The ENDF/B-VIII Library

D. Brown

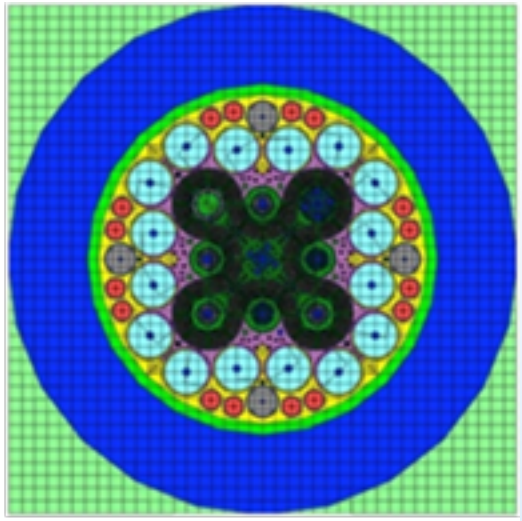
BROOKHAVEN NATIONAL LABORATORY

a passion for discovery

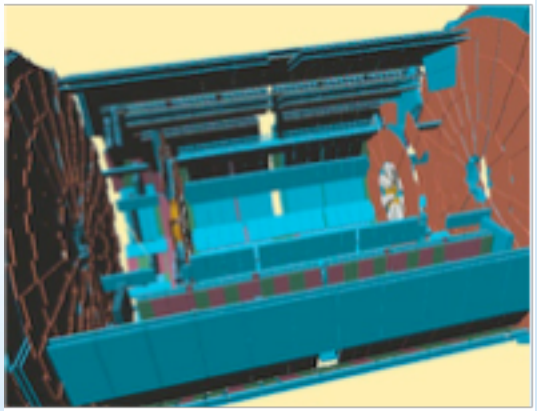
U.S. DEPARTMENT OF ENERGY | Office of Science

Users most likely interact with ENDF/B data using application codes

- **Particle transport codes (e.g. MCNP6, SCALE, & GEANT4) use transport data**
  - used for simulating nuclear energy generation
  - shielding and health physics calculations
- **Isotope burn-up codes (e.g. ORIGEN & CINDER) use cross sections and decay data**
  - nuclear waste management
  - radiochemical applications
- **All have modules that use ENDF/ENSDF data**
- **Codes switch between models and data tables based on:**
  - speed
  - fidelity to physics
- **Other code systems also use covariance data to estimate nuclear data uncertainty in application metrics (e.g. TSUNAMI, WHISPER)**



SCALE model of INL Advanced Test Reactor

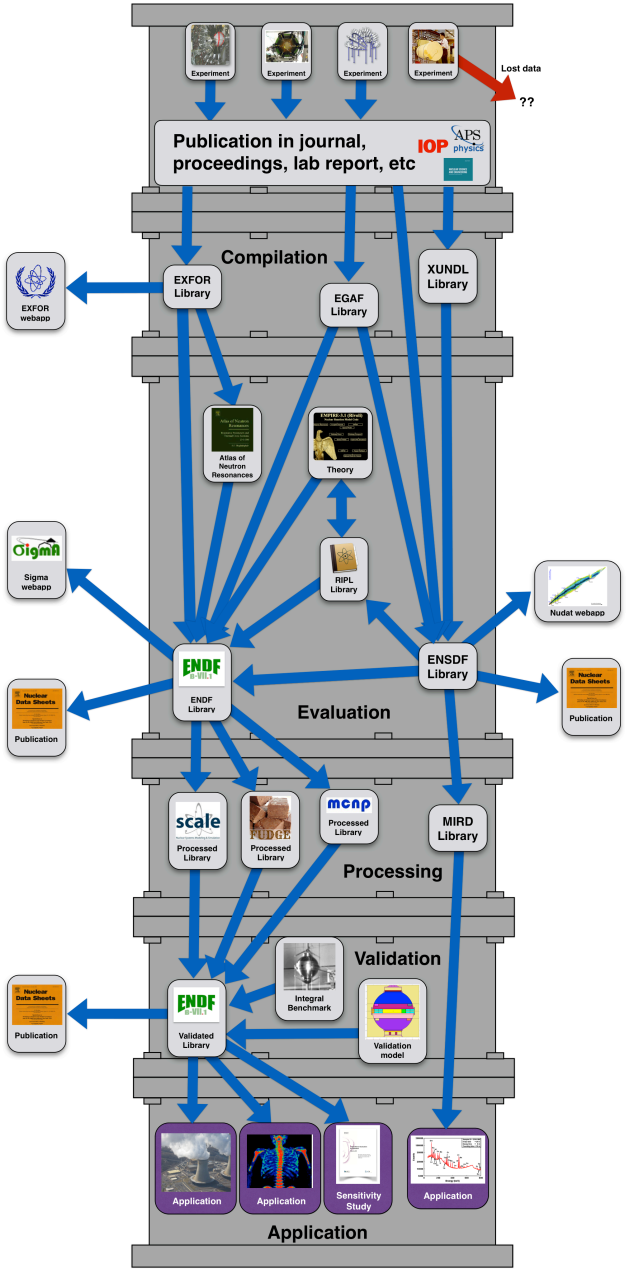


ATLAS detector muon system, simulated in GEANT4

The Nuclear Data Pipeline

- ***Compilation:*** **collect unevaluated data together**
- ***Evaluation:*** **combine all available information into one set of recommended values & covariance**
  - Embedding evaluator in experiment means evaluation can happen “in parallel” with analysis of experimental data
- ***Processing:*** **prepare data for use in an application code**
  - Automation with ADVANCE already has cut time of this step from months to hours; evaluators now get “instant” feedback
- ***Validation:*** **test data in simulation of a non-trivial but well understood nuclear system**
  - Further automation can speed up this step from months to a day or so, enabling “instant” feedback to evaluator

It can take years from the time an experiment concludes for a change to appear in an application code



The Cross Section Evaluation Working Group (CSEWG) shepherds ENDF/B data through the the data pipeline

Program	Measurement	Theory	Compilation	Evaluation	QA (V&V, IE)	Infrastructure (GForge, etc.)
DTRA	✓					
International (IAEA, NEA, …)		✓	✓	✓	✓	✓
NA-22	✓	✓		✓		
Naval Reactors	✓				✓	
NCSP	✓	✓		✓	✓	✓
Nuclear Energy					✓	
Other (NP, Fusion, …)	✓	✓				
Defense Programs	✓	✓		✓	✓	✓
USNDP	✓	✓	✓	✓	✓	✓

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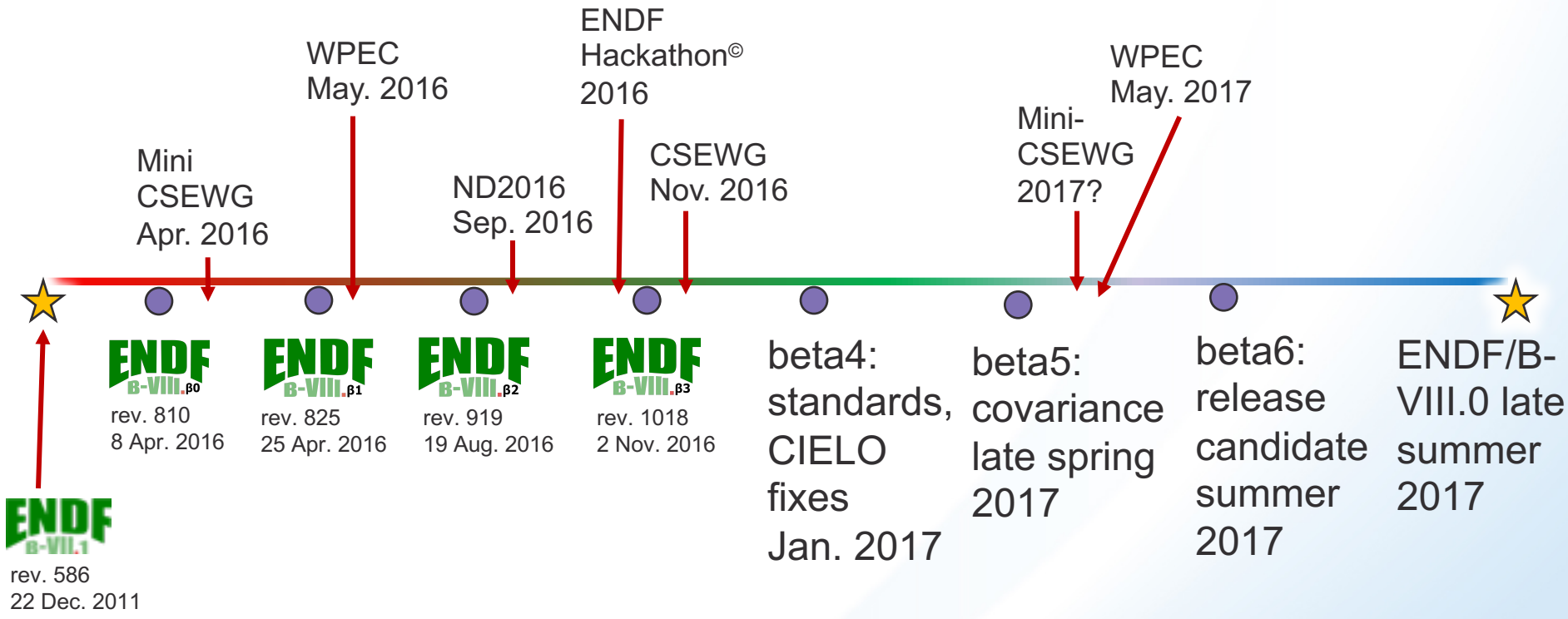
The USNDP chairs CSEWG and is involved in every step of ENDF/B

CSEWG is on track for release of ENDF/B-VIII in late FY17



Timeline not to scale

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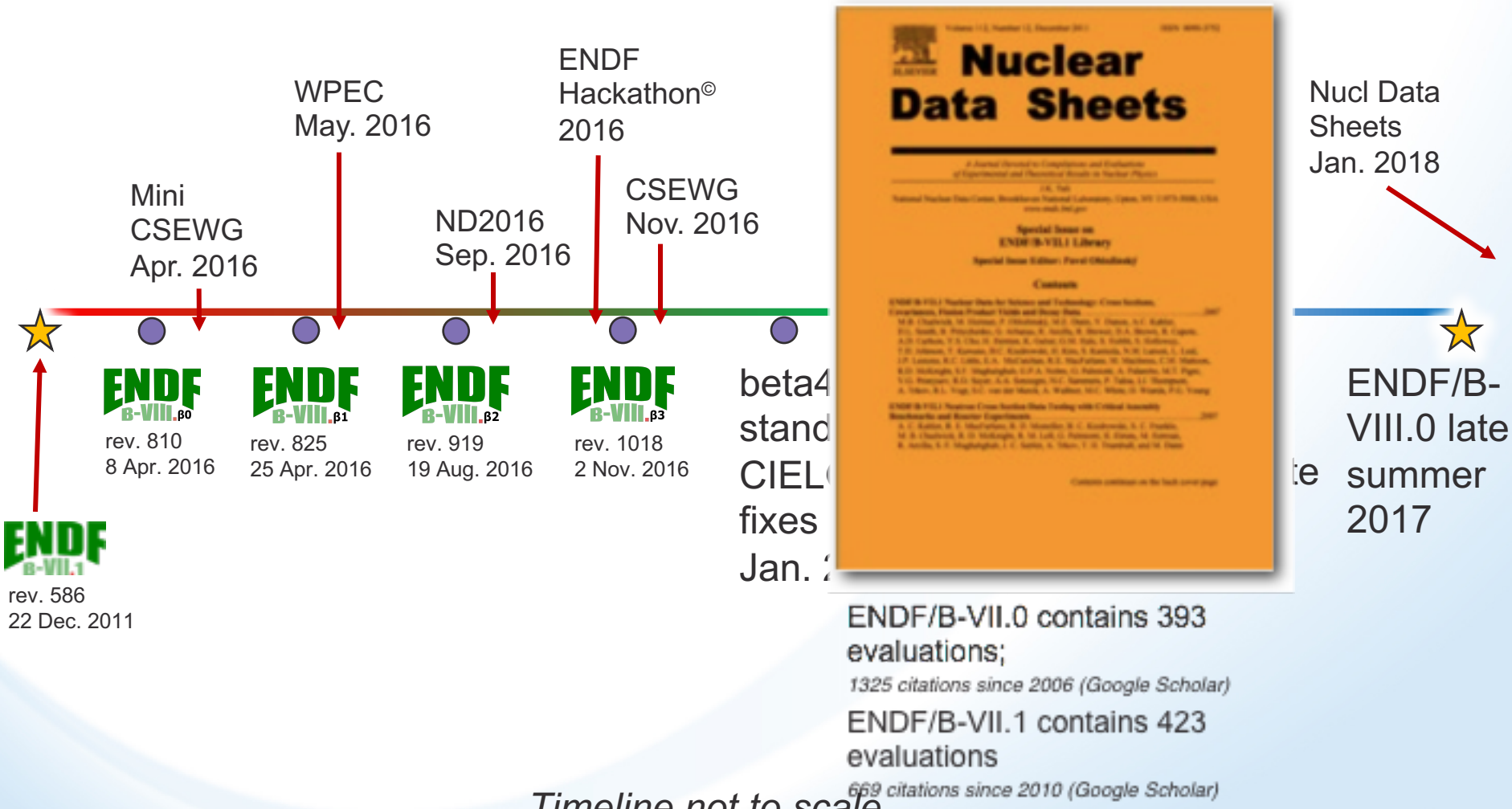


Timeline not to scale

ENDF/B-VIII highlights (so far...)

- **CIELO:**
  - ^{16}O
  - **^{56}Fe**
  - **^{235}U**
  - **^{238}U**
  - **^{239}Pu**
- **Structural materials:**
  - $^{12,13}C$
  - ^{40}Ca
  - **^{54}Fe, ^{57}Fe, ^{58}Fe**
  - **$^{58\text{-}61}Ni$**
  - Yb, Dy, Os (JENDL4)
  - **$^{63,65}Cu$**
  - $^{182,183,184,186}W$
  - **$^{174,176,178,179,180}Hf$**
- **Other non-CIELO:**
  - **n**
  - **^{7}Be**
  - ^{18}O (RUSFOND)
  - **$^{35,37}Cl$**
  - **^{59}Co**
  - **$^{73,74}As$**
  - **^{78}Kr**
  - **^{132}Te**
  - **^{124}Xe**
  - RQ Wright's nubars
  - **^{40}Ar**
  - **$^{236m1}Np$**
  - EGAF gammas
  - **Bug fixes**

ENDF/B-VIII highlights, continued

- **Charged particles**:
  - p+^{7}Li, p+a, p+^{13}C
  - d+7Li
  - t+a, t+^{7}Li
  - ^{3}He+a, ^{3}He+^{3}He
  - a+a
- **EPICS2014:**
  - photoat
  - electrons
  - atomic_relax
- **Decay data:**
  - ^{93,95,96}Rb
  - ^{95}Sr
  - ^{82,83}Ge
  - ^{95,98,98m,99}Y
  - ^{88,89,90,91}Br
  - ^{90}Kr
  - ^{140,141}Cs
  - ^{143}Ba
  - ^{143,144,145}La
  - ^{134}Sb
  - ^{138}I
- **Thermal Scattering:**
  - Be(metal)
  - UO_2 (x2)
  - Regular & reactor graphite
  - BeO (x2)
  - Polyethyline
  - SiO_2 (x2)
  - SiC
  - Lucite
  - Water: H_2O & D_2O (x2)

ENDF/B-VIII highlights, continued

- **Charged particles**:
  - p+^{7}Li, p+a, p+^{13}C
  - d+7Li
  - t+a, t+^{7}Li
  - ^{3}He+a, ^{3}He+^{3}He
  - a+a
- **EPICS**
  - photo
  - electr
  - atomic_relax
- **Decay data:**
  - ^{93,95,96}Rb
  - ^{95}Sr
  - ^{82,83}Ge
  - ^{95,98,98m,99}Y
  - ^{88,89,90,91}Br
- ^{90}Kr
- ^{140,141}Cs
- ^{143}Ba
- ^{143,144,145}La
- ^{134}Sb
- ^{138}I

Fission Product Yields conspicuously absent

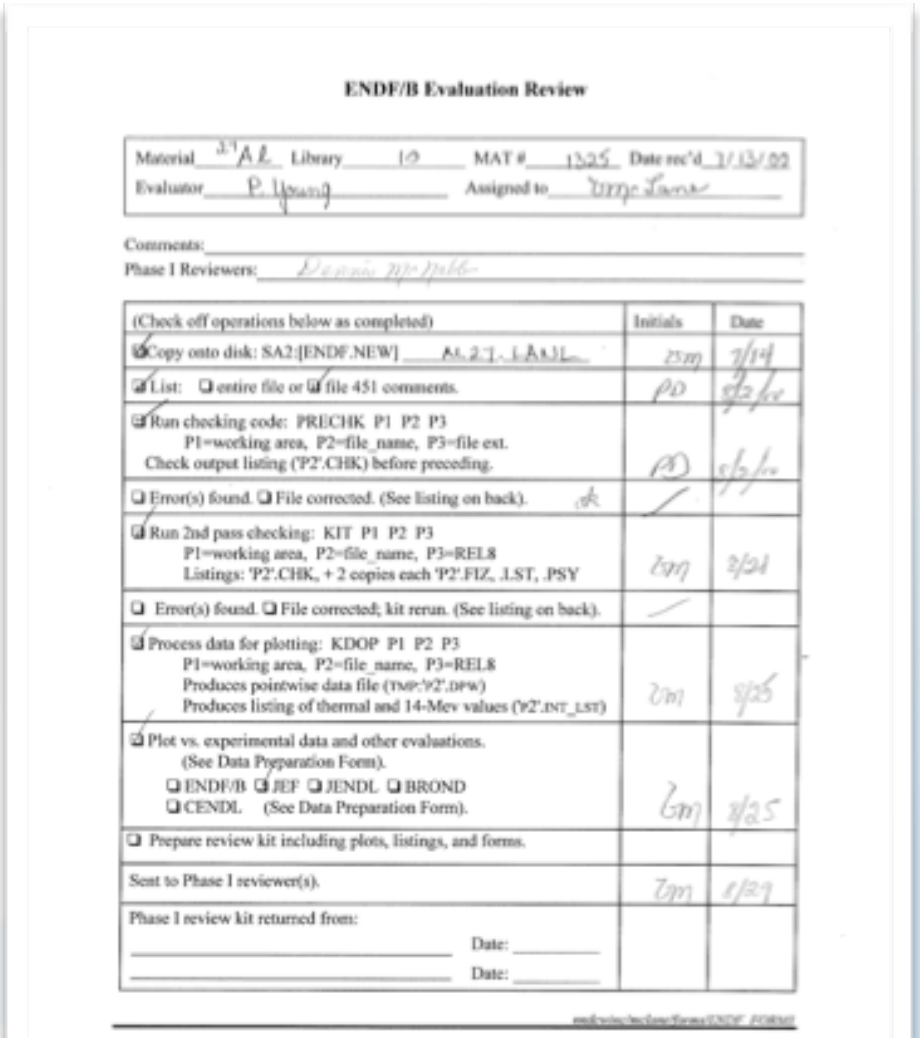
- **Thermal Scattering:**
  - graphite
  - BeO (x2)
  - Polyethyline
  - SiO_2 (x2)
  - SiC
  - Lucite
  - Water: H_2O & D_2O (x2)

The USNDP isn't bound to any one application -- Therefore, we take care of the things other CSEWG members can't or won't do

- ENDF file & release coordination [already covered]
- Neutron standards [see Allan Carlson's talk]
- **ENDF data QA with ADVANCE**
- **ENDF Hackathon coordination**
- **Lead iron evaluation for CIELO project**
- **The Atlas of Neutron Resonances**
- **New nuclear data formats & infrastructure coordination**

ENDF quality control in the days of yore

- CSEWG peer reviews all evaluations before accepting
- Phase I Testing:
  - ENDF/B-VI and earlier: pen & paper reviews
  - ENDF/B-VII.0: partially automated with EMPIRE tools
- Phase II Testing:
  - User/developer communication
  - Nuclear data week, CSEWG validation committee
- Version control by hand with ENDF/A & ENDF/B



ENDF/B Evaluation Review

Material 237Np Library 10 MAT # 1325 Date rec'd 3/13/00
Evaluator P. Young Assigned to Dave Brown

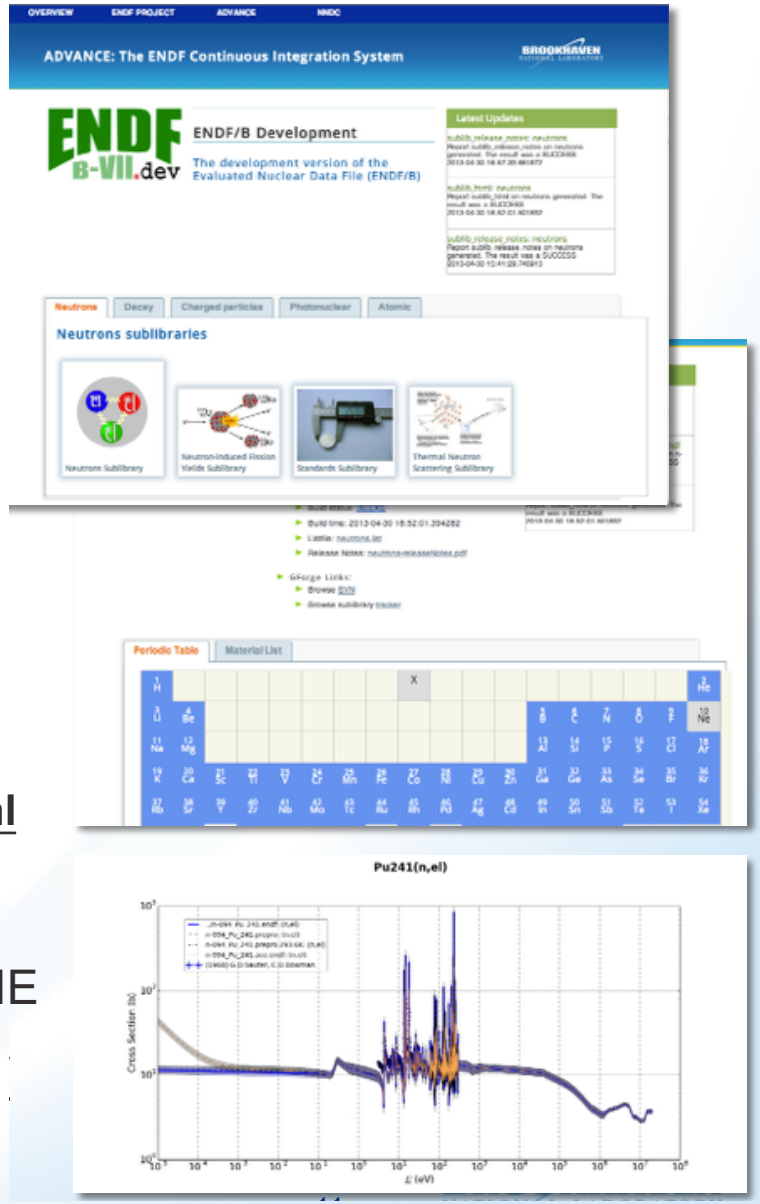
Comments:
Phase I Reviewers: Dennis McNabb

(Check off operations below as completed)	Initials	Date
☑ Copy onto disk: SA2:[ENDF.NEW] A6.2.7.1A31L	ZM	3/14
☑ List: ☐ entire file or ☑ file 451 comments.	PO	3/24/00
☑ Run checking code: PRECHK P1 P2 P3 P1=working area, P2=file_name, P3=file ext. Check output listing ('P2'.CHK) before proceeding.	PO	3/24/00
☐ Error(s) found. ☐ File corrected. (See listing on back).	✓	
☑ Run 2nd pass checking: KIT P1 P2 P3 P1=working area, P2=file_name, P3=REL8 Listings: 'P2'.CHK, + 2 copies each 'P2'.FIZ, .LST, .PSY	ZM	3/24
☐ Error(s) found. ☐ File corrected; kit rerun. (See listing on back).	✓	
☑ Process data for plotting: KDOP P1 P2 P3 P1=working area, P2=file_name, P3=REL8 Produces pointwise data file (TMP.'P2'.DPW) Produces listing of thermal and 14-Mev values ('P2'.INT_LST)	ZM	3/25
☑ Plot vs. experimental data and other evaluations. (See Data Preparation Form). ☐ ENDF/B ☐ JEF ☐ JENDL ☐ BROND ☐ CENDL (See Data Preparation Form).	ZM	3/25
☐ Prepare review kit including plots, listings, and forms.		
Sent to Phase I reviewer(s).	ZM	3/27
Phase I review kit returned from: _____ Date: _____ _____ Date: _____		

Sample PHASE I review packet cover page (June 2000)

ADVANCE quality assurance system for ENDF

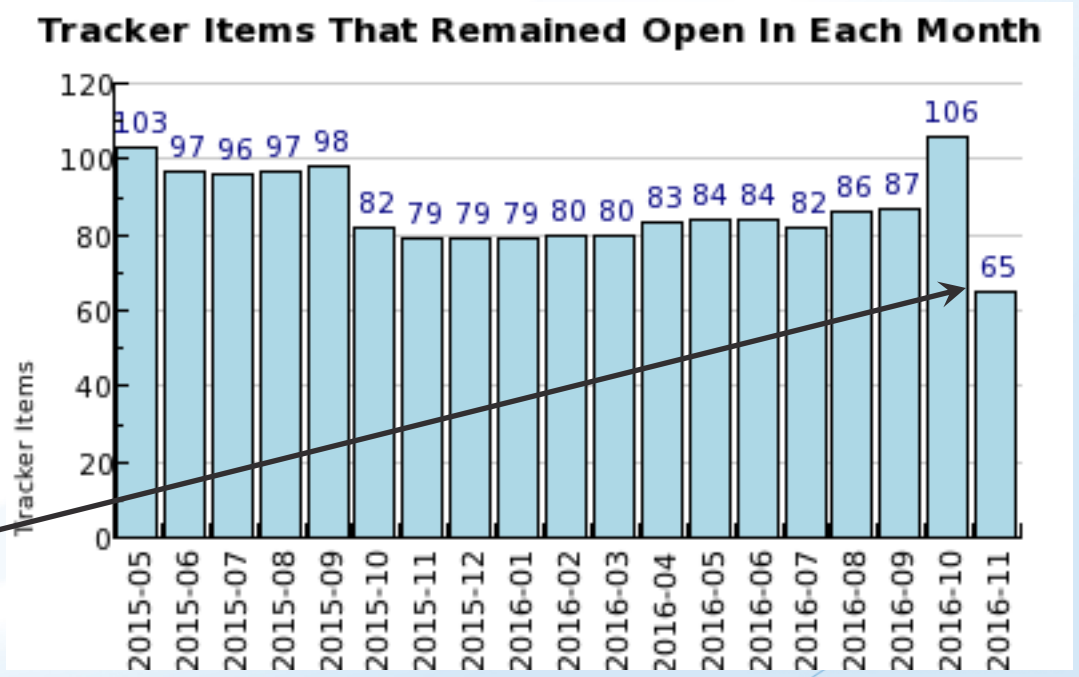
- **On every commit of every evaluation automatically:**
  - Run it through a battery of tests, including customer processing codes
  - Generate comparison plots
  - Generate HTML report of evaluation
- **Available at**
  http://www.nndc.bnl.gov/endf/b7.dev/qa/index.html
- **New in FY17:**
  - Update Fudge-4.2.1 add PREPRO/GROUPIE
  - Aesthetic improvements (AJAX & MathJax)
  - Full library ACE file tarballs
  - Per-isotope reports
  - Rewrote INTER using FUDGE



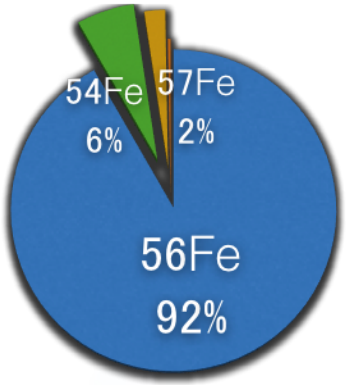
ENDF Hackathon© 2016

- **Participants (9/2016):** D. Brown, T. Kawano, S. Mughabghab, G. Nobre, V. Sobes, I. Thompson (remotely)
- **Clean up as many ENDF evaluations as possible using whatever evaluation tools you have**
- **Donuts and coffee provided…**
- **Schedule:**
  - M-Th — kill bugs
  - F — review changes, make sure OK

40% reduction in open trackers

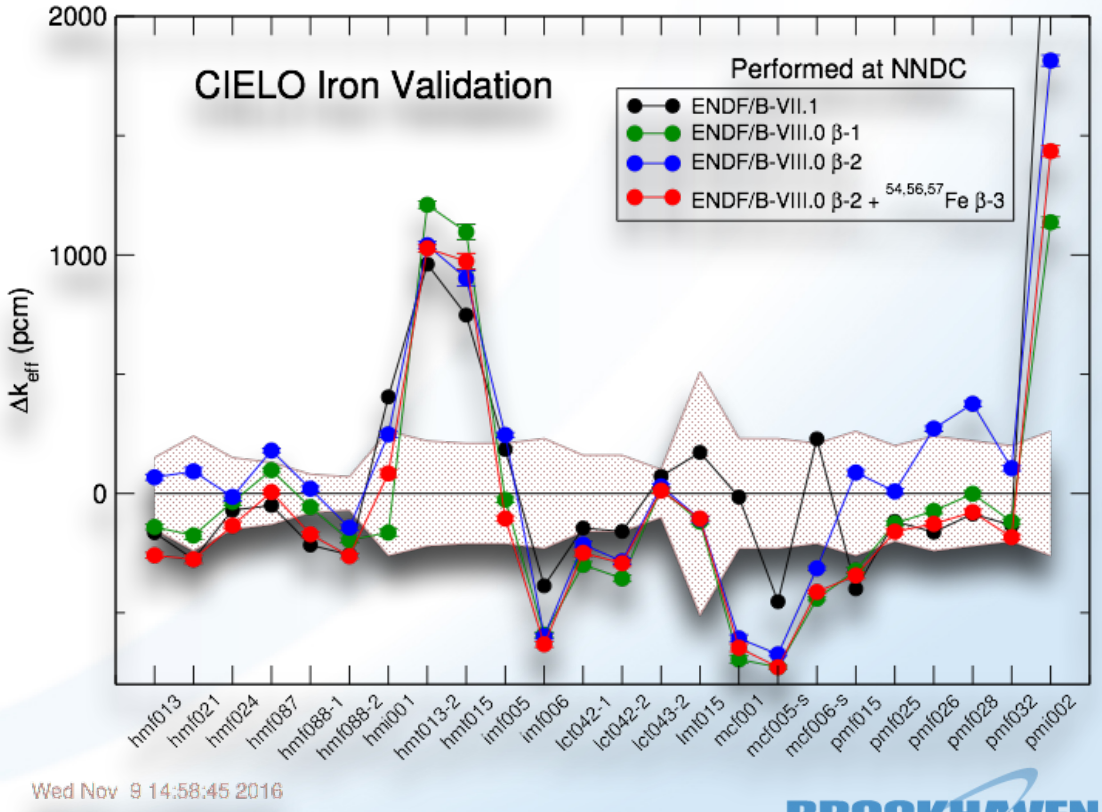


CIELO - Iron



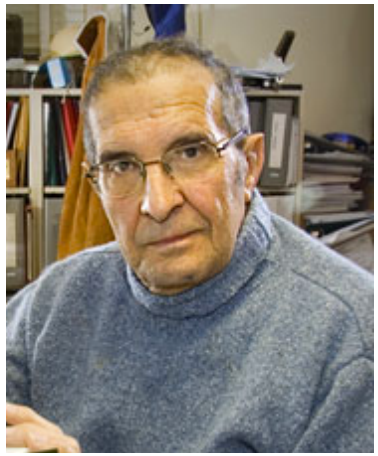
- Very important: Structural material
- Extensive review of exp. data available
- Analysis of previous evaluations

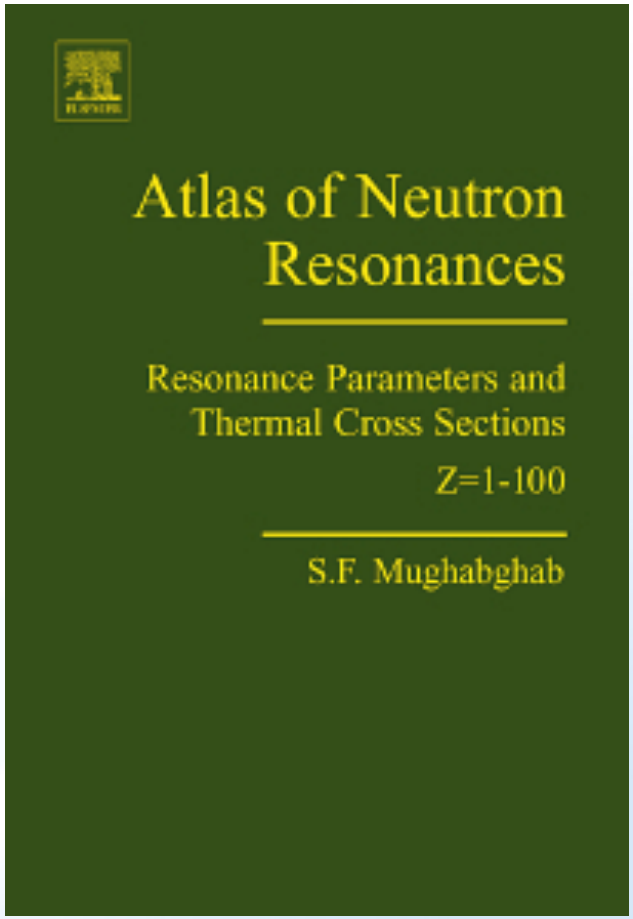
- Significant advances in fast region
- Incorporated dosimetry files
- Validation comparable to ENDF/B-VII.1 (some are better)
- Extensive review & reworking of ^{54,57,58}Fe resonances



New Atlas of Neutron Resonances in development

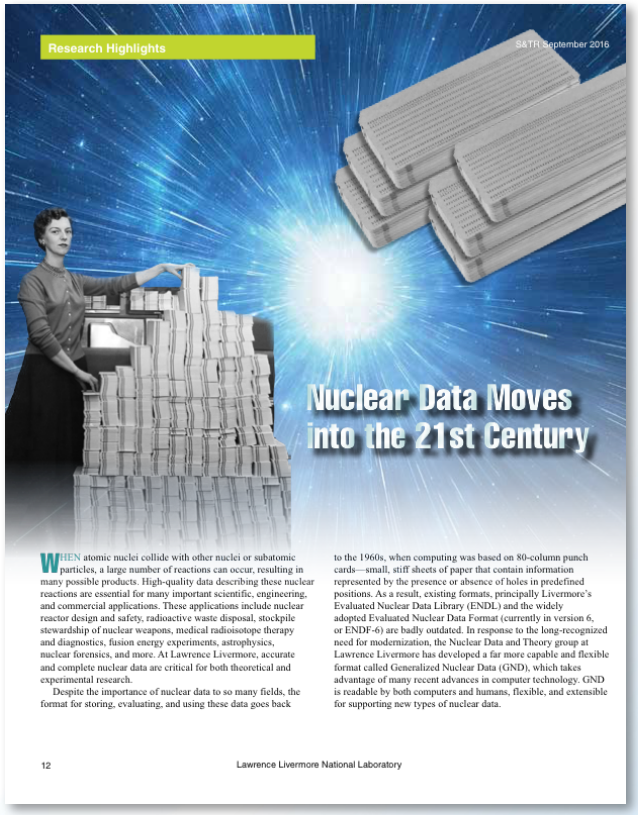
- The definitive resource for neutron resonances
- 5th edition published in 2006
- Continuation of BNL-325
- Said Mughabghab writing new edition, expected summer 2017





Major developments in data formats

- **The USNDP is a key player in effort to update the ENDF/B format**
  - LLNL & BNL active participants in WPEC SG-38, format development
  - BNL to chair SG-B, format governance
  - LLNL/LANL to chair SG-43, API development
- **FUDGE-4.2.1 Released Mar. 2016**
- **GND-1.7 Released Mar. 2016**
- **Requirements available in BNL report BNL-112394-2016-IR**
- **Complete format specifications due FY17**
- **ENDF/B-VIII to be released in both ENDF/B-6 and GND formats**


Research Highlights

S&TR September 2016

Nuclear Data Moves into the 21st Century

WHEN atomic nuclei collide with other nuclei or subatomic particles, a large number of reactions can occur, resulting in many possible products. High-quality data describing these nuclear reactions are essential for many important scientific, engineering, and commercial applications. These applications include nuclear reactor design and safety, radioactive waste disposal, stockpile stewardship of nuclear weapons, medical radioisotope therapy and diagnostics, fusion energy experiments, astrophysics, nuclear forensics, and more. At Lawrence Livermore, accurate and complete nuclear data are critical for both theoretical and experimental research.

Despite the importance of nuclear data to so many fields, the format for storing, evaluating, and using these data goes back to the 1960s, when computing was based on 80-column punch cards—small, stiff sheets of paper that contain information represented by the presence or absence of holes in predefined positions. As a result, existing formats, principally Livermore's Evaluated Nuclear Data Library (ENDL) and the widely adopted Evaluated Nuclear Data Format (currently in version 6, or ENDF-6) are badly outdated. In response to the long-recognized need for modernization, the Nuclear Data and Theory group at Lawrence Livermore has developed a far more capable and flexible format called Generalized Nuclear Data (GND), which takes advantage of many recent advances in computer technology. GND is readable by both computers and humans, flexible, and extensible for supporting new types of nuclear data.

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GND Highlighted in LLNL's Sep. 2016 issue of Science & Technology Review