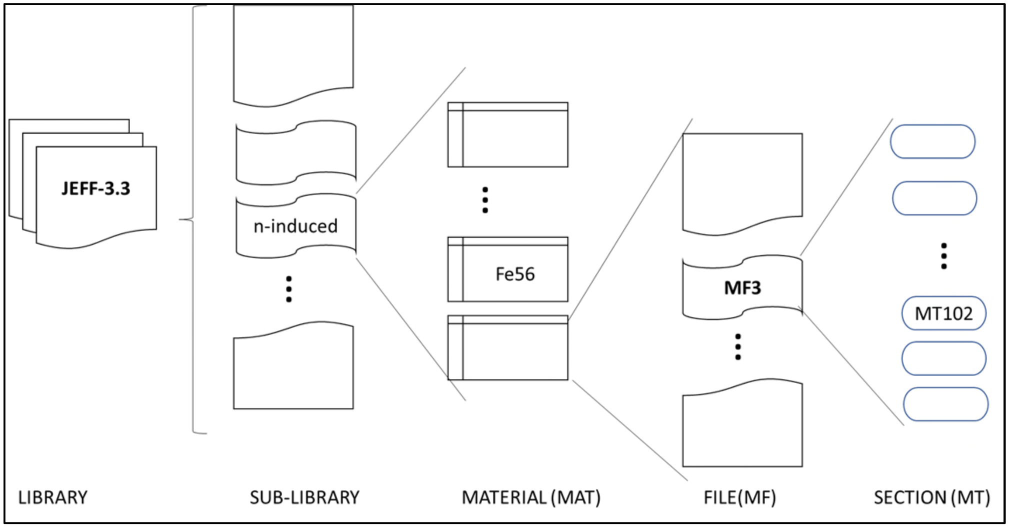


Figure 6. *Structure of ENDF Libraries*

Table 1. *An extract/example of* ***ENDF-6 format*** *(top) and* ***GNDS/XML*** *(bottom) for the 1H(n,elastic) in ENDF/B-VIII.0*

ENDF-6

MAT MF MT

```
 1.001000+3 9.991673-1          0          0          0          0 125 3  2     1
 0.000000+0 0.000000+0          0          0          1        153 125 3  2     2
        153          2                                            125 3  2     3
 1.000000-5 2.043608+1 2.000000-5 2.043608+1 5.000000-5 2.043608+1 125 3  2     4
 1.000000-4 2.043608+1 2.000000-4 2.043608+1 5.000000-4 2.043608+1 125 3  2     5
…
 1.900000+7 5.079599-1 1.950000+7 4.945948-1 2.000000+7 4.818408-1 125 3  2    54
 0.000000+0 0.000000+0          0          0          0          0 125 3  099999
```

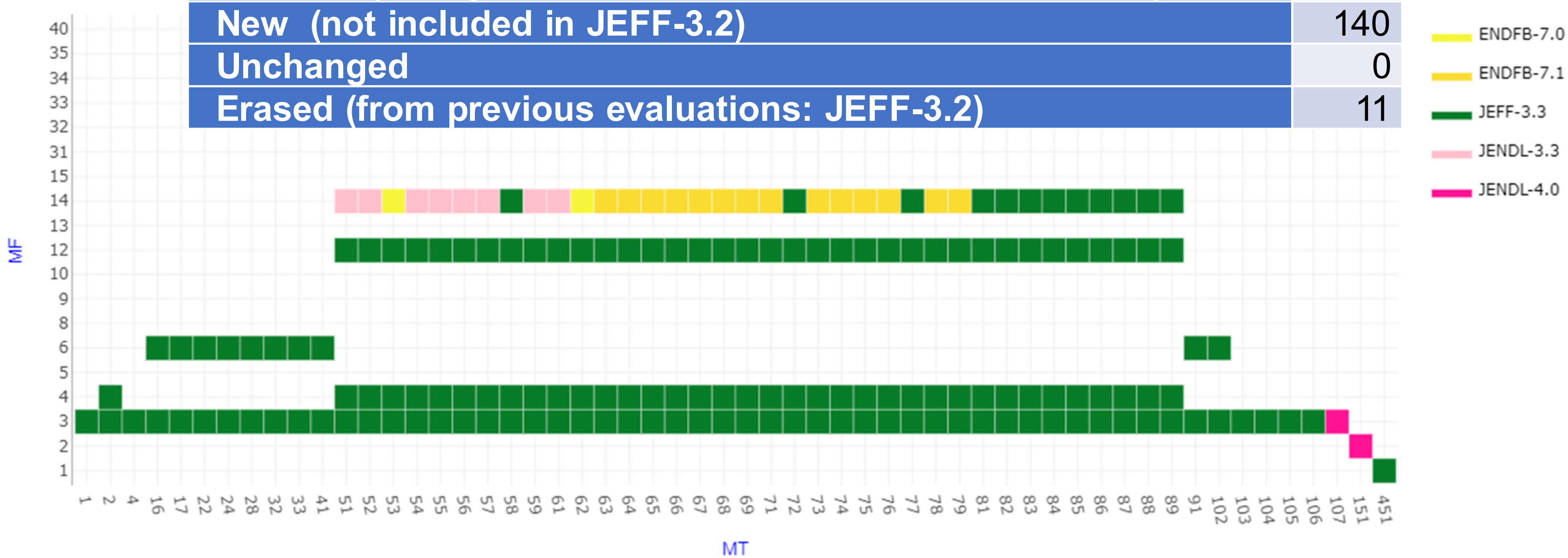
GNDS

```
<crossSection nativeData="linear">
<linear xData="XYs" length="153" accuracy="0.001">
<axes>
<axis index="0" label="energy_in" unit="eV" interpolation="linear,linear" frame="lab"/>
<axis index="1" label="crossSection" unit="b" frame="lab"/>
</axes>
<data> 1e-5 20.43608 2e-5 20.43608 5e-5 20.43608 1e-4 20.43608 2e-4 20.43608 5e-4 20.43608
... 1.75e7 0.5521863 1.8e7 0.5367046 1.85e7 0.5219803 1.9e7 0.5079599 1.95e7 0.4945948 2e7
0.4818408 </data>
</linear>
</crossSection>
```

Mapping ND evaluations

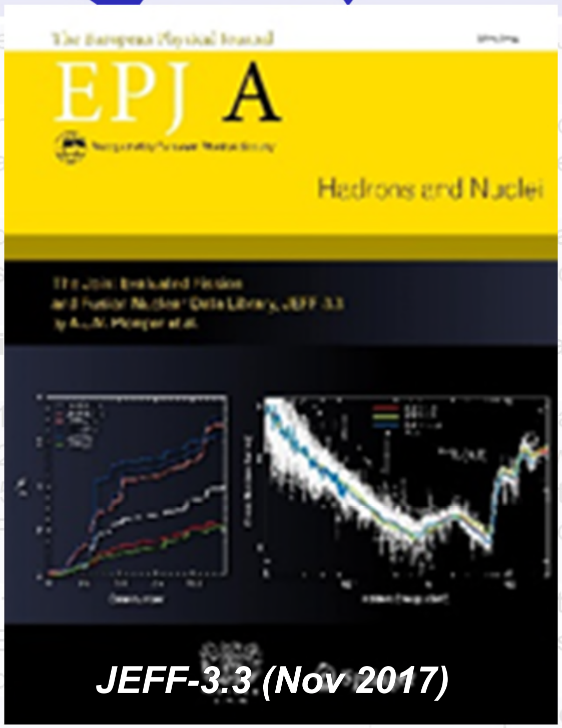
Figure 7. Map of information of 63-Eu-153/JEFF-3.3 using tool
https://www.oecd-nea.org/dbdata/jeff/jeff33/Maps.html

Total MFs/MTs	175
Updated (changed from previous evaluations: JEFF-3.2)	35
New (not included in JEFF-3.2)	140
Unchanged	0
Erased (from previous evaluations: JEFF-3.2)	11



The evolution of OECD/NEA/Data Bank JEFF project

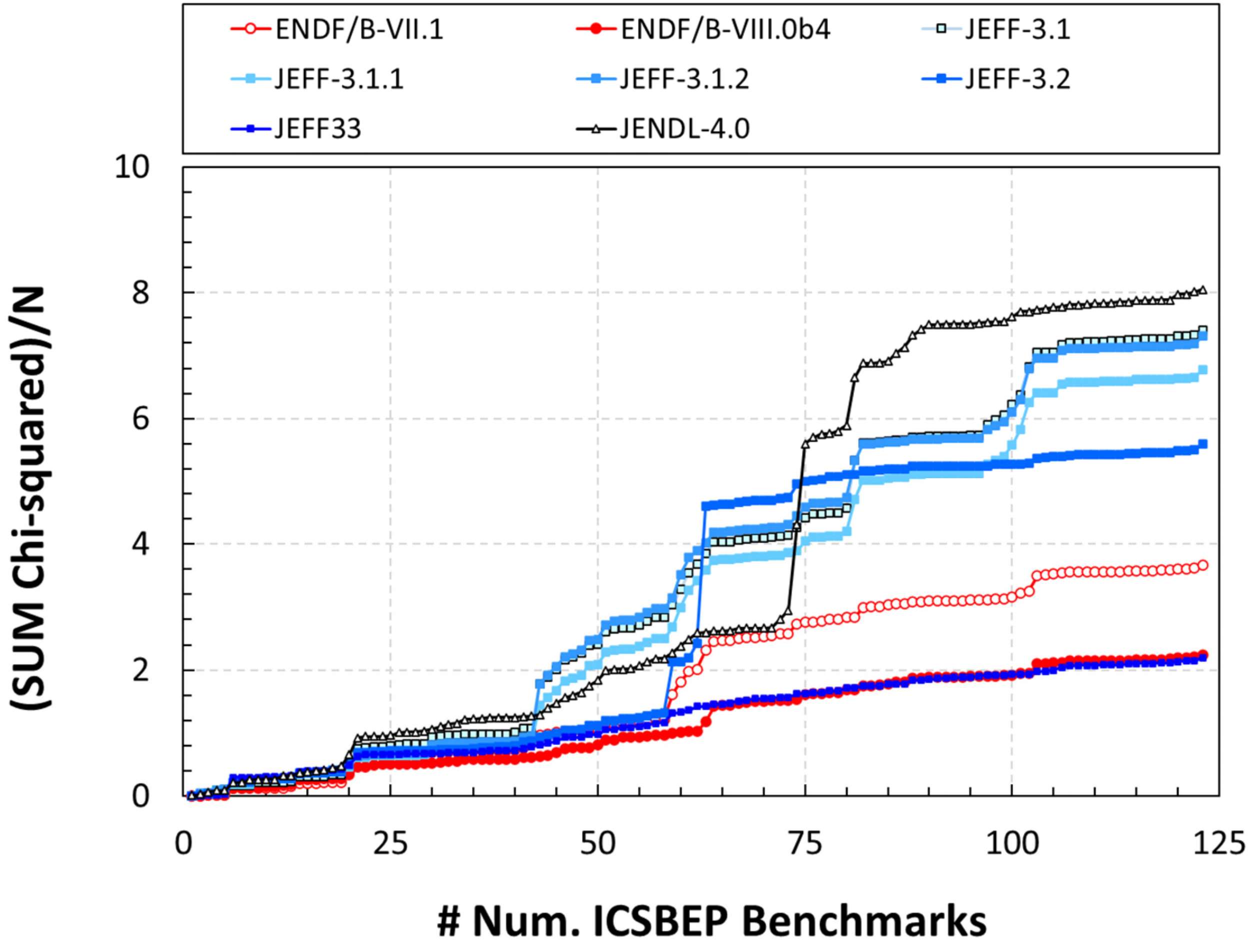
Version	Year released	Comments
	1981	The **Joint Evaluated File** (JEF) project starte Japanese effort on nuclear data evaluation in order to create
JEF-1	1986	The library contains information for neutron i d files from different institutions were converted into a sta e was not available in the US.
JEF-2.2	1992	The Joint Evaluated File (JEF)-2.2 contains c attering law data for 5 materials as well as special purpos otopes), fission yields data (fissile nuclides)
JEFF-3.0	2002	The **Joint Evaluated Fission and Fusion Fi** als as well as thermal scattering law data for 5 materials
JEFF-3.1	2005	JEFF-3.1 contains neutron reaction data (381 attering law data (9 materials), and incident proton data (2 well as special purpose files with radioactive decay data (385 tion data. JEFF-3.1 combines the efforts of the JEFF and EFF d to this combined fission and fusion file.
JEFF-3.1.1	2009	The JEFF-3.1.1 was an updated neutron file t ta and thermal neutron scattering law data are identical to JE so updated special purpose files with radioactive decay c
JEFF-3.1.2		This release was an update from JEFF-3.1.1 or elements were included
JEFF-3.2	2014	JEFF-3.2 was an update of the neutron file which contains 472 nuclides or elements and thermal neutron scattering law data for 10 materials
JEFF-3.3	2017	JEFF-3.3 is a thorough update of the neutron (563 materials), decay data (3852 files), fission yields, dpa (81 materials) and neutron activation libraries in the EAF format, with neutron thermal scattering files (20 compounds). Special sub-libraries for incident alphas (2809 files), deuterons (2811), gammas (2809), helium-3 (2806), protons (2804) and tritons have been contributed by the TENDL-2017 library and adopted as part of the JEFF-3.3 release



https://link.springer.com/content/pdf/10.1140/epja/s10050-020-00141-9.pdf

Benchmarking JEFF-3.3

Figure 8. *Comparison of cumulative chi-2 values using ICSBEP-**123-Mosteller's suite***



- Figure of Merit

$$\chi^2 = \sum_{i=1}^{N} \frac{\left(k_{C,i} - k_{E,i}\right)^2}{\Delta k_{C,i}^2 + \Delta k_{E,i}^2}$$

Benchmarking JEFF-3.3 in ICSBEP

Table 2. *JEFF-3.3: Nuclear data - covariance data in ICSBEP benchmarks*

Case	#Becnhm Num.	Avg C/E	Avg 1σ C/E (pcm)	Avg 1σ Exp Unc (pcm)	Avg 1σ ND Unc (pcm)	% cases where C/E is within 1σ		
						Exp. Unc. Band	ND Unc. Band	Exp+ND Unc. Band
HEU	815	0.99999	795	373	1447	35.9	91.4	92.9
IEU	101	0.99974	432	462	1488	70.3	99.0	100
LEU	522	0.99892	470	258	935	57.3	88.5	89.9
PU	485	1.00094	743	408	1672	57.6	92.5	94.1
MIX	206	0.99664	897	407	969	31.1	70.9	78.2
U233	104	0.99599	1164	563	813	46.2	53.9	57.7
All	2233	0.99950	755	371	1320	47.3	87.9	**89.3**

Benchmarking JEFF-3.3 … compensating effects in ND

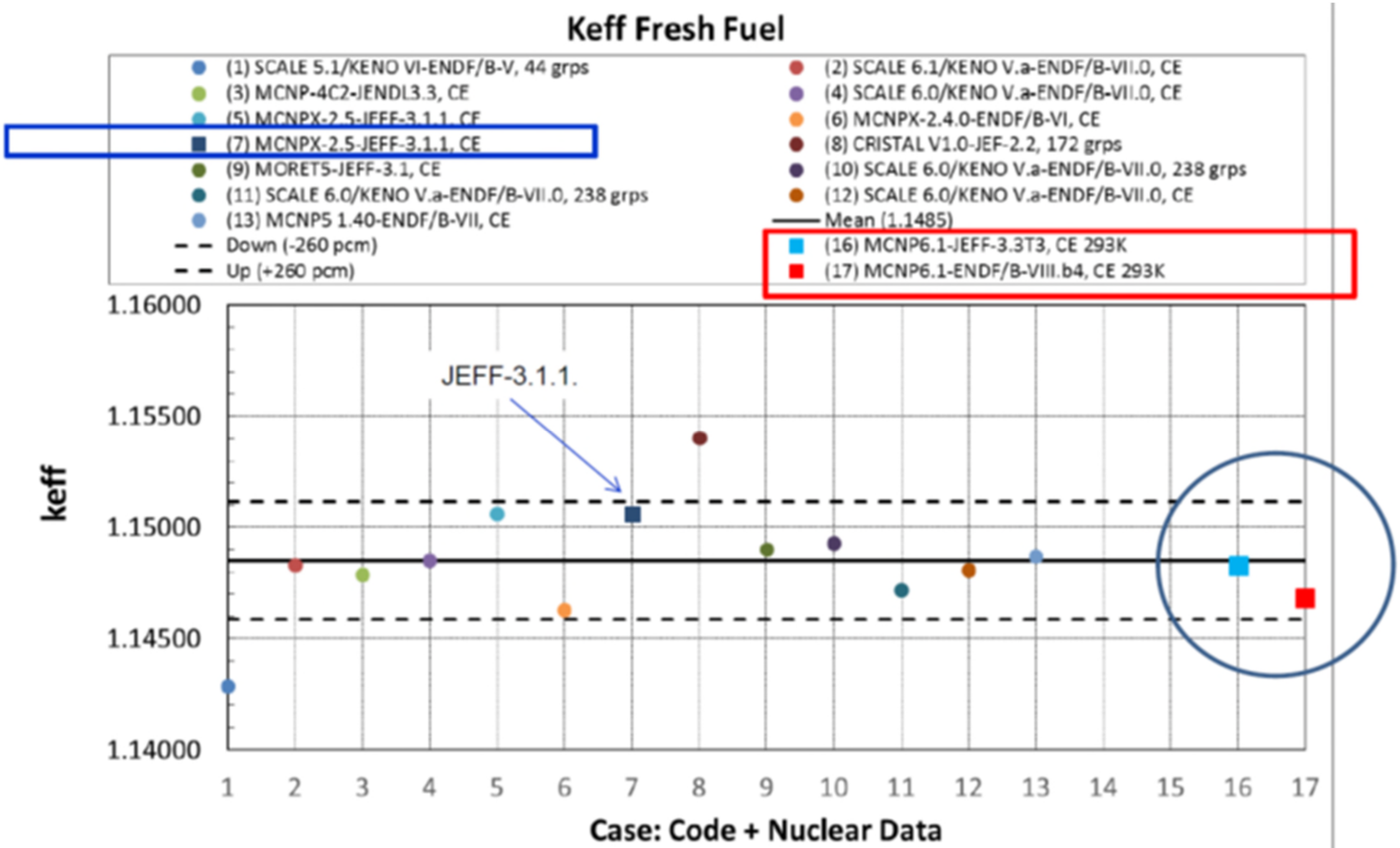
Table 3. *Bias and nuclear data uncertainties in HEU-MET-FAST-001 (Godiva)*

	JEFF-3.3		ENDF/B-VIII.0	JENDL-4.0u1
Exp. Uncertainty	±100		±100	±100
|C-E|	16		6	167
	NDAST	SANDY	NDAST	NDAST
Nubar	510	503	400	274
PFNS	364	216	124	176
Fission	648	643	788	320
Elastic	109	-	276	426
Inelastic	698	-	244	681
Capture	375	-	281	269
Correlated Sum	1342	1262	1036	962

- **Note:** (values in pcm)
- NDAST – sandwich formula
- Monte Carlo sampling using SANDY with 300 random samples

JEFF-3.3: Impact Studies – Spent Fuel Cask

Figure 9. *Comparison of keff results for fresh fuel for the 13 organizations participating in the* ***benchmark Phase VII exercise*** *with the criticality codes and nuclear data use*



JEFDOC-1844, April 2017

JEFF-3.3: Impact Studies – CSA of PWR spent fuel pool and storage cask

- **This work** presents the validation of JEFF-3.3 and ENDF/B-VIII.0 for PWR spent fuel pools and storage casks (NUREG/CR-6698)
- **This validation process is conducted in accordance with the recommendations**
  - 220 LCTs Benchmarks (keff-values provided by Steven van der Marck (NRG))
  - representative of the typical range of physical parameters (wt%235U, pitch, H/U, EALF, Boron) characterizing PWR spent fuel pools and storage casks with low-enriched UO2 fuel assemblies

Figure 10. *C/E trend as a function of EALF(eV)*

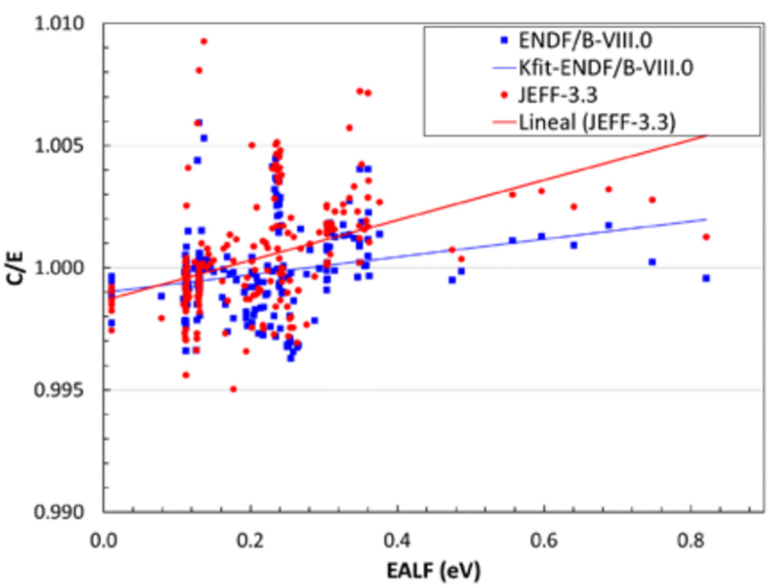


Table 4. KL (lower tolerance limit) and USL (Upper Safety Limit) predicted with JEFF-3.3 and ENDF/B-VIII.0

JEFF-3.3		ENDF/B-VIII.0	
KL	USL	KL	USL
0.99387	0.94387	0.99424	0.94424

$USL = K_L - \Delta_{SM}(5\%) - \Delta_{AOA}$

$\mathbf{K_L(JEFF\text{-}3.3) - K_L(ENDF/B\text{-}VIII.0) = -37pcm}$

JEFDOC-2041, April 2021

JEFF-3.3: Impact Studies – PWRs

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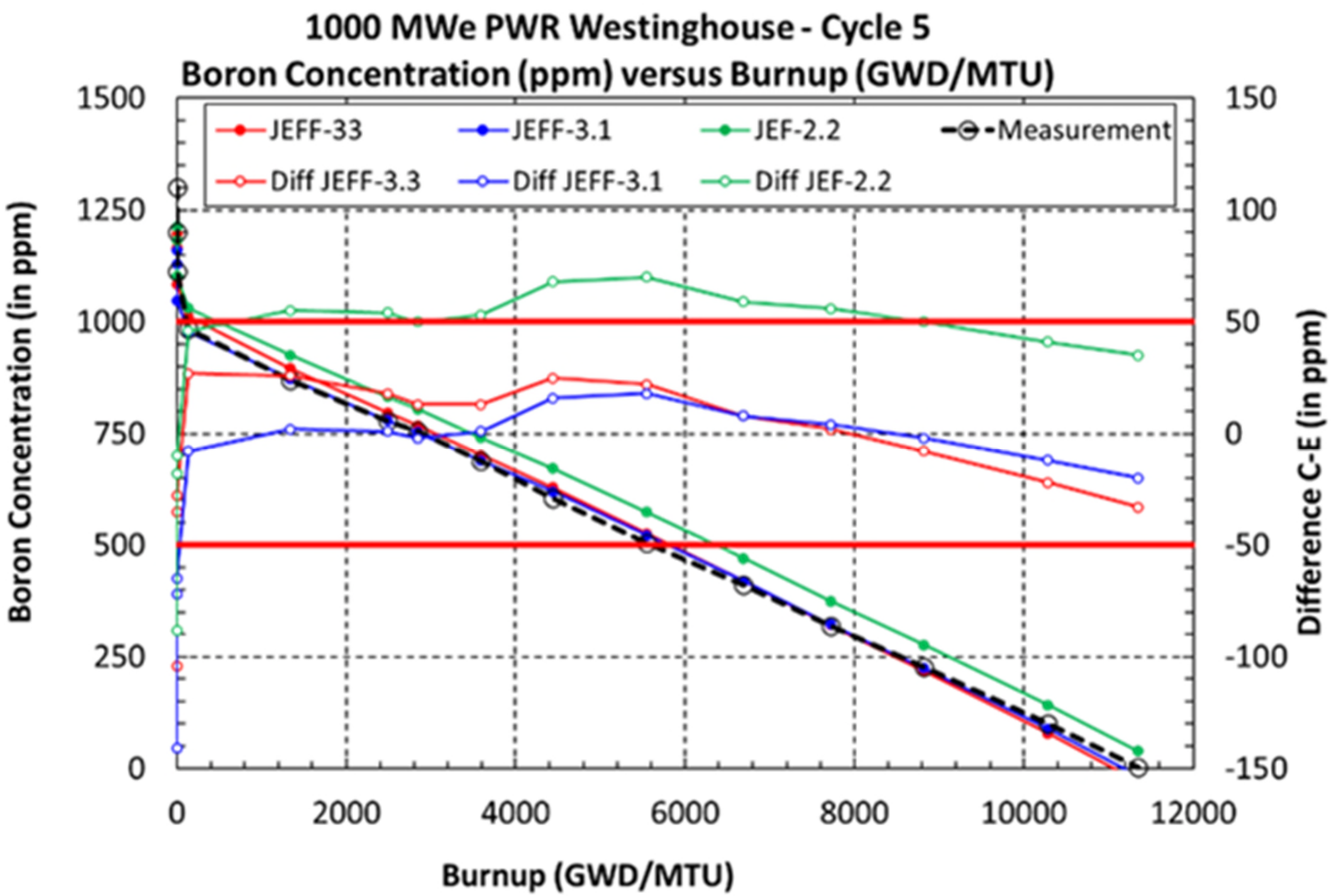
Figure 11. *Boron let-down curve in a 1000 Mwe PWR Westinghouse. Calculations performed with the SEANAP system with different nuclear data libraries*



JEFDOC-1968, April 2019

Some slides of this presentation are included in the course on "Nuclear data for energy and non-energy applications" of the GREaT-PIONEeR ("***Gr**aduate **E**ducation **A**lliance for **T**eaching the **P**hysics and safety of **N**uclear **R**eactors*" - https://great-pioneer.eu) that has received funding from the European Union's Euratom research and training programme 2019-2020 under the Grant Agreement n° 890675.

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