



# ENDF

G.P.A. Nobre\*  
On behalf of the USNDP

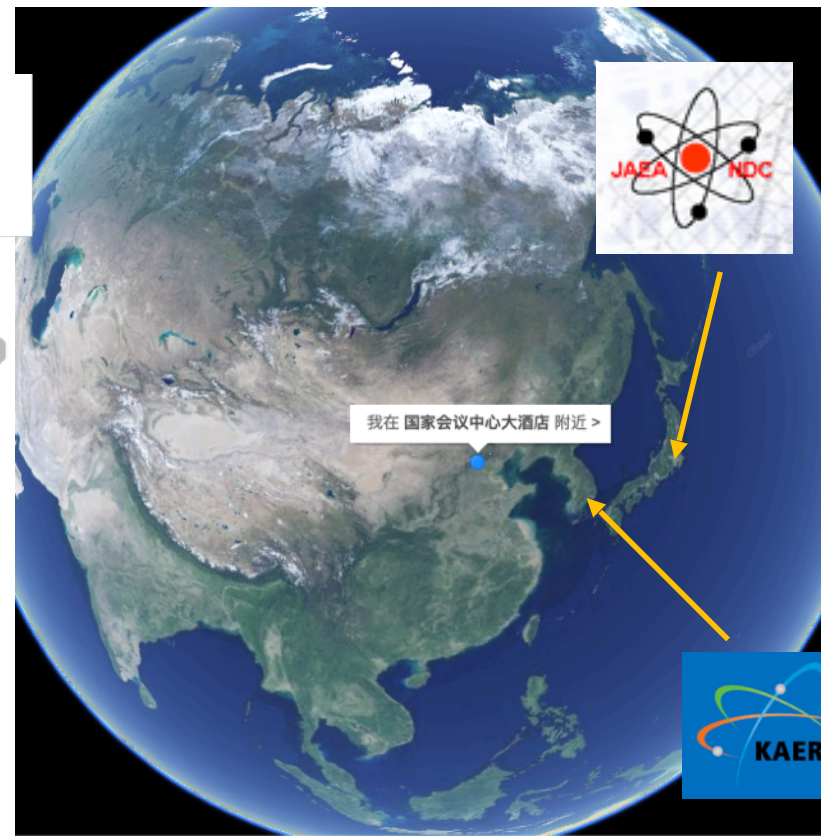


\*National Nuclear Data Center, Brookhaven National Laboratory



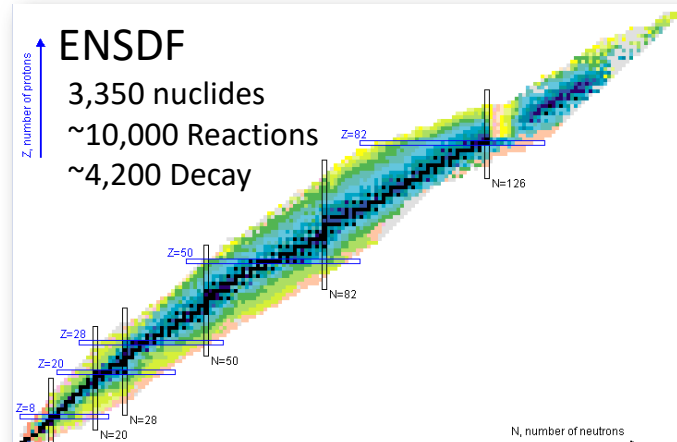


# CSEWG is not limited to the Americas

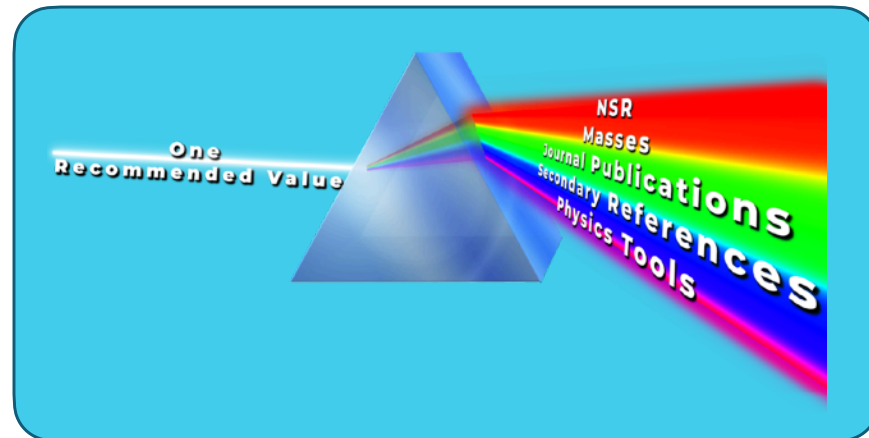


# ENSDF and ENDF

## Evaluated Nuclear Structure Data File



It is Unique: Only Nuclear Database of this kind in the world  
It is Complete: **All** nuclei and **all** level and radiation properties  
It is Versatile: Feeds back into both basic and applied sciences



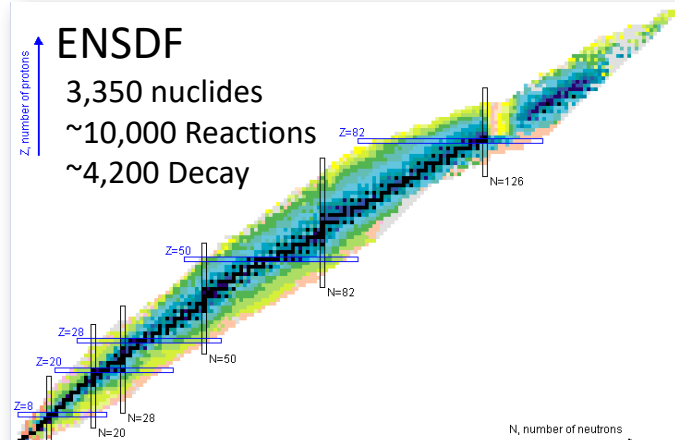
For **important** properties of **every** nucleus that's been measured

Critical evaluation of more than 100,000 primary publications

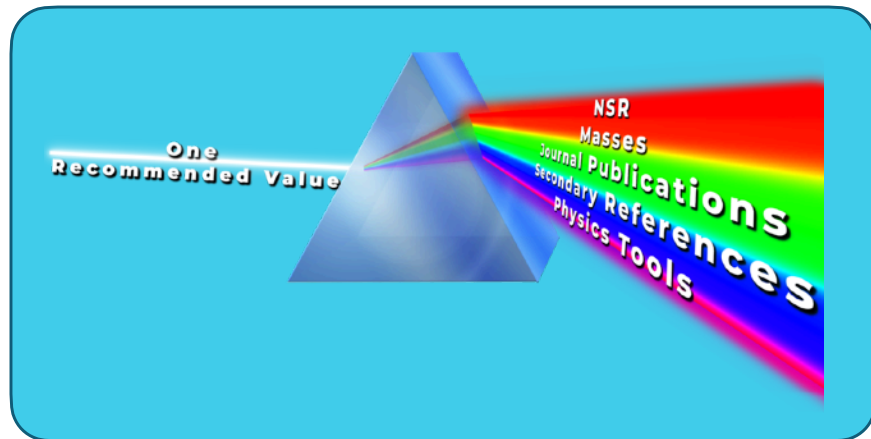


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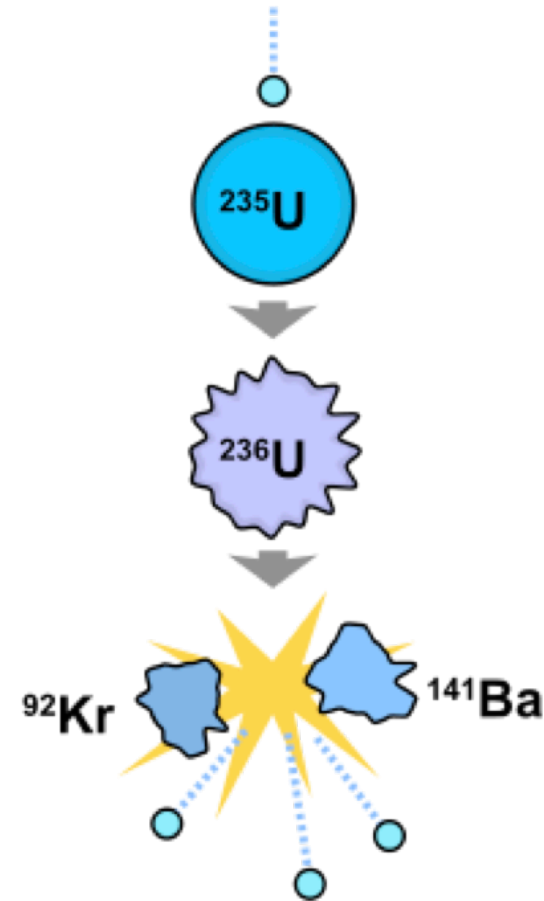


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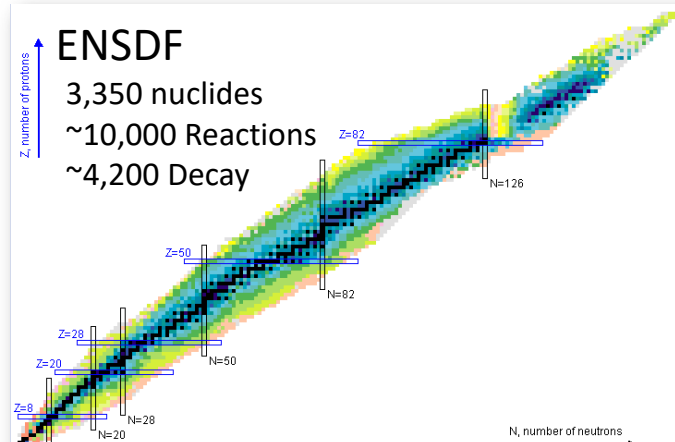
## Evaluated Nuclear Data File: Nuclear reactions

A reaction evaluation is the description of 1 target + 1 projectile  
(... and anything that can happen because of it!)

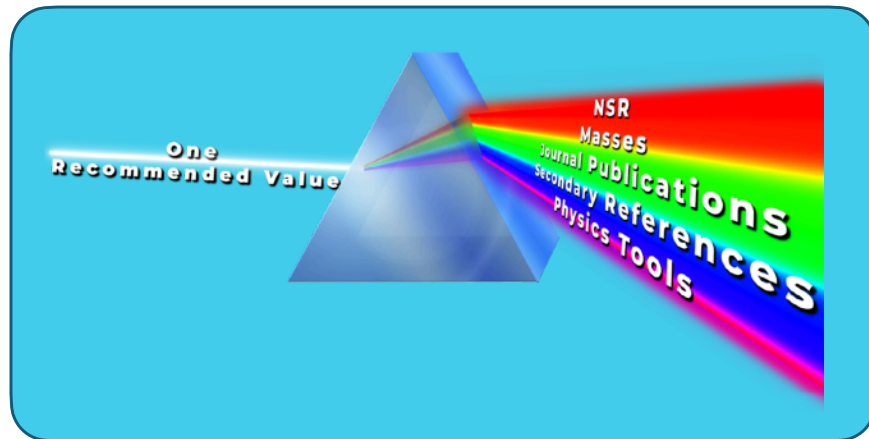


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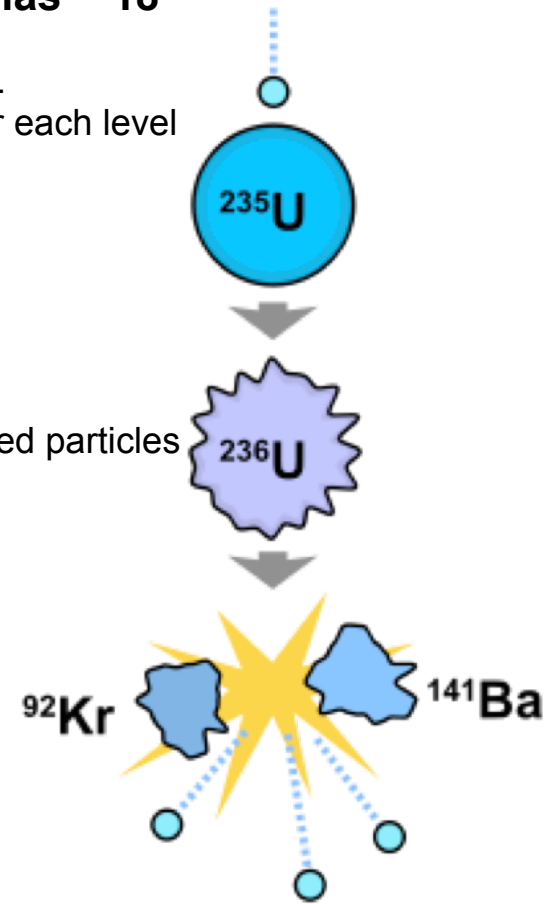
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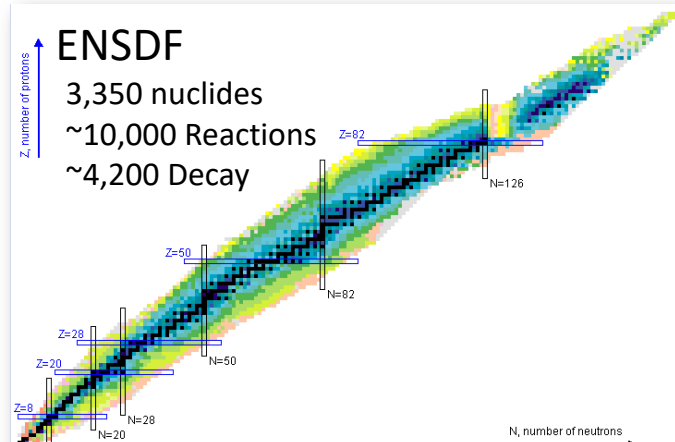
- **Typical neutron incident on non-actinide has ~ 18 relevant reactions**
  - ~ 5 threshold reactions:  $(n,2n)$ ,  $(n,3n)$ ,  $(n,p)$ , etc.
  - ~ 10 discrete level excitation reactions:  $(n,n')$  for each level in residual nucleus
  - 3 non-threshold reactions:  $(n,tot)$ ,  $(n,el)$ ,  $(n,\gamma)$
- **Actinides add fission,  $(n,f)$**
- **For transport studies, need:**
  - Cross sections
  - Multiplicities of all emitted particles
  - Outgoing energy-angle distributions for all emitted particles



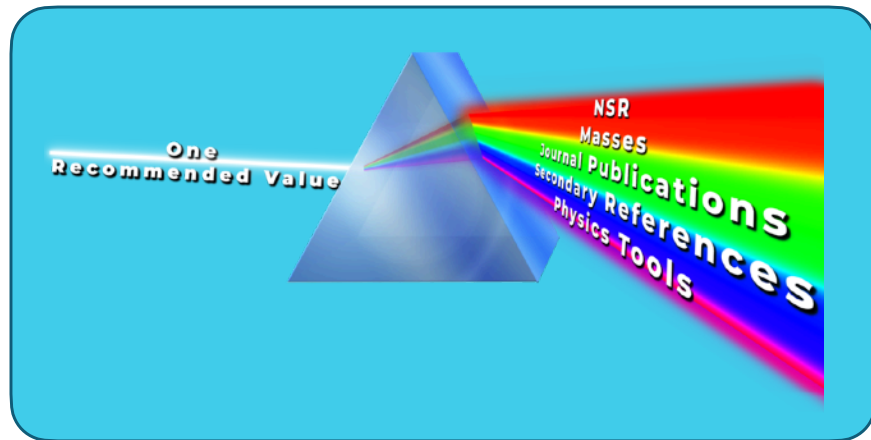


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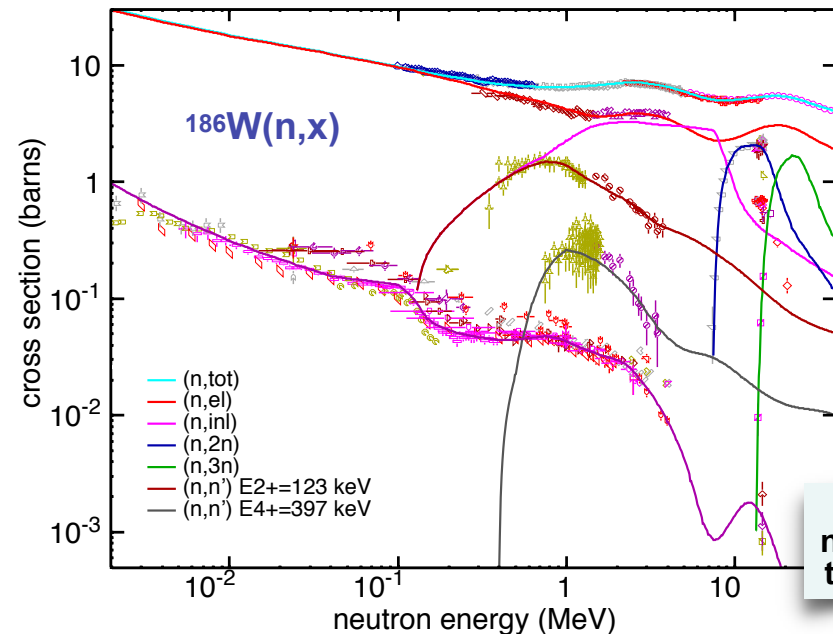
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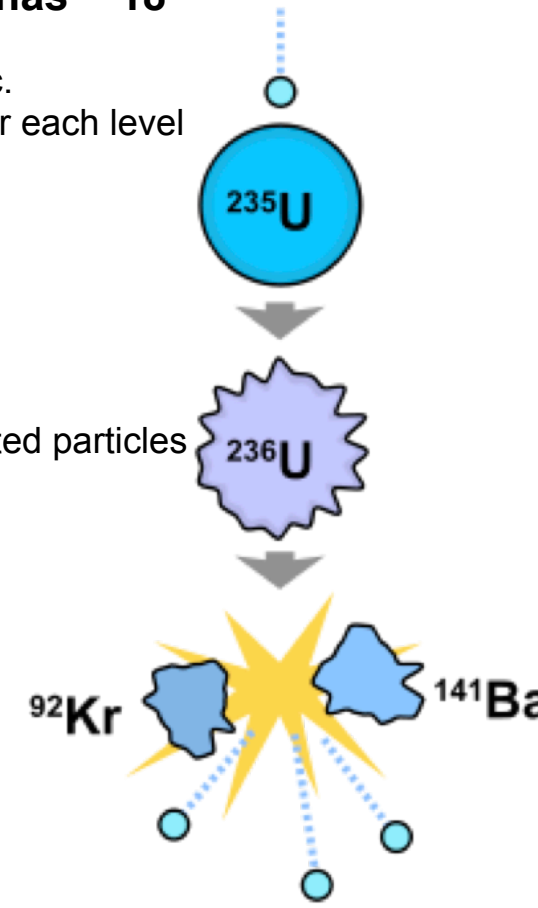
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  - Multiplicities of all emitted particles
  - Outgoing energy-angle distributions for all emitted particles



Experimental data never enough: need theory to fill in gaps



# This is really, really impactful!



## Nuclear Data Sheets 148, 1-142 (2018)



Nuclear Data Sheets  
Volume 148, February 2018, Pages 1-142



### ENDF/B-VIII.0: The 8<sup>th</sup> Major Release of the Nuclear Reaction Data Library with CIELO-project Cross Sections, New Standards and Thermal Scattering Data

D.A. Brown<sup>a</sup>, M.B. Chadwick<sup>b</sup>, R. Capote<sup>c</sup>, A.C. Kahler<sup>b</sup>, A. Trkov<sup>d</sup>, M.W. Herman<sup>e</sup>, A.A. Sonzogni<sup>f</sup>, Y. Danon<sup>g</sup>, A.D. Carlson<sup>h</sup>, M. Dunn<sup>i</sup>, D.L. Smith<sup>j</sup>, G.M. Hale<sup>k</sup>, G. Arbanas<sup>l</sup>, R. Arcilla<sup>m</sup>, C.R. Bates<sup>n</sup>, B. Beck<sup>o</sup>, B. Becker<sup>p</sup>, F. Brown<sup>q</sup>, R.J. Casperson<sup>r</sup>, J. Conlin<sup>s</sup>, D.E. Cullen<sup>t</sup>, M.-A. Descalle<sup>u</sup>, R. Firestone<sup>v</sup>, I. Gaines<sup>w</sup>, K.H. Guber<sup>x</sup>, A.J. Hawari<sup>y</sup>, J. Holmes<sup>z</sup>, T.D. Johnson<sup>aa</sup>, T. Kawano<sup>ab</sup>, B.C. Kiedrowski<sup>ac</sup>, A.J. Koning<sup>ad</sup>, S. Kopecky<sup>ae</sup>, L. Leal<sup>af</sup>, J.P. Lestone<sup>ag</sup>, C. Lubitz<sup>ah</sup>, J.L. Márquez Damián<sup>ai</sup>, C.M. Mattoon<sup>aj</sup>, E.A. McCuschan<sup>ak</sup>, S. Mughabghab<sup>al</sup>, P. Navrátil<sup>am</sup>, D. Neudecker<sup>an</sup>, G.P.A. Nobre<sup>ao</sup>, G. Noguere<sup>ap</sup>, M. Paris<sup>aq</sup>, M.T. Pigni<sup>ar</sup>, A.J. Plompen<sup>as</sup>, B. Pritychenko<sup>at</sup>, V.G. Prinyayev<sup>au</sup>, D. Roubtsov<sup>av</sup>, D. Rochman<sup>aw</sup>, P. Romano<sup>ax</sup>, P. Schillebeeckx<sup>ay</sup>, S. Simakov<sup>az</sup>, M. Sin<sup>ba</sup>, J. Sirakov<sup>bb</sup>, B. Sleaford<sup>bc</sup>, V. Sobes<sup>bd</sup>, E.S. Soukhovitskii<sup>be</sup>, I. Stetcu<sup>bf</sup>, P. Talou<sup>bg</sup>, I. Thompson<sup>bh</sup>, S. van der Marck<sup>bi</sup>, L. Welser-Sherrill<sup>bj</sup>, D. Wierda<sup>bk</sup>, M. White<sup>bl</sup>, J.L. Wormald<sup>bm</sup>, R.Q. Wright<sup>bn</sup>, M. Zerkle<sup>bo</sup>, G. Zerovnik<sup>bp</sup>, Y. Zhu<sup>bq</sup>

Cited 1,658 times!





# This is really, *really* impactful!

Nuclear Data Sheets 112, 2887-2996 (2011)



Nuclear Data Sheets  
Volume 112, Issue 12, December 2011, Pages 2887-2996



ENDF/B-VII.1 Nuclear Data for Science and Technology: Cross Sections, Covariances, Fission Product Yields and Decay Data

M.B. Chadwick<sup>a</sup>, M. Herman<sup>b</sup>, P. Obložinský<sup>b</sup>, M.E. Dunn<sup>c</sup>, Y. Danon<sup>d</sup>, A.C. Kahler<sup>a</sup>, D.L. Smith<sup>b</sup>, B. Pritychenko<sup>b</sup>, G. Arbanas<sup>e</sup>, R. Arcilla<sup>b</sup>, R. Brewer<sup>a</sup>, D.A. Brown<sup>b</sup>, R. Capote<sup>f</sup>, A.D. Carlson<sup>g</sup>, Y.S. Cho<sup>h</sup>, H. Derrien<sup>i</sup>, K. Guber<sup>j</sup>, G.M. Hale<sup>k</sup>, S. Hoblit<sup>l</sup>, S. Holloway<sup>m</sup>, T.D. Johnson<sup>n</sup>, T. Kawano<sup>o</sup>, B.C. Kiedrowski<sup>p</sup>, H. Kim<sup>q</sup>, S. Kunieda<sup>r</sup>, N.M. Larson<sup>s</sup>, L. Leal<sup>t</sup>, J.P. Lestone<sup>u</sup>, R.C. Little<sup>v</sup>, E.A. McCutchan<sup>w</sup>, R.E. MacFarlane<sup>x</sup>, M. MacInnes<sup>y</sup>, C.M. Mattoon<sup>z</sup>, R.D. McKnight<sup>aa</sup>, S.F. Mughabghab<sup>ab</sup>, G.P.A. Nobre<sup>ac</sup>, G. Palmiotti<sup>ad</sup>, A. Palumbo<sup>ae</sup>, M.T. Pigni<sup>af</sup>, V.G. Proryaev<sup>ag</sup>, R.O. Sayer<sup>ah</sup>, A.A. Sonzogni<sup>ai</sup>, N.C. Summers<sup>aj</sup>, P. Talou<sup>ak</sup>, I.J. Thompson<sup>al</sup>, A. Trkov<sup>am</sup>, R.L. Vogt<sup>an</sup>, S.C. van der Marck<sup>ao</sup>, A. Wallner<sup>ap</sup>, M.C. White<sup>aq</sup>, D. Wiarda<sup>ar</sup>, P.G. Young<sup>as</sup>

Cited 3,138 times!

Nuclear Data Sheets, 107 (2006), p. 2931



Nuclear Data Sheets  
Volume 107, Issue 12, December 2006, Pages 2931-3060



ENDF/B-VII.0: Next Generation Evaluated Nuclear Data Library for Nuclear Science and Technology

Cited 2,753 times!

## ENDF B-VIII.0

Nuclear Data Sheets 148, 1-142 (2018)



Nuclear Data Sheets  
Volume 148, February 2018, Pages 1-142



ENDF/B-VIII.0: The 8<sup>th</sup> Major Release of the Nuclear Reaction Data Library with CIELO-project Cross Sections, New Standards and Thermal Scattering Data

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Volume 148, February 2018 ISSN 0969-3752

## Nuclear Data Sheets

A Journal Devoted to Compilations and Evaluations of Experimental and Theoretical Results in Nuclear Physics

E. A. McCutchan, Editor  
National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY 11973-5000, USA  
www.nndc.bnl.gov

Special Issue on Nuclear Reaction Data

Special Issue Editor: Pavel Obložinský  
Special Issue Assistant Editor: Boris Pritychenko

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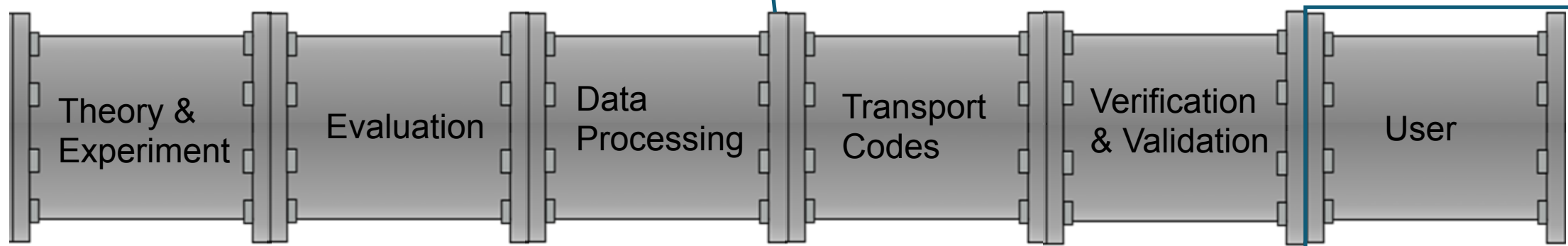
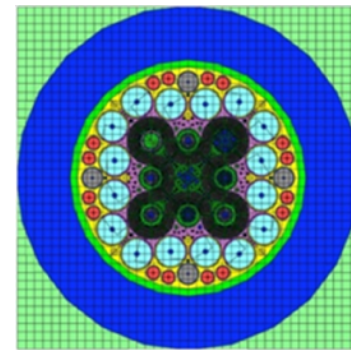
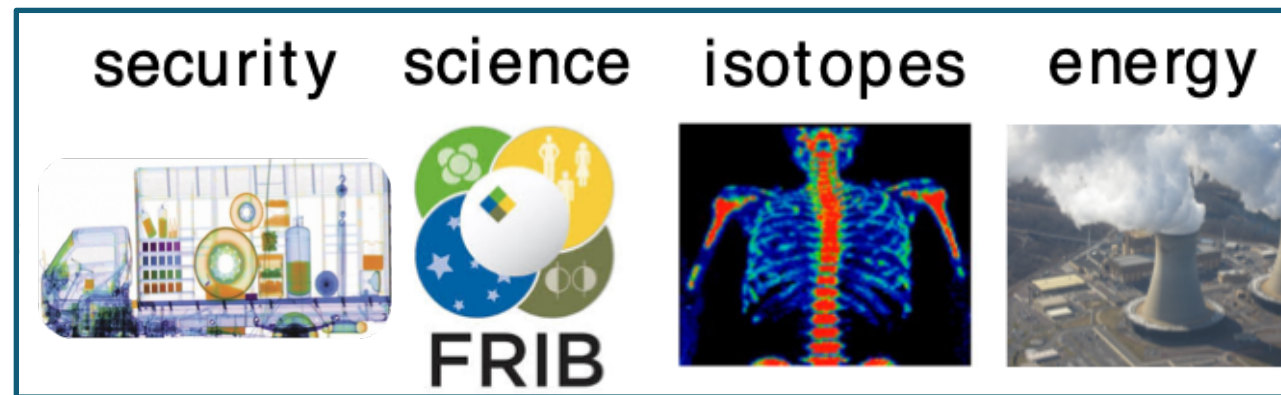
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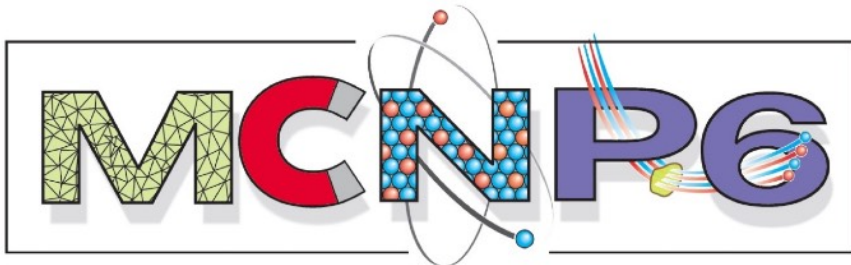
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# The Nuclear Data Pipeline

Our goal is to get the highest quality data to users

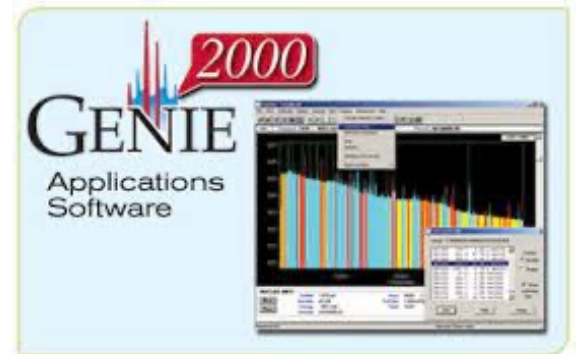
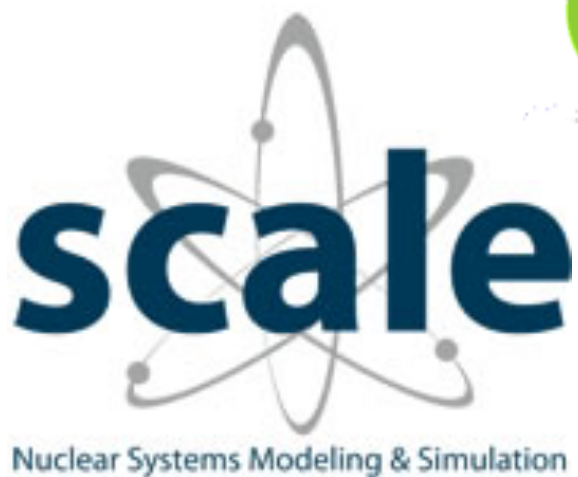






**Many software packages use embedded ENDF/B data**

- Reactor design, simulation and licensing codes.
- Nuclear waste and repositories.
- Radiation spectroscopy, dose, detectors and shielding.
- Defense and CTBTO.



# The Cross Section Evaluation Working Group produces ENDF/B library



- Formed 1966 & Chaired by BNL
- Currently ~200 members of the collaboration from 25 institutions
  - US programs, industry and international partners
  - If you see something in the library, at some point a sponsor somewhere wanted it
- All steps of nuclear data pipeline coordinated through CSEWG
- Depending on what needs to be done, getting required data in library can be major effort

**We are always open to new users  
and collaborators**



CSEWG collaboration meeting in November 2022: our first in-person meeting since the pandemic started!

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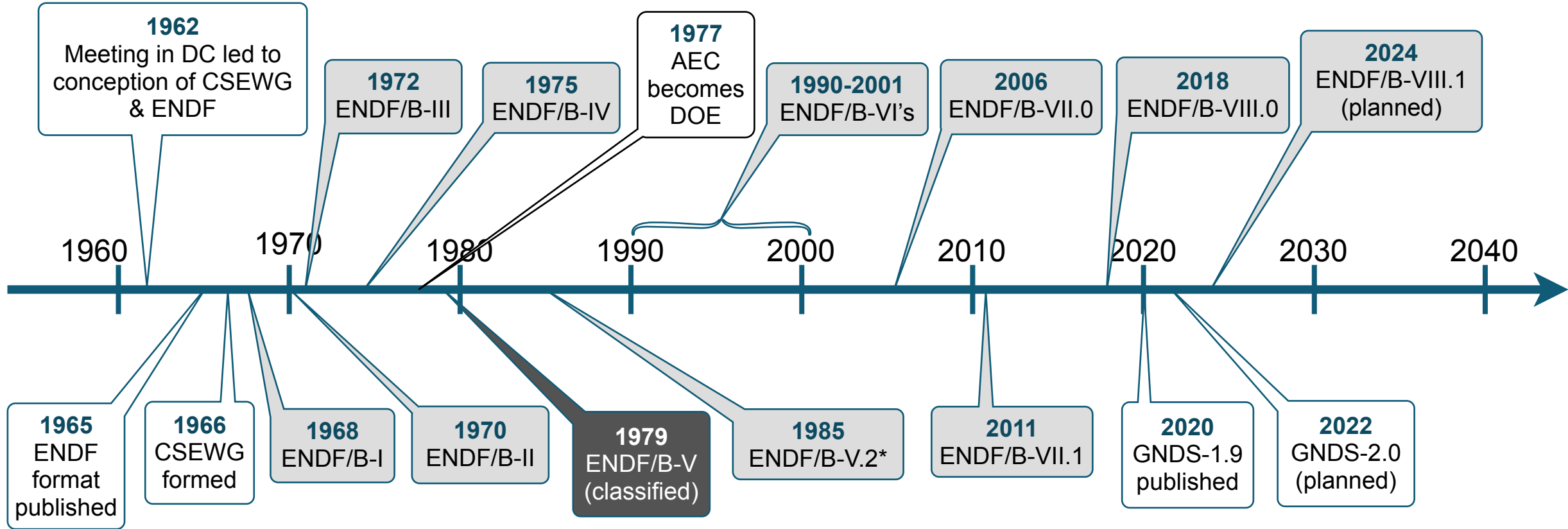


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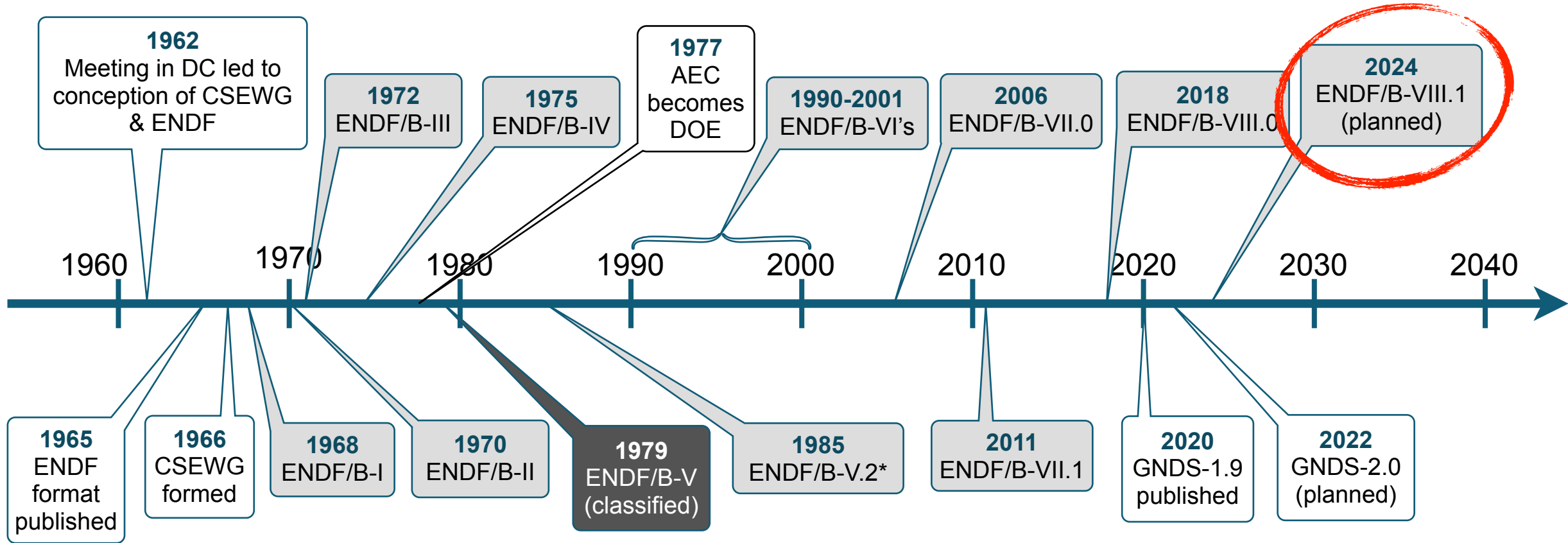


# ENDF Timeline



\* everybody's favorite release

# ENDF Timeline



\* everybody's favorite release

# ENDF/B-VIII.1 release

The next release of the ENDF/B library is scheduled for **February 2024!**

Although technically “minor”, it will have major impact.




- Why **VIII.1** and not **IX**?
  - There are no planned updates of the standards library for this release
  - Standards are well-established cross sections, in specific energy ranges, used in ratios with other measurements
  - However, many, many important and impactful changes are on the way!!
- Next release will be in both legacy **ENDF-6** format and **GNDS-2.0**
- Will have an accompanying “**Big Paper**”
- Implemented review system: Multiple VIII.1 Beta versions have been released
- Preliminary validation indicate that this will be the best-performing library ever!

**ENDF/B**  
**VIII.1-β2**



# ENDF versioned repository: GitLab

USNDP Collaboration Platform



The U.S. nuclear data community working together to continuously advance the state of nuclear data for science and technology applications.

NOTICE TO USERS

This is a Federal computer system (and/or it is directly connected to a BNL local network system) and is the property of the United States Government. It

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ENDF/B library

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ENDF > library

















ENDF/B VIII.dev library Group ID: 8 [Leave group](#) [New subgroup](#) [New project](#)

The ENDF library project itself. At the time of creation of this project area, ENDF comprises 15 sublibraries. The full ENDF/B history is available as an archived project named "svn-export". See the "README" in each project for more information.

Recent activity Last 30 days

Merge requests created	327	Issues created	12	Members added	0
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Subgroups and projects Shared projects Archived projects  Updated

 <b>neutrons</b> ENDF/B neutron sublibrary <span>★ 2</span> 55 minutes ago
 <b>sfy</b> ENDF/B spontaneous FPY sublibrary <span>★ 0</span> 4 days ago
 <b>nfy</b> ENDF/B neutron FPY sublibrary <span>★ 0</span> 4 days ago
 <b>gammas</b> ENDF/B gamma sublibrary <span>★ 0</span> 2 weeks ago
 <b>thermal_scatt</b> ENDF/B thermal neutron scattering sublibrary <span>★ 1</span> 2 weeks ago
 <b>helium3s</b> ENDF/B 3He sublibrary <span>★ 0</span> 2 months ago
 <b>deuterons</b> ENDF/B deuteron sublibrary <span>★ 0</span> 3 months ago
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 <b>alphas</b> ENDF/B alphas sublibrary <span>★ 1</span> 4 months ago
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 <b>standards</b> ENDF/B nuclear data standards sublibrary <span>★ 0</span> 5 months ago
 <b>atomic_relax</b> ENDF/B atomic relaxation sublibrary <span>★ 0</span> 8 months ago
 <b>electrons</b> ENDF/B electron sublibrary <span>★ 1</span> 8 months ago
 <b>super</b> Super project for the entire ENDF library. <span>★ 0</span> 1 year ago
 <b>photoat</b> ENDF/B photo-atomic sublibrary <span>★ 0</span> 2 years ago

- Constantly updated and maintained
- Keeps track of
  - Any changes
  - Development, review and release branches
  - Issue trackers
  - etc...
- Usage is growing! Currently ~60 active members in ENDF library group (unfortunately there's a seat limit)
- Integration of library repository in GitLab with a **Continuous Integration system: ADVANCE** (R. Arcilla, R. Coles, B. Shu, D. Brown)

# ENDF versioned repository: GitLab

USNDP Collaboration Platform



The U.S. nuclear data community working together to continuously advance the state of nuclear data for science and technology applications.

NOTICE TO USERS

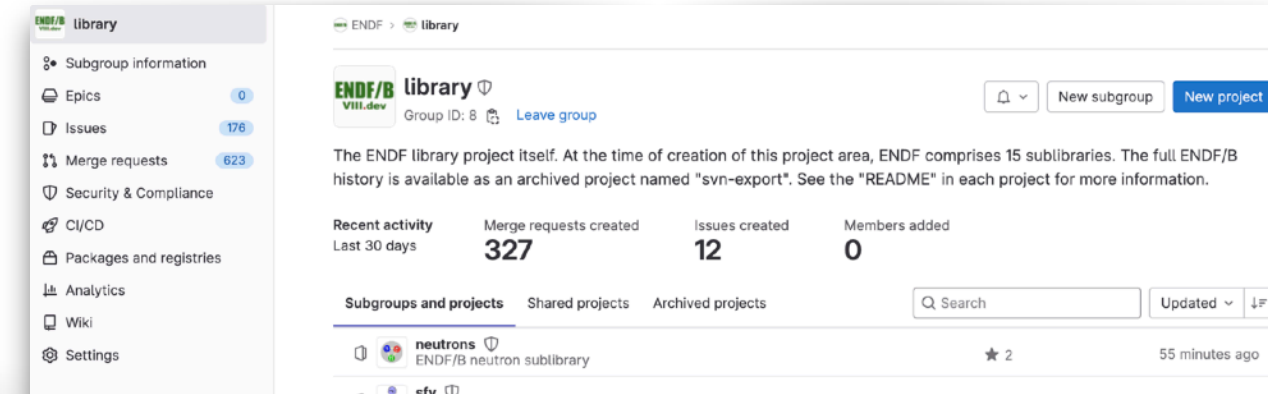
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ENDF/B library

Subgroup information

- Epics 0
- Issues 176
- Merge requests 623
- Security & Compliance
- CI/CD
- Packages and registries
- Analytics
- Wiki
- Settings

ENDF/B library

Group ID: 8 [Leave group](#)

The ENDF library project itself. At the time of creation of this project area, ENDF comprises 15 sublibraries. The full ENDF/B history is available as an archived project named "svn-export". See the "README" in each project for more information.

Recent activity Last 30 days

Merge requests created	327	Issues created	12	Members added	0
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Subgroups and projects

Subgroup	Stars	Updated
neutrons	2	55 minutes ago
sfy	0	4 days ago
	0	4 days ago
	0	2 weeks ago
	1	2 weeks ago
	0	2 months ago
	0	3 months ago
	2	4 months ago
protons	0	4 months ago
alphas	1	4 months ago
tritons	0	4 months ago
standards	0	5 months ago
atomic_relax	0	8 months ago
electrons	1	8 months ago
super	0	1 year ago
photoat	0	2 years ago

- Constantly updated and maintained
- Keeps track of
  - Any changes
  - Development, review and release branches
  - Issue trackers
  - etc...
- Usage is growing! Currently ~60 active members in ENDF library group (unfortunately there's a seat limit)
- Integration of library repository in GitLab with a **Continuous Integration system: ADVANCE** (R. Arcilla, R. Coles, B. Shu, D. Brown)

CI/CD through Kubernetes system behind BNL firewall allows for full **automation** and for **machine-learning** approaches!

# What to expect when expecting... ... the ENDF/B-VIII.1 release

## Neutrons:

- Actinides:
    - **<sup>239</sup>Pu**: multi-institution effort, with important updates to fission, nubar, PFNS, capture, URR, RRR, (n,2n)
    - **<sup>235</sup>U**: resonances, nubar, covariances,
    - **<sup>238</sup>U**: resonance update to improve performance on depletion benchmarks
    - **<sup>240,241</sup>Pu**: work in concert with changes in <sup>239</sup>Pu and <sup>238</sup>U to recover burnup performance
  - Stainless steel & other structure materials:
    - **<sup>54,56,57</sup>Fe**: Corrects leakage deficiency from ENDF/B-VIII.0
    - **<sup>50,52,53,54</sup>Cr**: Thorough re-evaluation, impact in criticality and leakage benchmarks
  - **<sup>206,207,208</sup>Pb**: complete evaluations (RPI/LANL)
  - **<sup>63,65</sup>Cu**: improved performance
  - **<sup>55</sup>Mn**: Gamma spectra
  - **<sup>28,29,30</sup>Si**: resonance evaluations
- Others:
    - **<sup>6</sup>Li, <sup>9</sup>Be** (LANL)
    - **<sup>234,236</sup>U** (LANL)
    - **<sup>140,142</sup>Ce** (ORNL)
    - **<sup>103</sup>Rh** (RPI/IRSN)
    - **<sup>86</sup>Kr** (BNL)
    - **<sup>181</sup>Ta** (RPI/ORNL/LANL)
    - **<sup>95</sup>Mo** (IRSN/LANL)
    - Many, many, many more...



# What to expect when expecting the ENDF/B-VIII.1 release

## TSL:

- 70+ new updated/files
- **Polystyrene, zirconium hydride, UC, UN, UO<sub>2</sub>, sapphire, lucite, FLiBe, etc...**
- Fuel materials with different enrichments
- So many new evaluations that we had to re-think how to identify them.
- Possible tweaks to light water

- Community-wide review and validation

## Fission Yields:

- Many fixes

## Photo-nuclear:

- **200+** updates coming from IAEA CRP

## Charged particles:

- A few improvements and fixes

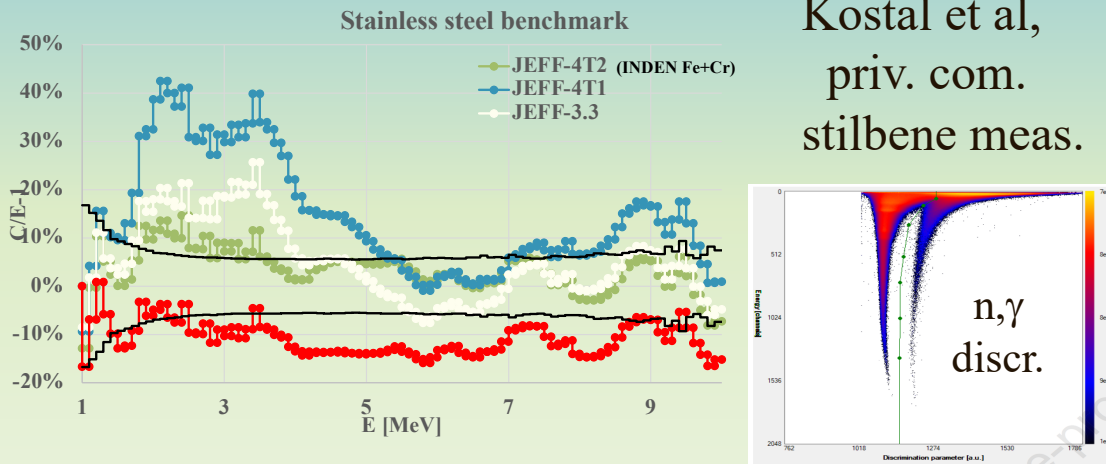
# Results sensitive to stainless steel

## INDEN updated “structural” evaluations:

see [nds.iaea.org/INDEN/](https://nds.iaea.org/INDEN/) - **Validation**

- ✓ Fe isotopes (IAEA/JSI), fe54e80o, fe56e80X29r41, fe54e80o
- ✓ Cr isotopes, BNL/ORNL/IAEA/JSI/CEA, v2.3.2

Kostal et al,  
priv. com.  
stilbene meas.



Stainless steel, neutron leakage (Rez, CZ, 11/2021)

The Pool Critical Assembly (PCA) Pressure Vessel Simulator experiment was performed in the early 1980s as part of the NRC’s LWR Pressure Vessel Surveillance Dosimetry Improvement Program (LWR-PV-SDIP)

Benchmark was recently re-analyzed with exact geometry by Dr. Kulesza (LANL/X-5), and MCNP inputs were published and available for use:  
 – NUCLEAR TECHNOLOGY · VOLUME 197 · 284–295 · MARCH 2017  
 – Paper: <https://doi.org/10.1080/00295450.2016.1273711>  
 – MCNP Inputs: <https://doi.org/10.2172/1601379>

## Pool Critical Assembly Benchmarking

- C/E Results (ENDF/B-VIII.1b1):  
 – MC uncertainty  $\approx 1\%$

**Depends on U-235, water & SS**

	al27a	ni48p	rh103n	in115n	u238f	np237f	avg	std dev
	0.97	0.96	1.04	1.00			<b>0.99</b>	3.9%
	1.02	0.98	1.08	1.01			<b>1.02</b>	4.3%
	1.05	1.01	1.07	1.06			<b>1.05</b>	2.5%
	1.03	0.96	1.00	1.01	0.98	1.03	<b>1.00</b>	2.7%
	1.03	0.96	0.95	1.00	0.98	1.05	<b>0.99</b>	4.0%
	1.04	1.02	0.93	1.03	0.98	1.03	<b>1.00</b>	4.1%
			0.96	0.99	0.99	1.13	<b>1.02</b>	7.6%
avg	<b>1.02</b>	<b>0.98</b>	<b>1.01</b>	<b>1.01</b>	<b>0.98</b>	<b>1.06</b>	<b>1.01</b>	
std dev	2.8%	2.9%	6.4%	2.1%	0.1%	1.0%		4.2%

Presented by Greg Fischer, Westinghouse @ miniCSWEG April 2023

4 Mini-CSWEG meeting (presented by video link)  
April 2023, Livermore Valley Open Campus, CA

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Slides taken from Roberto Capotes’s talk at 2023 mini-CSEWG

- Significant performance improvements in SS (Fe and Cr)
- Users are happy with new files!

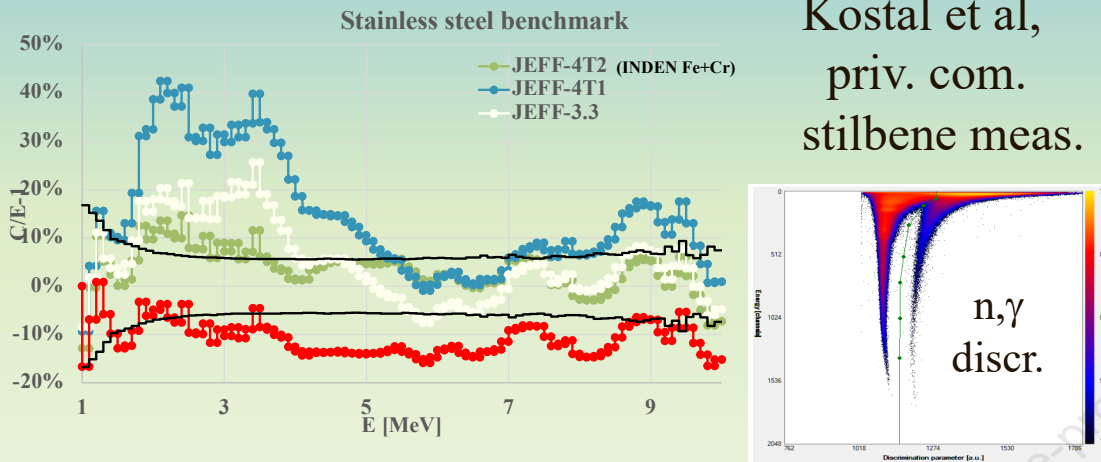
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	1.03	0.96	0.95	1.00	0.98	1.05	<b>0.99</b>	4.0%
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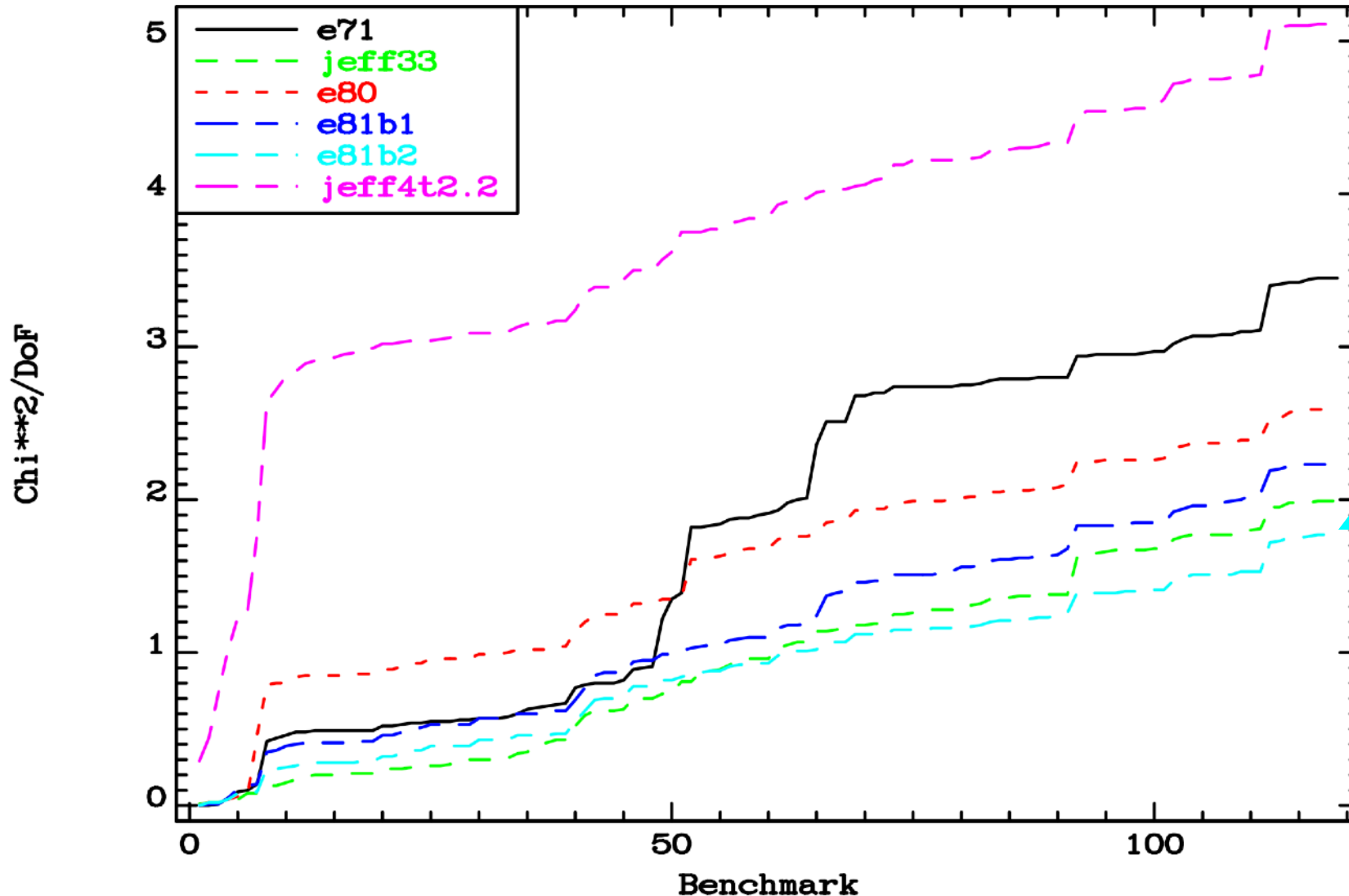
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# Preliminary validation on Beta2, by Andrej Trkov (JSI)

LANL (Mosteller) suite of benchmarks  
Cumulative  $\chi^2$  per degree of freedom



ENDF/BVIII.1 is on track to be the best-performing library to-date!

**Caveat:** Cumulative  $\chi^2$  of benchmarks provide only a global view. Detailed investigation of performance on specific benchmark are also important.

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- Managerial tasks and the relentless passing of time is chipping away capabilities related to USNDP goals
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We need to rebuild and maintain evaluation capabilities and infrastructure, in alignment with USNDP ENDF goals

# Acknowledgements

This work was supported by the Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the U.S. Department of Energy. Additionally, work at Brookhaven National Laboratory was sponsored by the Office of Nuclear Physics, Office of Science of the U.S. Department of Energy under Contract No. DE-SC0012704 with Brookhaven Science Associates, LLC.