ENDF/B-VIII.0 Status

D. Brown for the CSEWG collaboration
National Nuclear Data Center, BNL

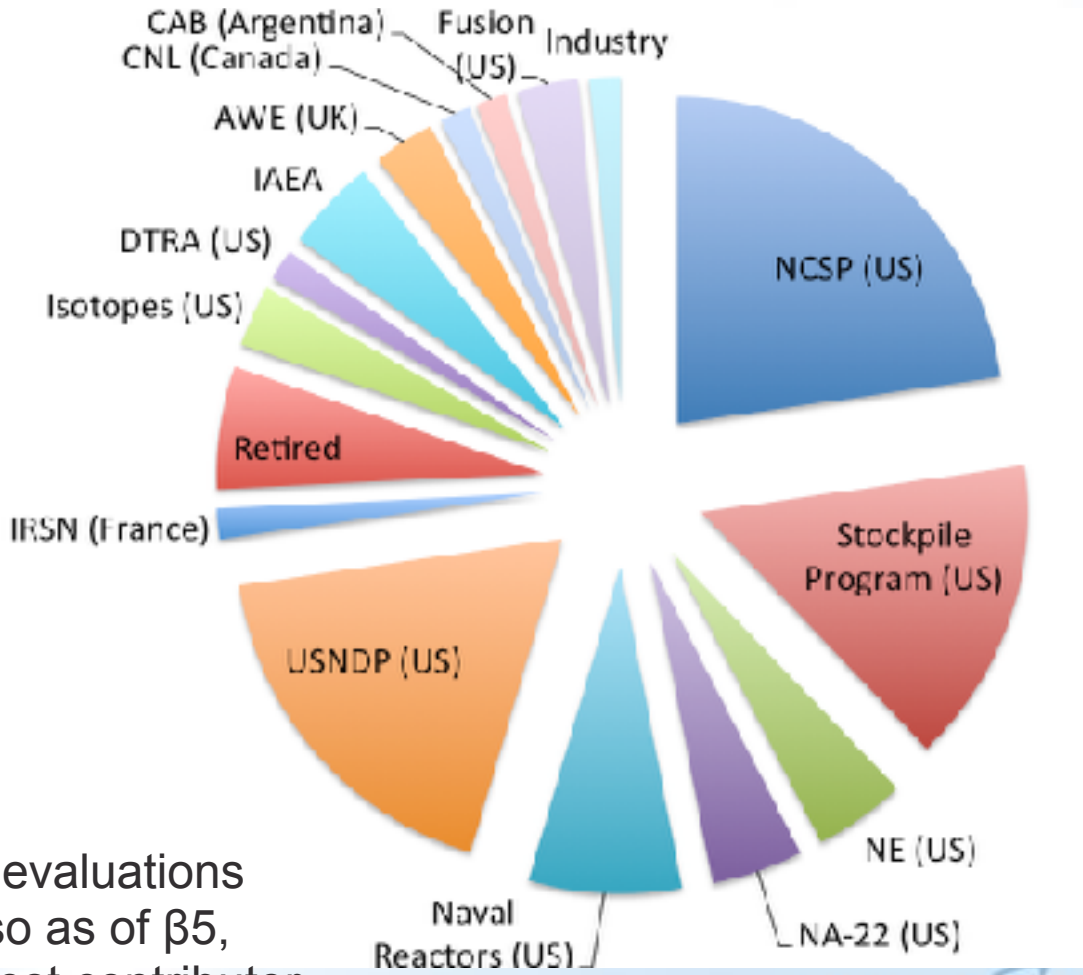
BROOKHAVEN NATIONAL LABORATORY
a passion for discovery

U.S. DEPARTMENT OF ENERGY | Office of Science

The ENDF/B library is the product of the Cross Section Evaluation Working Group (CSEWG).

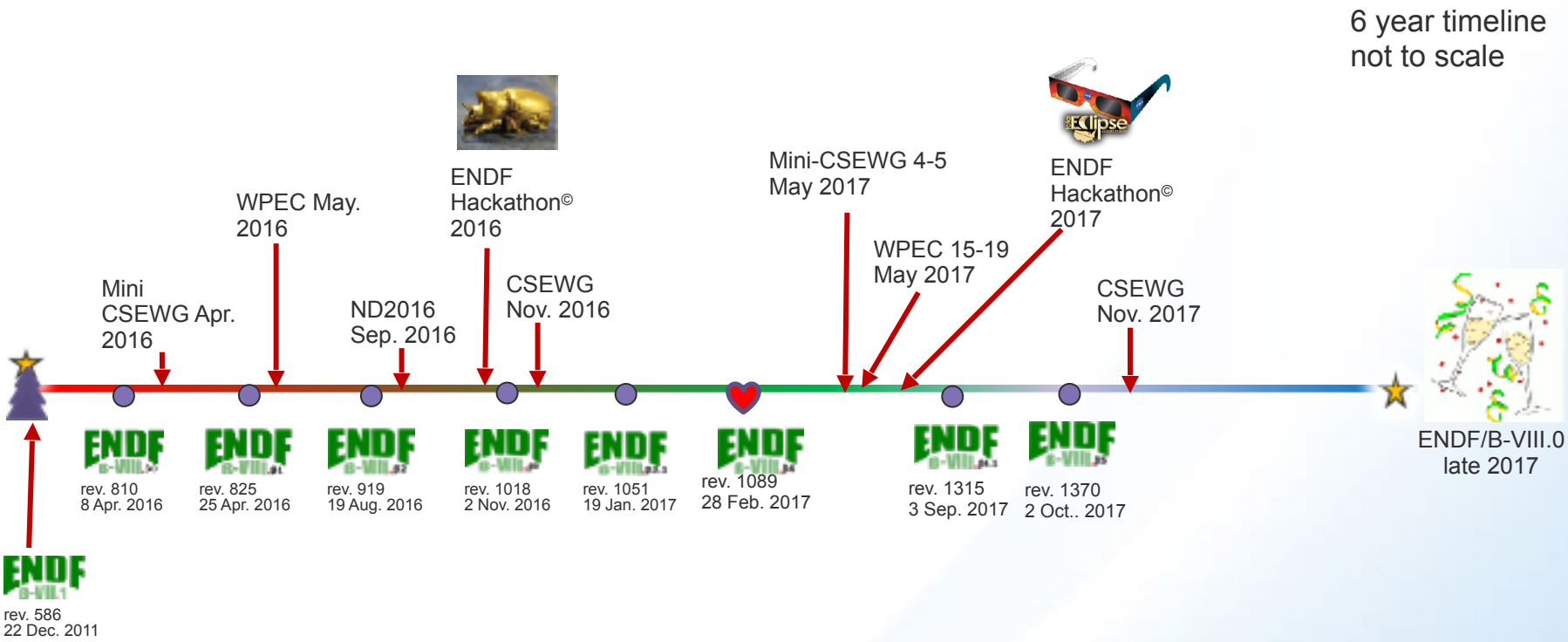
CSEWG is a long standing collaboration between data users who, incidentally, are also the biggest content providers

Fraction of evaluations provided for ENDF/B-VIII.0β3



We added 125 evaluations over summer, so as of β5, USNDP is biggest contributor

ENDF/B-VIII on track for late FY17



ENDF/B-VIII highlights

- **CIELO:**
  - ^{16}O
  - ^{56}Fe
  - ^{235}U
  - ^{238}U
  - ^{239}Pu
- **Neutron standards**
  - ^{1}H
  - ^{6}Li
  - ^{10}B
  - ^{197}Au
- **Structural materials:**
  - $^{12,13}C$
  - ^{40}Ca
  - ^{54}Fe, ^{57}Fe, ^{58}Fe
  - $^{58\text{-}61}Ni$
  - Yb, Dy, Os (JENDL4)
  - $^{63,65}Cu$
  - $^{182,183,184,186}W$
  - $^{174,176,178,179,180}Hf$
  - ^{132}Te
- **Other non-CIELO:**
  - n
  - ^{7}Be
  - ^{18}O (RUSFOND)
  - $^{35,37}Cl$
  - ^{59}Co
  - $^{73,74}As$
  - ^{78}Kr
  - ^{124}Xe
  - RQ Wright's nubars
  - ^{40}Ar
  - $^{236m1}Np$
  - ^{240}Pu
  - EGAF gammas
  - Bug fixes

ENDF/B-VIII highlights, continued

- **Charged particles:**
  - p+d, p+^{7}Li, p+a, p+^{13}C, p+^{207}Pb
  - d+^{7}Li
  - 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)
  - Polyethylene
  - SiO_2 (x2)
  - SiC
  - Lucite
  - UN
  - *Water: H_2O & D_2O (x2)*
  - Water Ice Ih (x2)
  - YH_2 (x2)

What has changed since ENDF/B-VII.1?

- CIELO evaluations
- TSL evaluations
- Many other ENDF evaluations
- V&V, QA
- New format

} These are what most users care about

What has changed since ENDF/B-VII.1?

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} But many other applications need these

What has changed since ENDF/B-VII.1?

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} This is how we insure good performance

What has changed since ENDF/B-VII.1?

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} This is how we prepare for the future

ENDF/B-VIII.0

- **CIELO evaluations**
- TSL evaluations
- Many other ENDF evaluations
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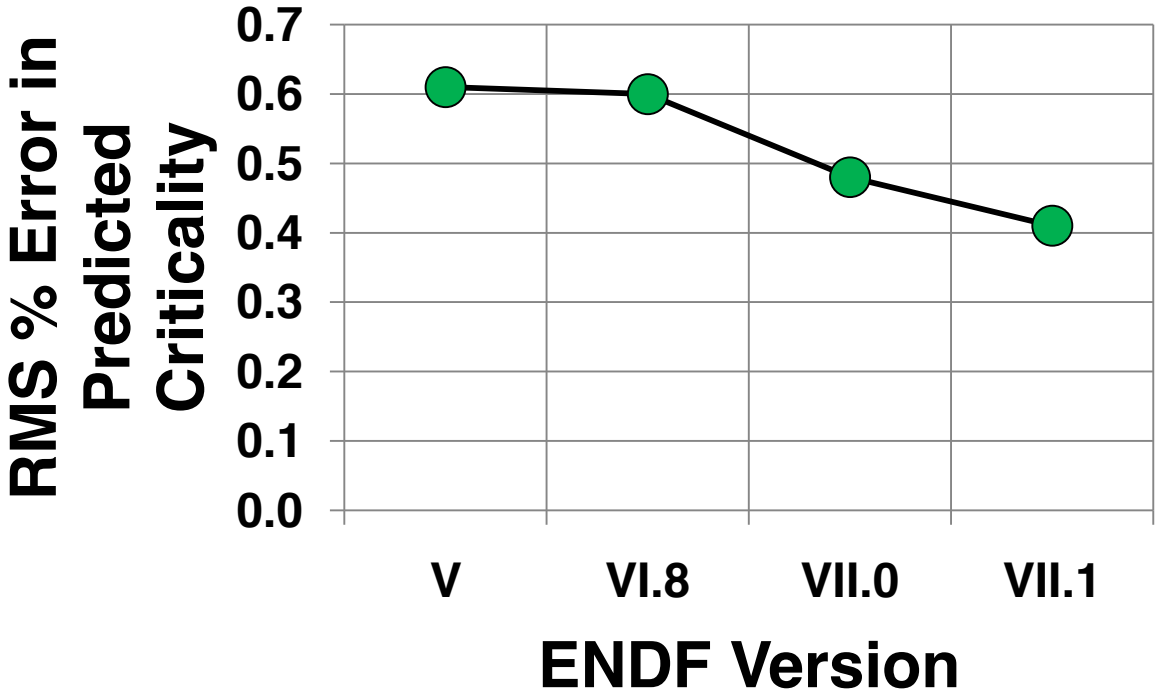
- New format

CIELO:
Rationale ….

- **Nuclear data are physical constants – there's only one correct answer! And they are used as a trusted repository for scientific data**
  - Existing ENDF, JENDL, JEFF, …. have reached a level of maturity enabling us to contemplate this next step – *they're already converging!*
- **Quality: advances will benefit from collaboration of world's experts**
  - Evaluations are extremely complex, with very broad scope
  - We are relying more on complementary expertises
- **Computational & sens./covariance advances can expedite advances**
- **We have experts in place to do this (including key retirees)**
- **Build on steps already taken through international collaborations**
  - IAEA/WPEC Standards … IAEA CRPs, NEA WPEC Working Groups …..

Progress in Modeling Criticality in ENDF

"Mosteller" suite of 119 critical assemblies that we track over time (MCNP6 calculations)



Initial goal: *equivalent performance, with better underlying physics*

CIELO1.0?

Diminishing returns: it is increasingly difficult to improve our overall performance using the present approaches

Slide from M. Chadwick, NEMEA 7 Workshop, Geel, Belgium 2013

CIELO isotopes

- 1H
- 16O

LANL Lead, later realized need for H_2O TSL, NIST to discuss 1H

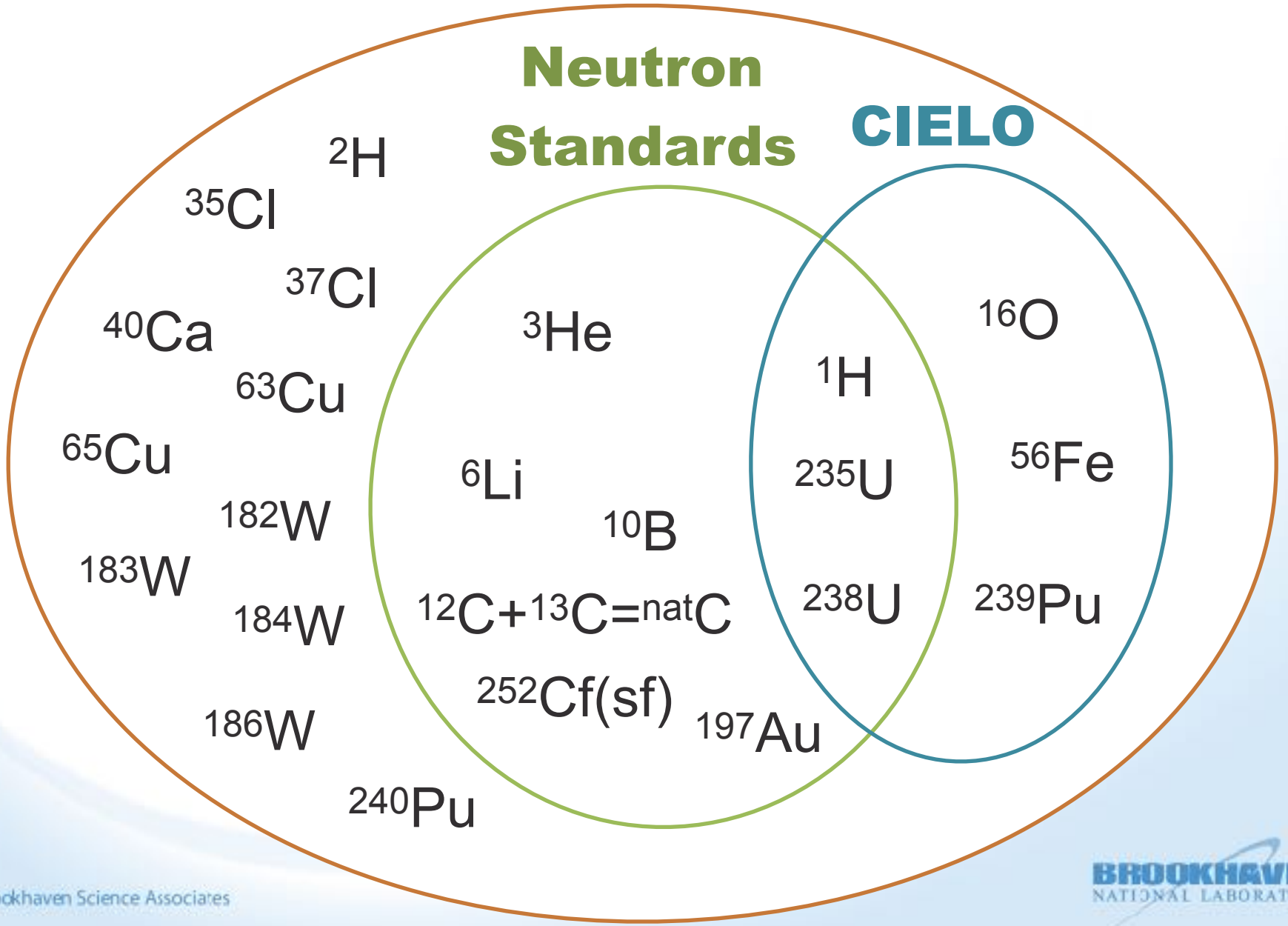
- 56Fe — BNL Lead — Gustavo Nobre to discuss (and by extension, all components of steel)

- 235U
- 238U

IAEA Lead, NIST to discuss

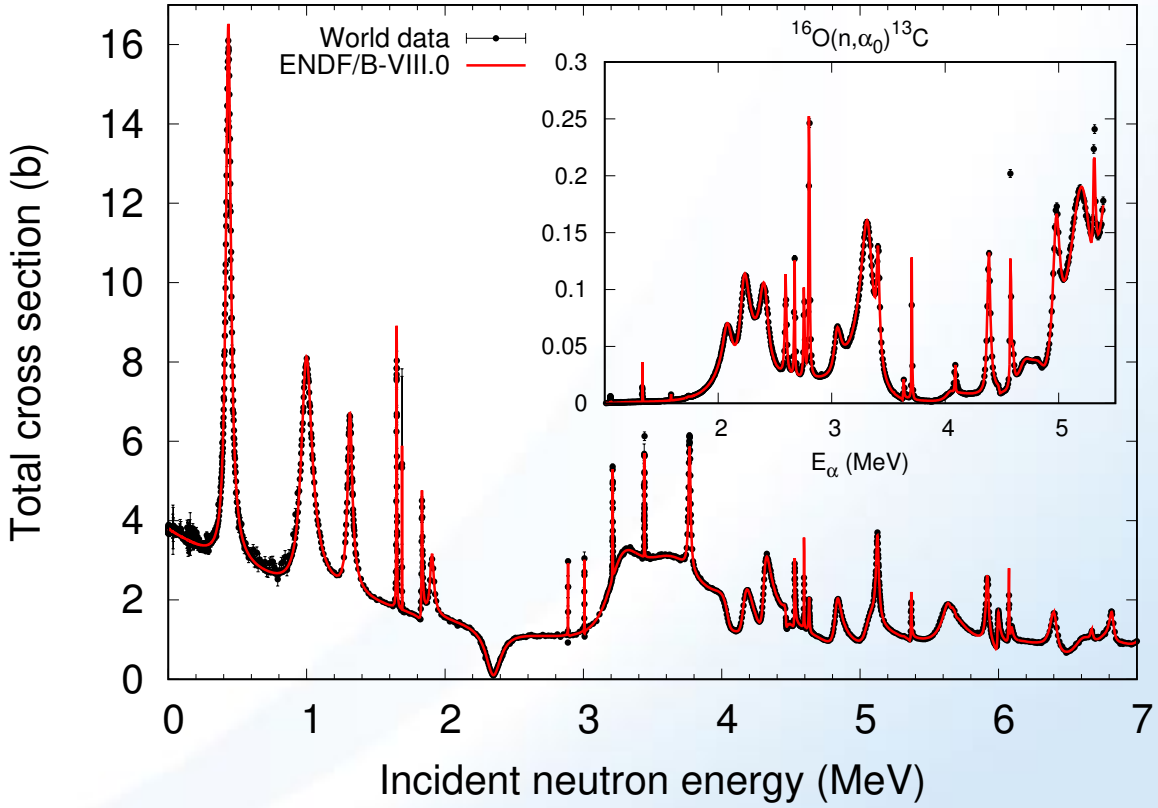
- 239Pu — LANL Lead

ENDF/B-VIII.0, with NEW covariances



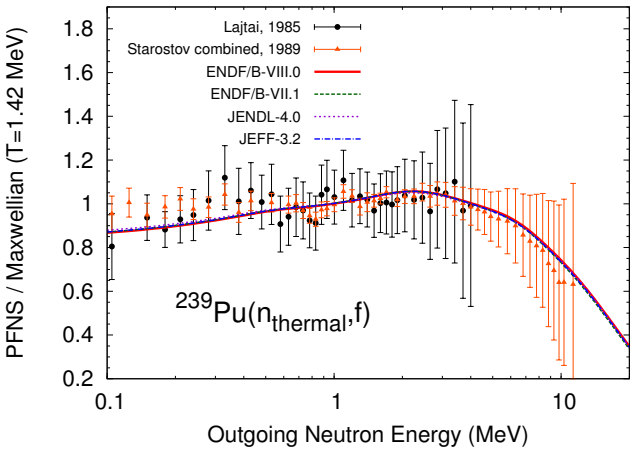
^{16}O

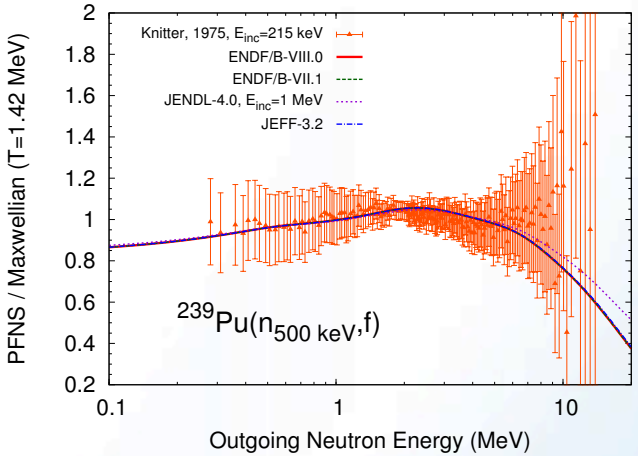
- Astrophysical impact (capture & $^{13}C(\alpha,n)$)
- 1/3 of light or heavy water
- R-matrix fit from LANL
- Disagreements over how samples prepared in legacy experiments made for contentious evaluation

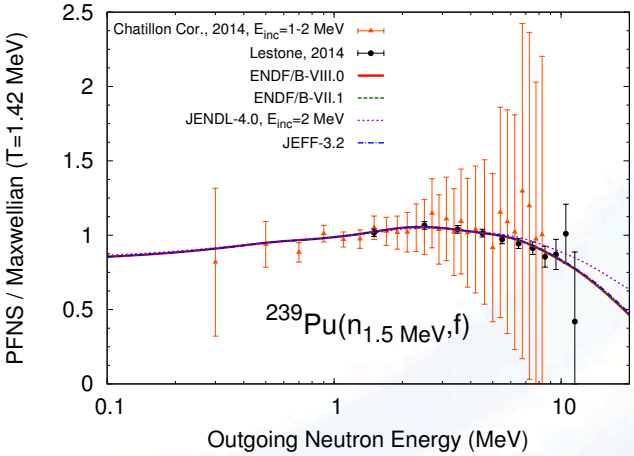


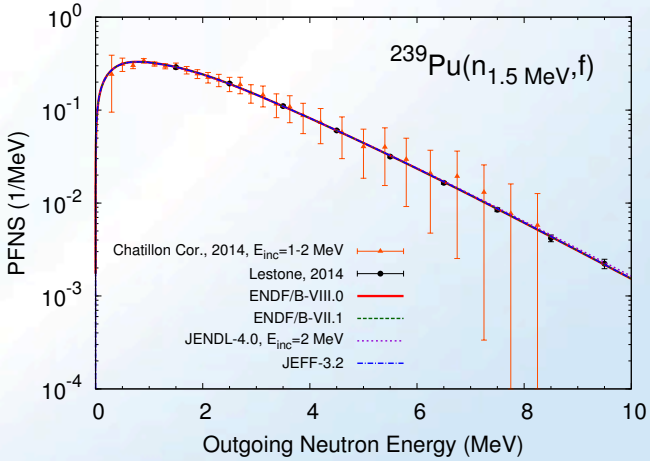
^{239}Pu

- LANL evaluation
- Harder spectrum improved modeling of solution assemblies, resolving long-standing problem







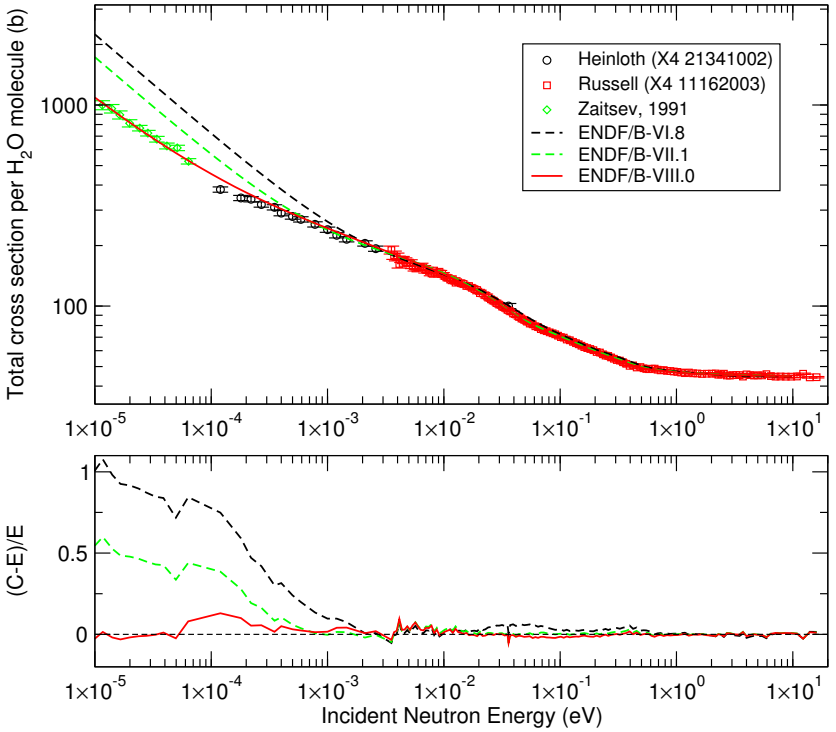


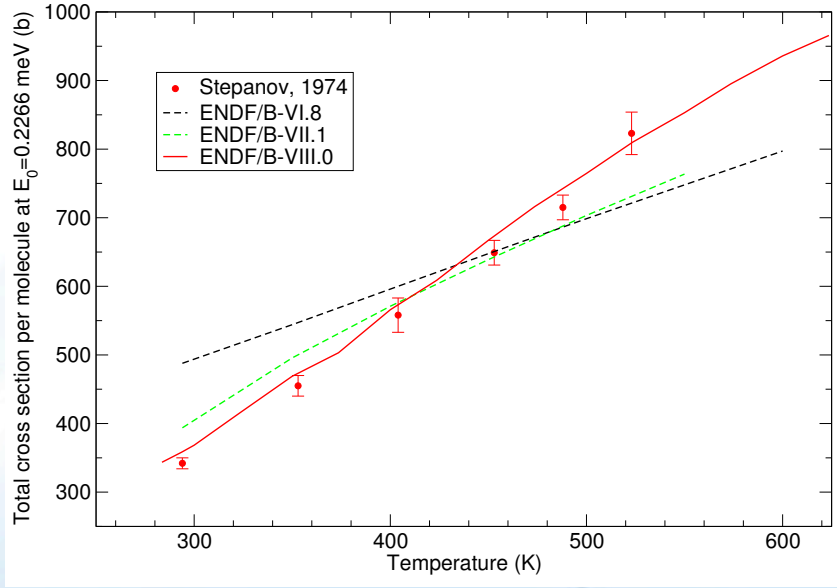
ENDF/B-VIII.0

- CIELO evaluations
- **TSL evaluations**
- Many other ENDF evaluations
- V&V, QA
- New format

Light water

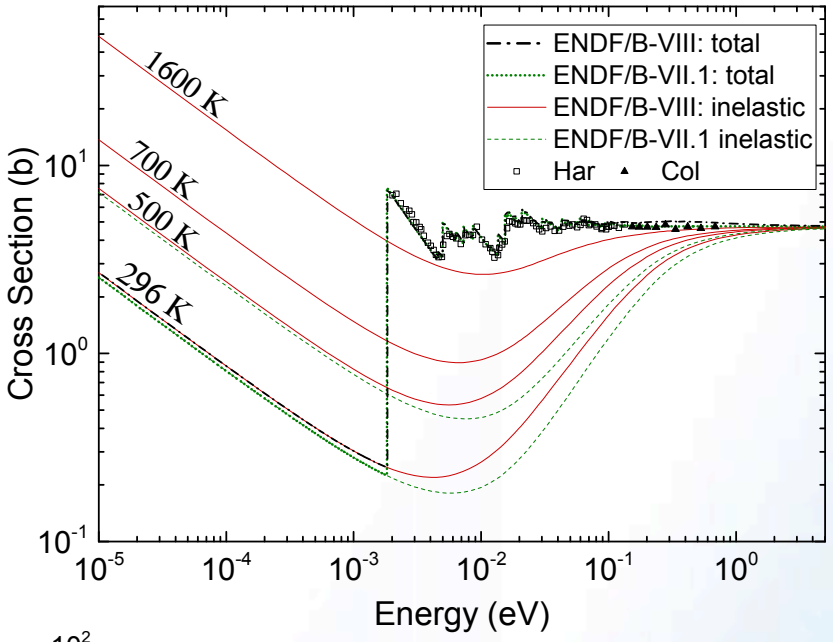
- From Centro Atómico Bariloche, Argentina
- Found in all solution assemblies
- PWR and LWR need
- High temperature behavior in β4 led to predicted (and scary) increase in reactivity; resolved in β5

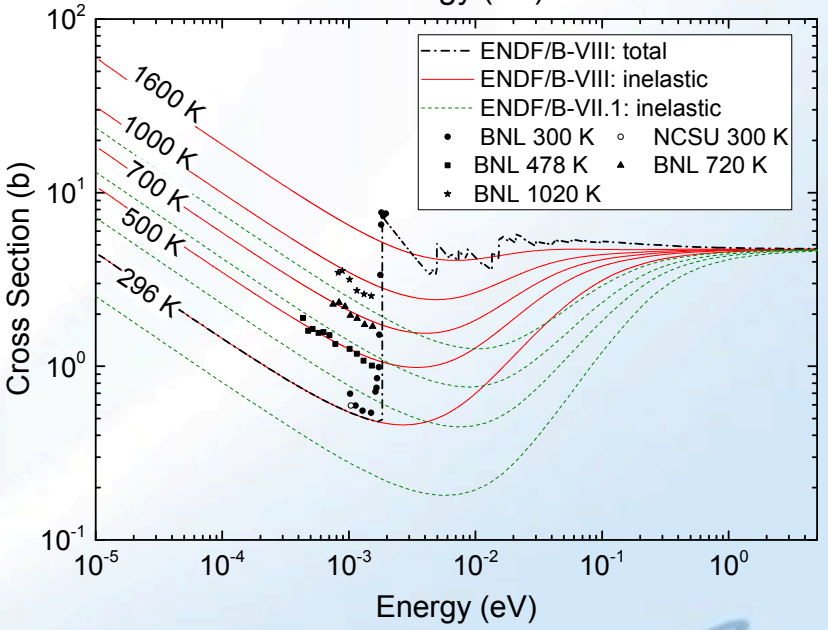




Graphite

- From A. Hawari's group at North Carolina State Univ.
- Crystalline "ideal" graphite
- Porous "reactor-grade" graphite
- Hexagonal lattice not supported by LEAPR module in NJOY; needed custom evaluation tools
- Legacy LEAPR/NJOY assumes all solids are cubic lattice
- Two forms of graphite in library may cause bookkeeping troubles





ENDF/B-VIII.0

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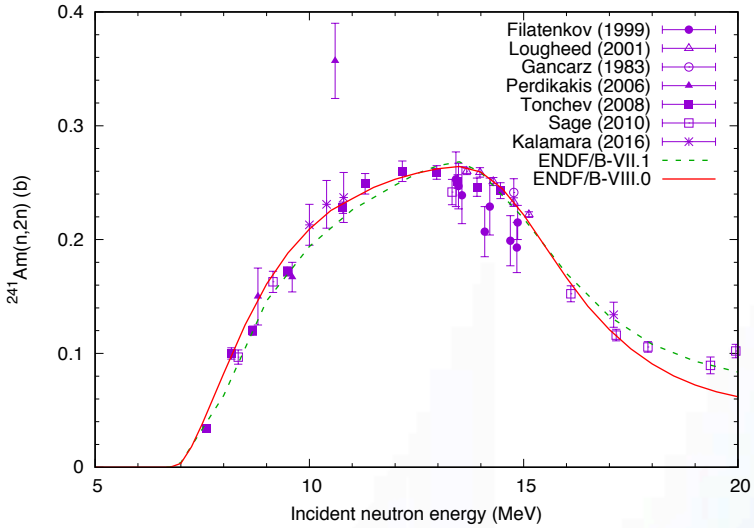
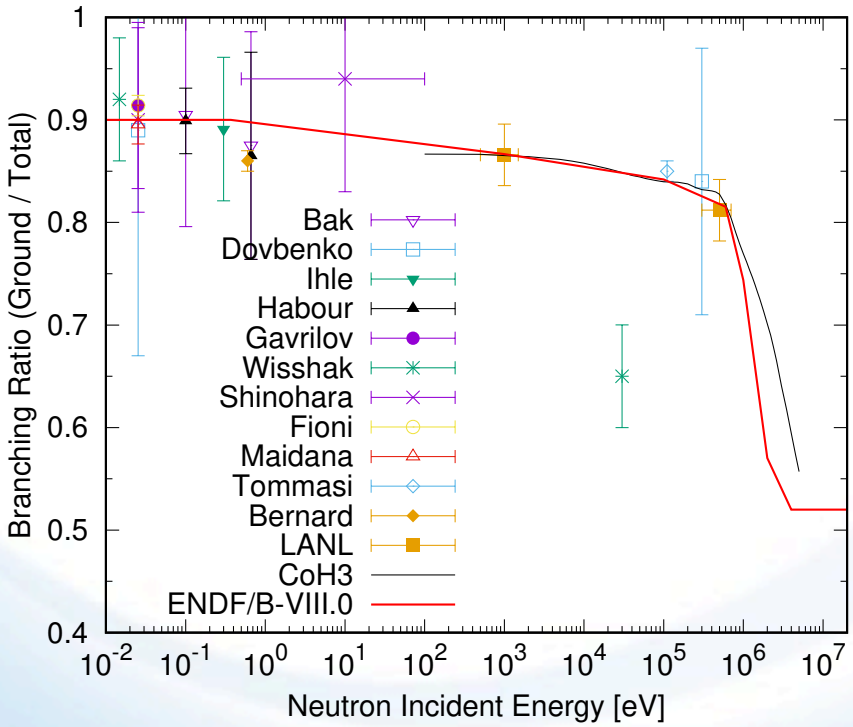
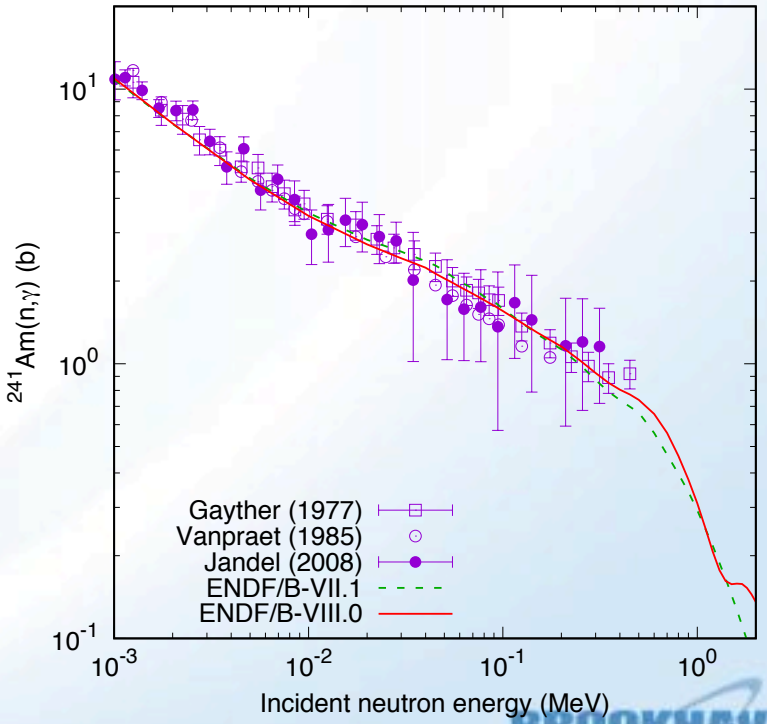
^{241}Am

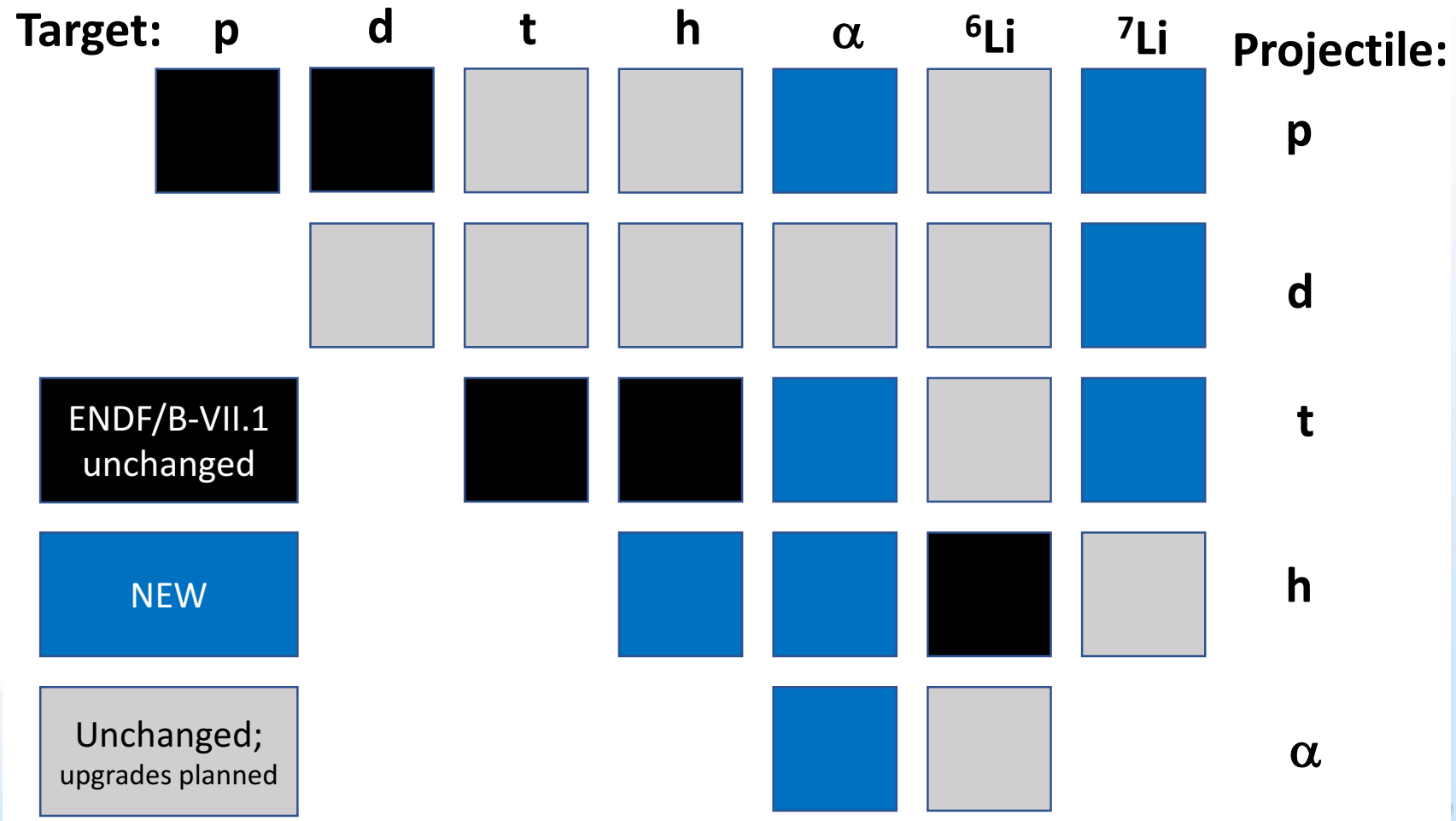
- T. Kawano evaluation using CoH
- Tuned to all available data







New & updated charged particle reactions to be discussed by Ian Thompson



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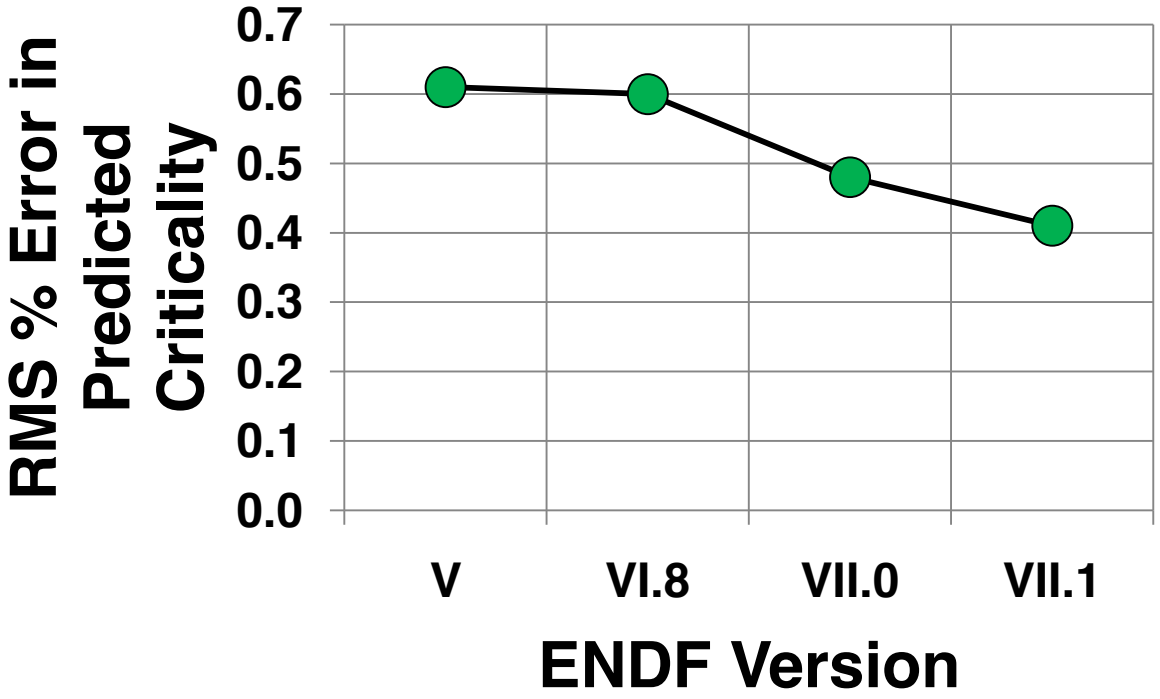

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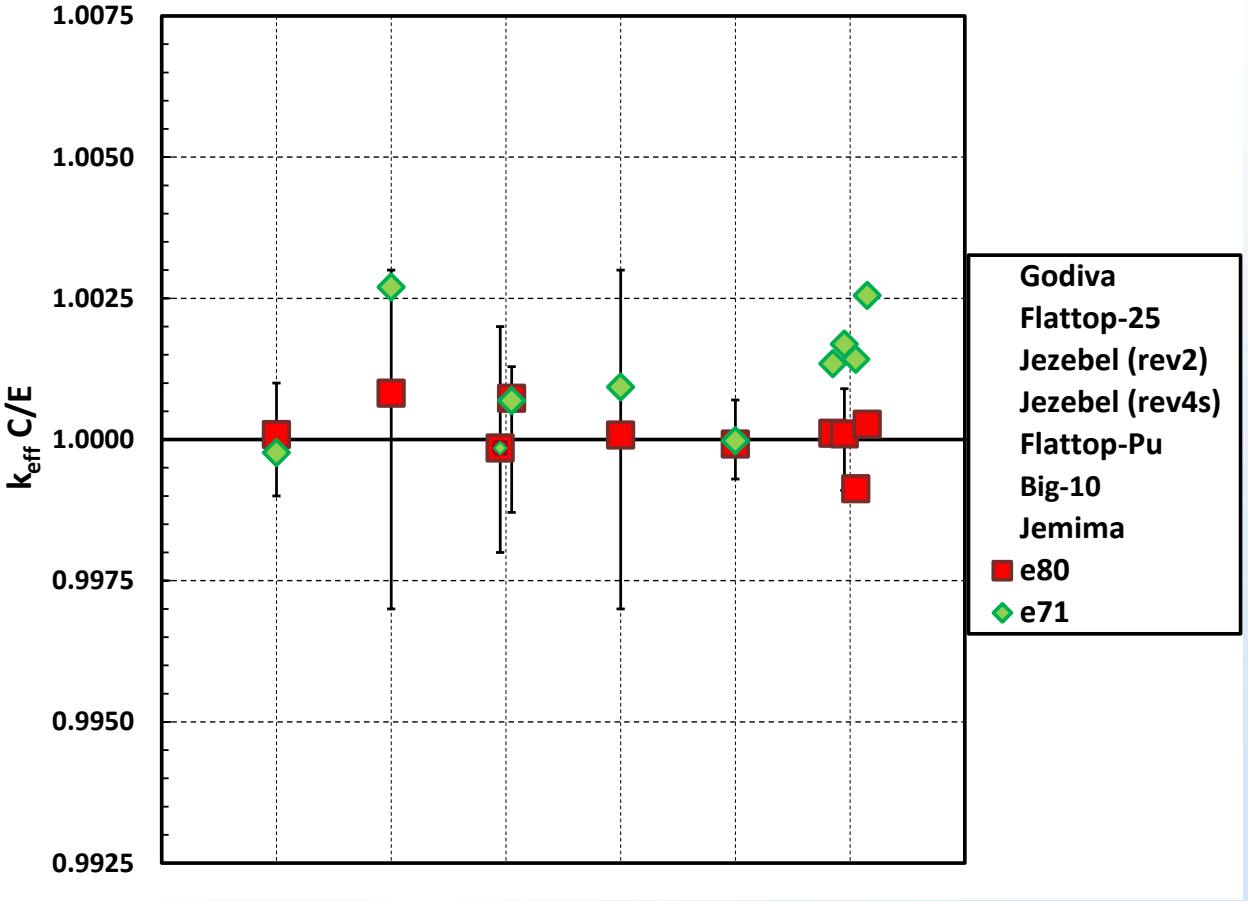
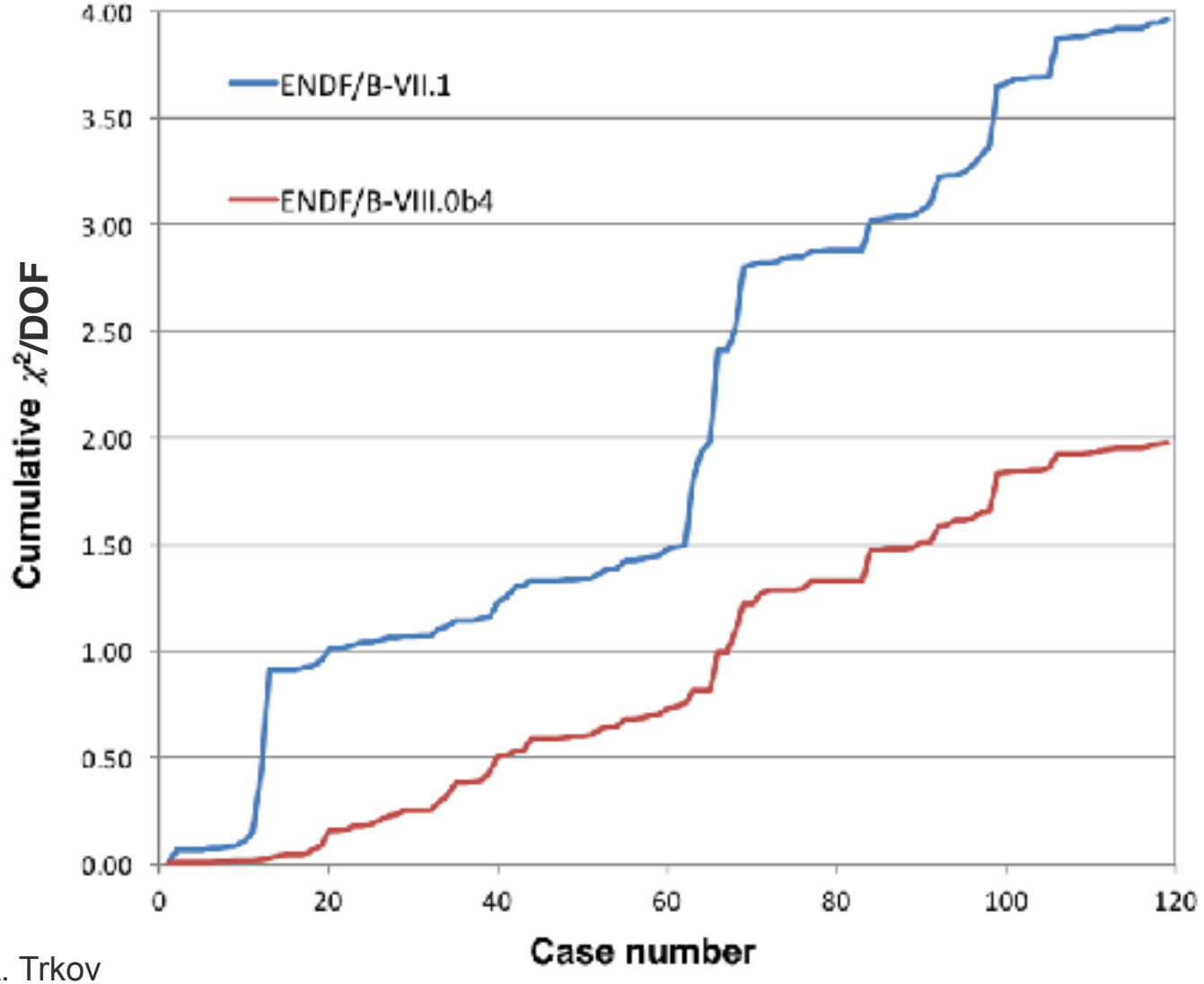
Slide from M. Chadwick, NEMEA 7 Workshop, Geel, Belgium 2013

Fast LANL test suite

- Our “go to” suite for a quick check of library quality
- Improved calculation of k_{eff} (neutron gain/neutron loss) relative to ENDF/B-VII.1



Combined critical assembly performance



Plot curtesy A. Trkov

ENDF/B-VIII.0

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FUDGE and GND(S) information are available in several places

- **https://www.oecd-nea.org/science/wpec/sg38/**
  - "Detailed requirements for a next generation nuclear data structure";
  - "Specifications for the next generation nuclear data hierarchy"
  - "Requirements and specifications for a particle database"
  - "General purpose data containers"
- **https://ndclx4.bnl.gov/gf/project/gnd/**
  - Fudge 4.2.1
    - Allows to translate ENDF-6 ↔ GND (V1.7)
- **http://www.nndc.bnl.gov/endf/b7.1/**
  - **ENDF/B-VII.1 translated into GND**
- **http://www.nndc.bnl.gov/endf & IAEA NDS**
  - **Built into ENDF retrievals**

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  - "General purpose data contain[illegible]"
- **https://ndclx4.bnl.gov/gf/p[illegible]**
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- **http://www.nndc.bnl.gov/e[illegible]**
  - **ENDF/B-VII.1 translated into**
- **http://www.nndc.bnl.gov/e[illegible]**
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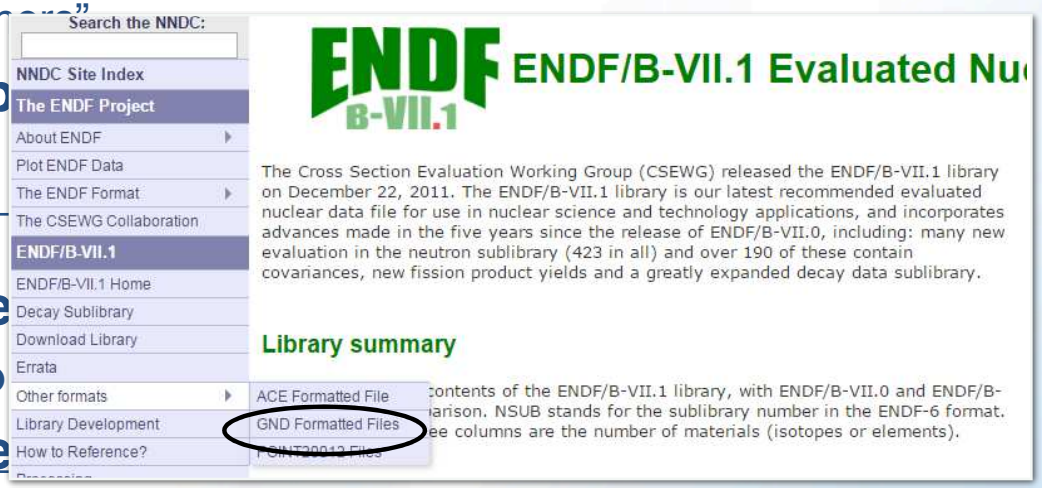

Slide based on slide from F. Malvagi

GND is under active development, stable version due with END/B-VIII.0 release

- **Standard transportable particles:**
  - alphas/
  - deuterons/
  - gammas/
  - helium3s/
  - neutrons/
  - protons/
  - standards/
  - thermal_scatt/
  - tritons/
- **Particle properties:**
  - atomic_relax/
  - decay/
- **Atomic physics:**
  - electrons/
  - photoat/
- **Fission product yields**
  - nfy/
  - sfy/

Paper Status

Each ENDF/B release is documented in an NDS special issue

ENDF/B-VII.0 contains 393 neutron evaluations;
1764 citations since 2006 (Google Scholar)

ENDF/B-VII.1 contains 423 neutron evaluations;
1253 citations since 2011 (Google Scholar)

Paper Status

Each ENDF/B release is documented in an NDS special issue

Not shown:

- Neutron standards (in revision),
- ^{235,238}U (w/ referees)

ENDF/B-VIII.0: in revision

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

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(Dated: October 29, 2017; Received xx July 2017; revised received xx September 2017; accepted xx October 2017)

We describe the new ENDF/B-VIII.0 evaluated nuclear reaction data library. ENDF/B-VIII.0 fully incorporates the new IAEA standards, includes improved thermal neutron scattering data and uses new evaluated data from the CIELO project for neutron reactions on ^{16}O, ^{56}Fe, ^{235,238}U and ^{239}Pu, described in companion papers in the present issue of *Nuclear Data Sheets*. The evaluations benefit from recent experimental data obtained in the U.S. and Europe, and improvements in theory and simulation. Notable advances include updated evaluated data for light nuclei, structural materials, actinides, fission energy release, prompt fission neutron and γ-ray spectra, thermal neutron scattering data, and charged-particle reactions. Integral validation testing is shown for a wide range of criticality, reaction rate, and neutron transmission benchmarks. In general, integral validation performance of

CIELO: w/ referees

CIELO Collaboration Summary Results: International Evaluations of Neutron Reactions on Uranium, Plutonium, Iron, Oxygen and Hydrogen

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The CIELO collaboration has studied neutron cross sections on nuclides that significantly impact criticality in nuclear technologies - ^{235,238}U, ^{239}Pu, ^{16}O, ^{56}Fe, and H - with the aim of improving the accuracy of the data and resolving previous discrepancies in our understanding. This multi-laboratory pilot project, coordinated via the OECD/NEA Working Party on Evaluation Cooperation (WPEC) Subgroup 40 with support also from the IAEA, has motivated experimental and theoretical work and led to suites of new evaluated libraries that accurately reflect measured data and also perform

PFNS: Accepted

Evaluations of Energy Spectra of Neutrons Emitted Promptly in Neutron-induced Fission of ^{235}U and ^{239}Pu

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The energy spectra of neutrons emitted promptly in the neutron-induced fission reactions of ^{235}U and ^{239}Pu were re-evaluated for ENDF/B-VIII.0. These evaluations are based on a careful modeling of all relevant physics processes, an extensive analysis of experimental data and a detailed quantification of pertinent uncertainties. Energy spectra of neutrons emitted in up to fourth chance fission are considered and both compound and pre-equilibrium processes are included. Also, important nuclear model parameters, such as the average total kinetic energy of the fission fragments and the multiple chance fission probabilities, and their uncertainties are estimated based on experimental knowledge, model information and evaluated data. In addition to experimental information already available for ENDF/B-VII.1, these new evaluations make use of recently published experimental data either of high precision or spanning a broad incident energy range, information on legacy measurements explaining discrepancies and recently measured data of the average total kinetic energy as a function of incident neutron energy. The resulting evaluated data and covariances agree well with the experimental database used for the evaluation. However, the evaluated spectra are softer than the ^{235}U and ^{239}Pu ENDF/B-VII.1, JENDL-4.0 and JEFF-3.2 evaluations for incident neutron energies $E_{in} \leq 1.5$ MeV and $E_{in} \leq 5$ MeV, respectively. For $E_{in} > 5$ MeV, the evaluated spectra show structures due to the improved modeling which are not present in ENDF/B-VII.1 and JEFF-3.2 but can be observed in JENDL-4.0 evaluations. Part of these new evaluations were adopted for ENDF/B-VIII.0, while the ENDF/B-VII.1 ^{239}Pu PFNS was retained for $E_{in} \leq 5$ MeV awaiting more conclusive experimental evidence.

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I. INTRODUCTION

We present evaluations of ^{235}U and ^{239}Pu prompt fission neutron spectra (PFNS), i.e., energy spectra of neutrons emitted promptly in the neutron-induced fission reactions of ^{235}U and ^{239}Pu. Accurate ^{235}U and ^{239}Pu PFNS and reasonable associated uncertainties are vital quantities to simulate the reactivity and its bounds of nuclear reactors and answer questions of global and national security. This is easy to understand as the PFNS informs us on the energy of neutrons emitted as part of the fission process and thus enters prominently in the simulation of effective neutron multiplication factors of fission systems.

Due to the importance of the PFNS for nuclear data applications, the major goal of an IAEA "Coordinated Research Project (CRP) on Prompt Fission Neutron Spectra of Actinides" was to provide PFNS evaluations and

CIELO Fe: w/ referees

Evaluation of Neutron Reactions on Iron Isotopes for CIELO and ENDF/B-VIII.0

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The new suite of evaluations for ^{54,56,57,58}Fe has been developed in the frame of the CIELO international collaboration. New resolved resonance ranges were evaluated for ^{54}Fe and ^{57}Fe, while modifications were applied to resonances in ^{56}Fe. The low energy part of the ^{56}Fe file is almost totally based on the measurements. At higher energies in ^{56}Fe and in the whole fast neutron range for minor isotopes evaluation consist of model predictions carefully adjusted to available experimental data. We also make use of the high quality and well experimentally-constrained dosimetry evaluations from the IRDFF library. Special attention was dedicated to the elastic angular distributions, which were found to affect results of the integral benchmarking. The new set of iron evaluations was developed in concert with other CIELO evaluations and they were tested together in the integral experiments before being adopted for the ENDF/B-VIII.0 library.

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