IAEA
International Atomic Energy Agency
Atoms for Peace and Development

IAEA Nuclear Data Section, NDDU: International Nuclear Data Evaluation Network (INDEN)

Roberto Capote
Deputy Section Head, NDDU head

33th Meeting of International Nuclear Data Committee (virtual), March 2020, IAEA, Vienna

Int. ND Evaluation Network (INDEN)

CIELO follow-up: Technical Meeting on Long-term International Collaboration to Improve Nuclear Data Evaluation and Evaluated Data Files (18-21 December 2017, IAEA Headquarters, Vienna, Austria)

International Network of Nuclear Data Evaluators

nds.iaea.org/INDEN/

Int. ND Evaluation Network (INDEN)

CIELO follow-up: Technical Meeting on Long-term International Collaboration to Improve Nuclear Data Evaluation and Evaluated Data Files (18-21 December 2017, IAEA Headquarters, Vienna, Austria)

International Network of Nuclear Data Evaluators

- **International Nuclear Data Evaluation Network** is an activity aimed at streamlining the evaluation activities, taking advantage of expertise in different laboratories in IAEA Member States.
- The activities would follow the pattern of the highly successful CIELO project, organised through the NEA Data Bank with a strong technical contribution from IAEA research projects.
- The aim is to define evaluation priorities, identify issues and discrepancies, and minimise duplication of work, except for the testing of different approaches to the evaluation.
- Team-work and technical discussions to resolve issues are foreseen
- Evaluated data files will be produced with a broad consensus that can be adopted fully or in parts by other Data Evaluation projects.

Int. ND Evaluation Network (INDEN)

INDEN Plan:

- One large TM on setting priorities and discussion of results (every 2.5-3 years)
- 3 CMs/year on evaluation issues and challenges
- Additional TMs as needed focusing on an identified issue

International Network of Nuclear Data Evaluators

Three working groups operating through one CM/year
(9 CMs in three years)

1) INDEN-LE : Evaluation of light elements
2) INDEN-SM: Evaluated Data of structural materials
3) INDEN-RR : Actinide Evaluation in the resonance region

Each group met once in 2018,2019,2020 (last INDEN-LE CM shifted to 2021)

A first review INDEN TM is planned for 21-24 June 2021

Int. ND Evaluation Network (INDEN-LE)

International Atomic Energy Agency
Atoms for Peace and Development

INDEN-LE: Evaluations of light elements

Focus: R-Matrix evaluations of neutron/charged-particle induced reactions on light/medium targets

CM #3: 15-19 March 2021, INDC(NDS)-0827

- New experimental data for $^{16}O(n,\alpha)^{13}C$, $^{13}C(\alpha,n)^{16}O$ extensively discussed
- New evaluations presented for n+^{9}Be, n+^{14,15}N, n+^{23}Na

CM #2: 15-17 May 2019, INDC(NDS)-0788

- New evaluations presented for n+^{9}Be, n+^{14,15}N, alpha+^{17,18}O
- New full evaluation of n+^{9}Be with RAC
- Create common shared experimental database for all evaluated systems
- Evaluation challenges discussed in-depth
- Full R-matrix treatment considering all channels endorsed

CM #1: 30-31 August 2018, INDC(NDS)-0768

- Established list of evaluations and responsible evaluators for:

  n+^{9}Be, n+^{14,15}N, n+^{16}O, n+^{23}Na, alpha+^{17,18}O
- Aim is to push to higher energies possible with R-matrix theory
- Treat break-up channels

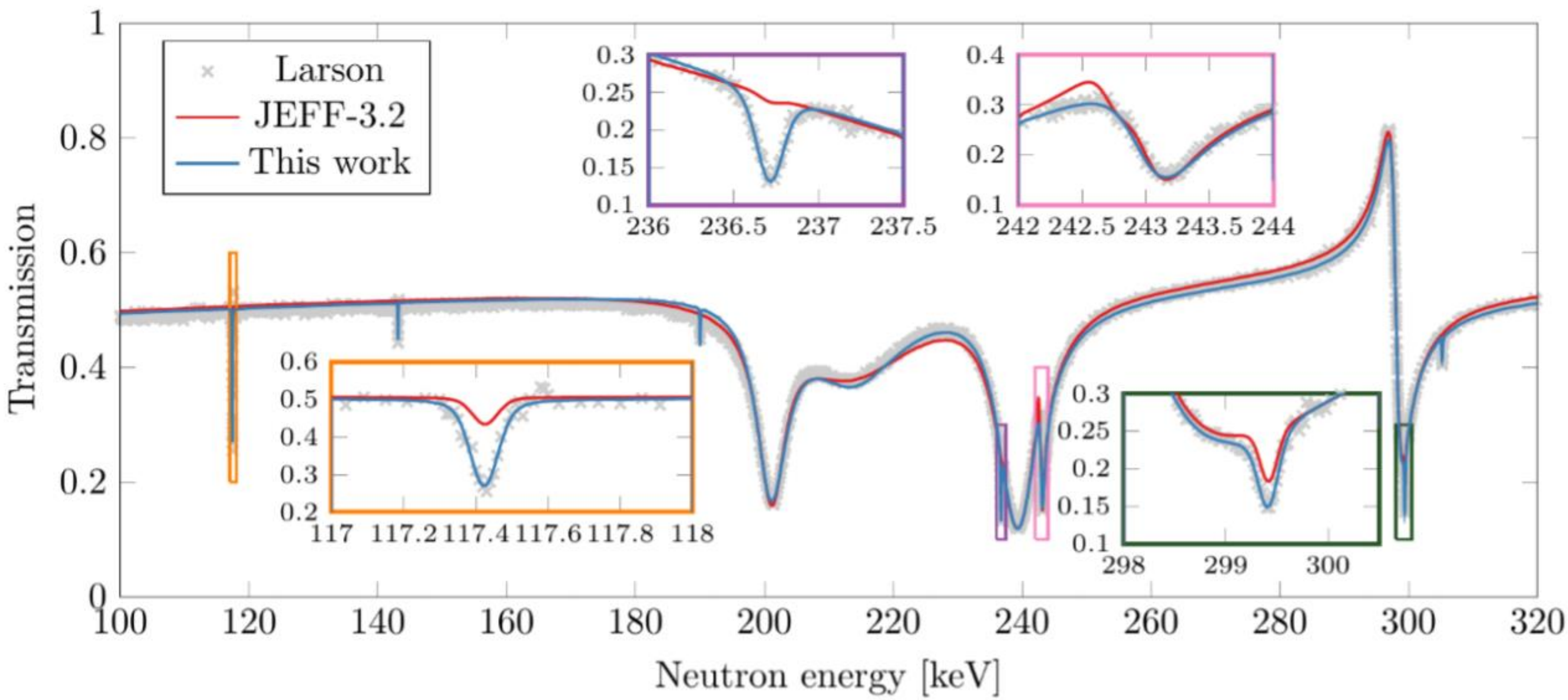
Int. ND Evaluation Network (INDEN-LE)

INDEN-LE: Evaluations of light elements

Focus: R-Matrix evaluations of neutron/charged-particle induced reactions on light/medium targets

New analysis [0, 460keV]

n+^{23}Na



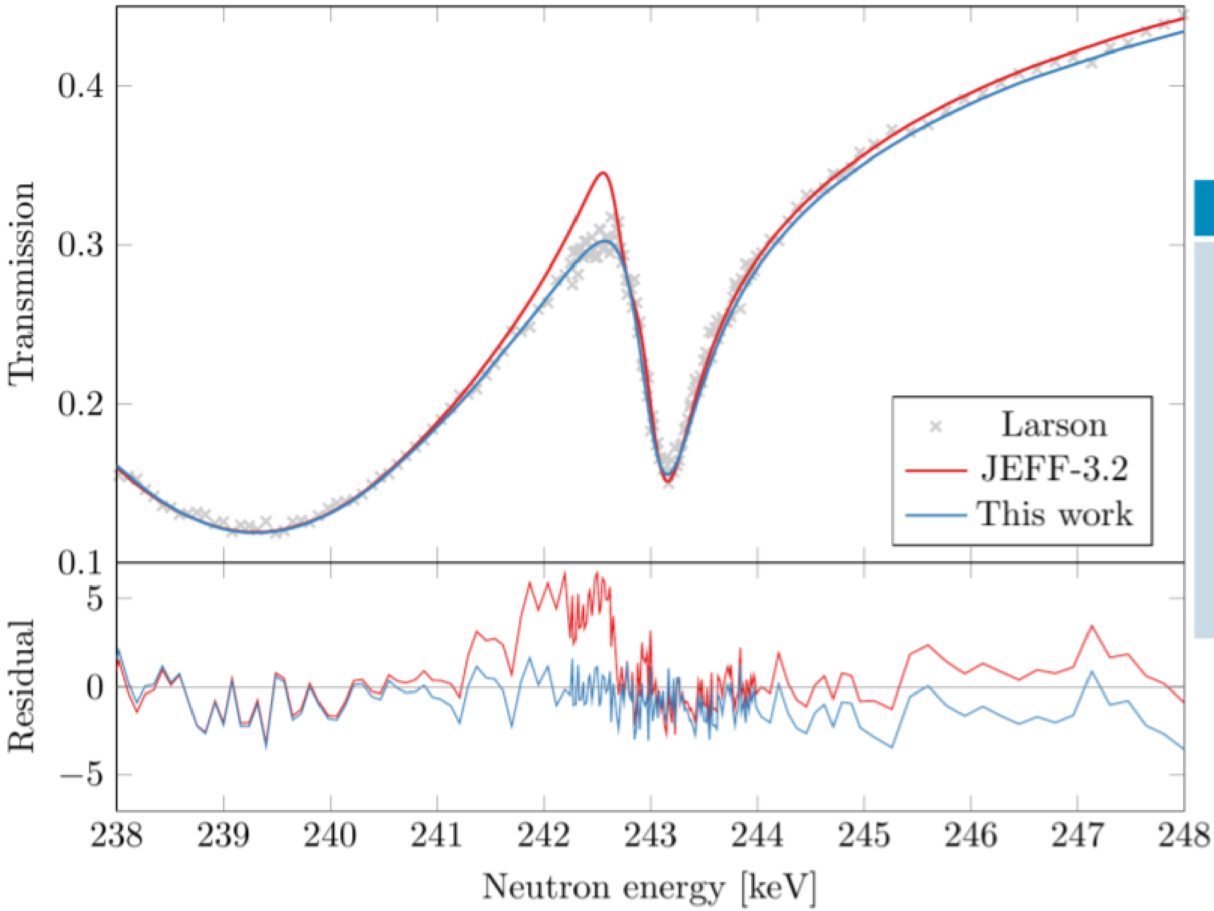
Int. ND Evaluation Network (INDEN-LE)

INDEN-LE: Evaluations of light elements

Focus: R-Matrix evaluations of neutron/charged-particle induced reactions on light/medium targets

New analysis [0, 460keV] : general R-matrix definition of channels

n+^{23}Na



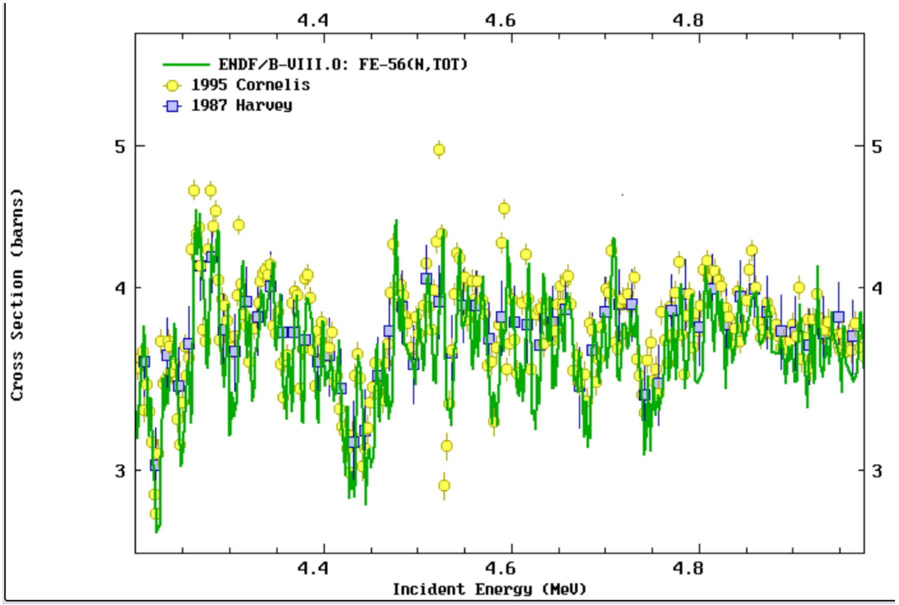
JEFF-3.2	This Work
$E = 242.79$ keV $J^\pi = 0^-$ $\ell = 1$ $E = 243.05$ keV $J^\pi = 1^+$ $\ell = 0$	$E = 243.04$ keV $J^\pi = 1^+$ $\ell = 0, \gamma_n = 20$ eV$^{1/2}$ $\ell = 2, \gamma_n = 134$ eV$^{1/2}$

Int. ND Evaluation Network (INDEN-SM)

INDEN-SM: Evaluated Data of Structural Materials

Focus: evaluations of neutron induced reactions on medium and heavy mass targets (e.g., Fe, Cr, Ni, Mn, Cu, Zr, W, Pb)

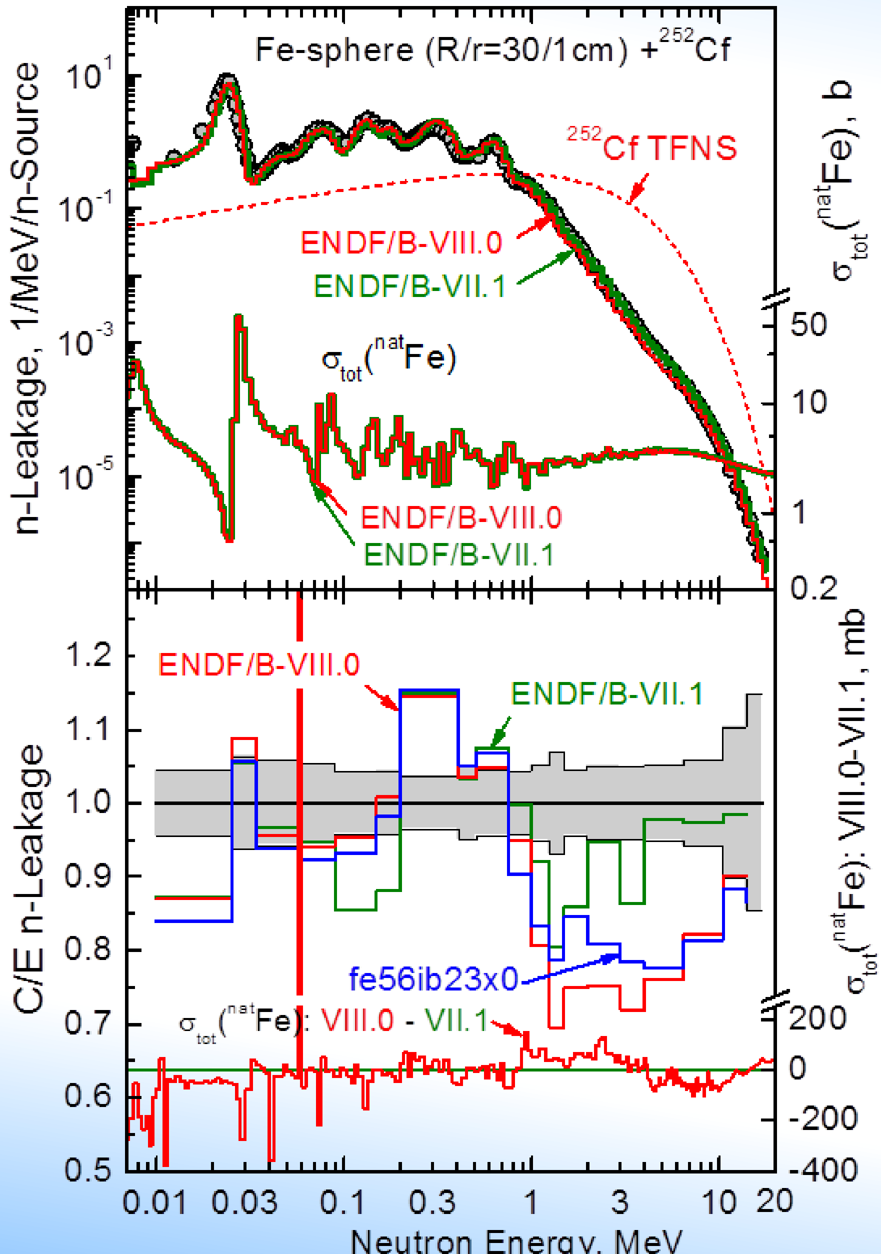
Problems: Fluctuating cross sections in the "fast" range due to low level density near magic nuclei

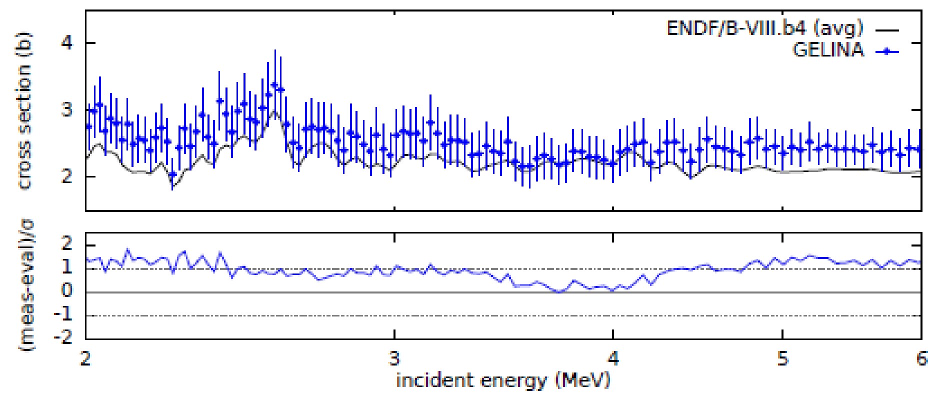


CM #3: 14-17 December 2020 (virtual), **INDC(NDS)-0824**
CM #2: 2-5 December 2019, **INDC(NDS)-0806**
CM #1: 29 October – 1st November 2018, **INDC(NDS)-0770**

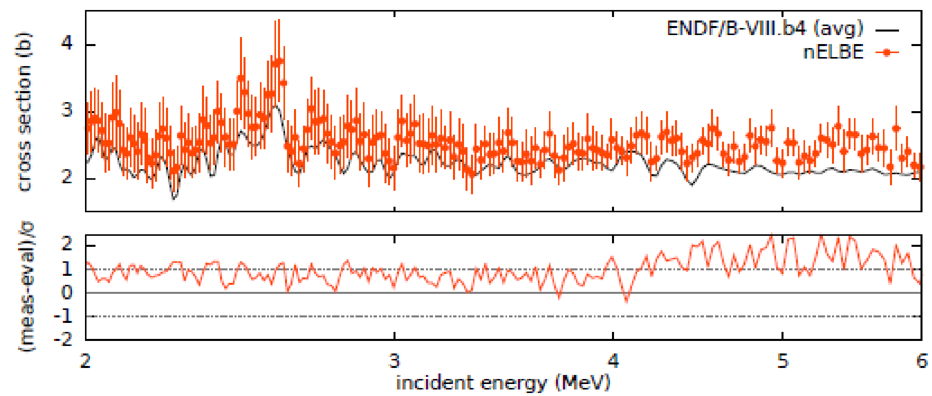
Int. ND Evaluation Network (INDEN-SM)

^{56}Fe evaluation





(a) Comparison with the GELINA dataset.



(b) Comparison with the nELBE dataset.

New measurements ^{56}Fe(n,el)
E. Pirovano et al, JRC Geel

Int. ND Evaluation Network (INDEN-SM)

INDEN-SM: Evaluated Data of Structural Materials

Fe 14 MeV – problem, Indep. confirmation

中国原子能科学研究院
CNNC CHINA INSTITUTE OF ATOMIC ENERGY

CNDC
CHINA NUCLEAR DATA CENTER

Polyethylene $(C_2H_4)_n$

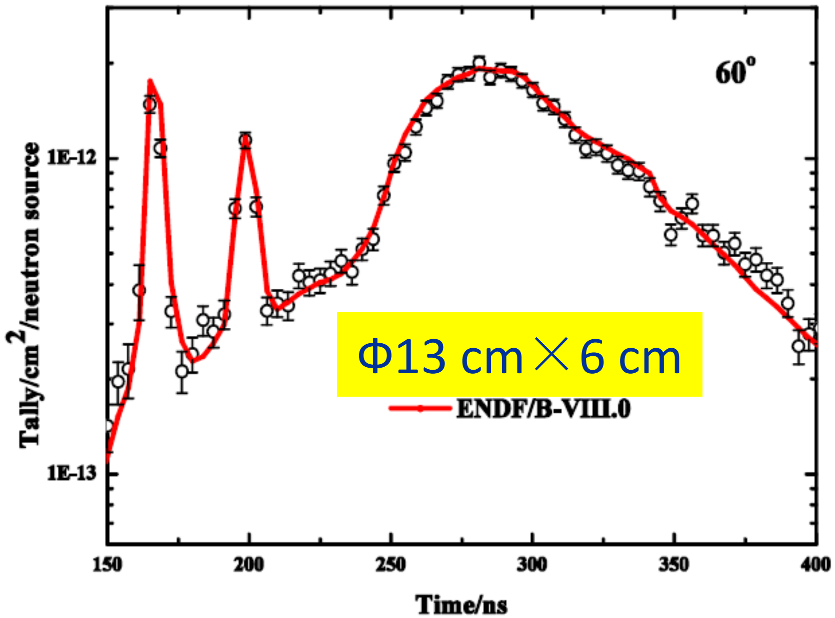
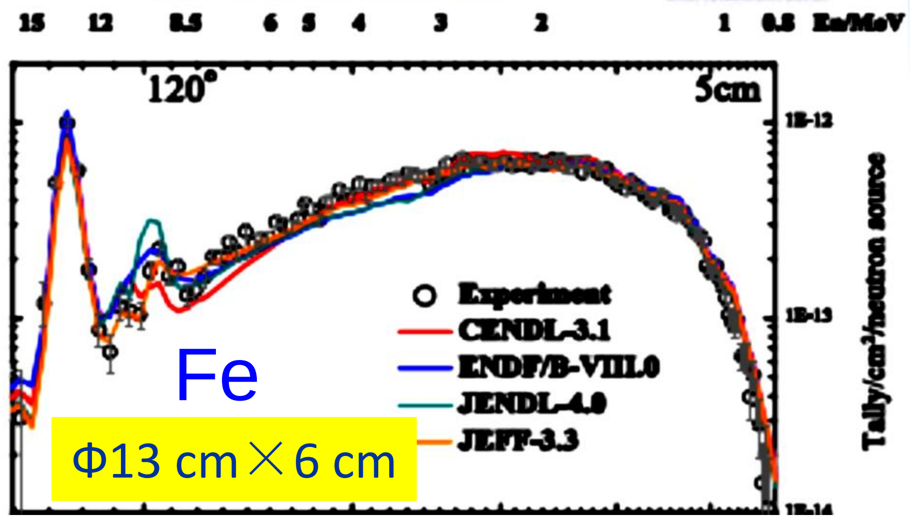
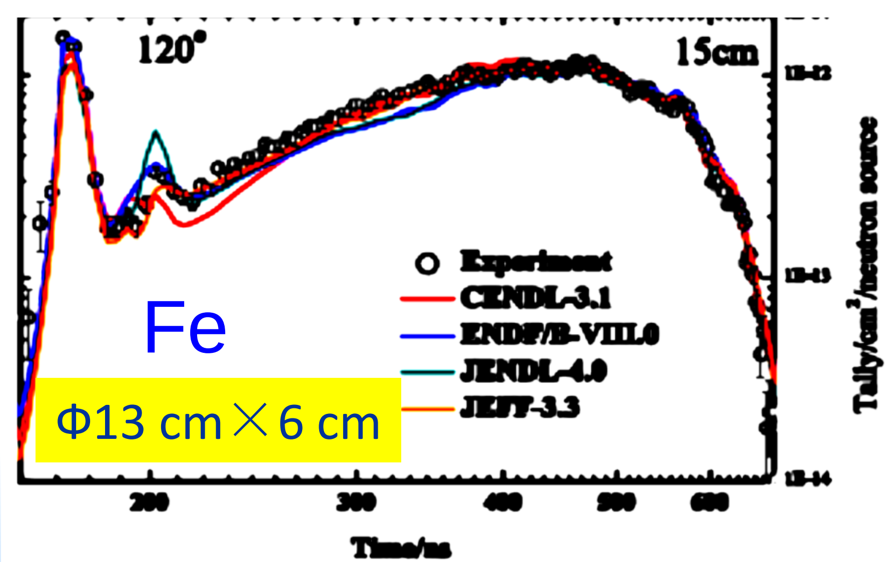


Fig.3 Leakage neutron spectrum from polyethylene sample at 60° (Φ13 cm×6 cm)





Int. ND Evaluation Network (INDEN-SM)

INDEN-SM: Evaluated Data of Structural Materials

Focus: evaluations of neutron induced reactions on medium and heavy mass targets

Available Materials

U-235 | Pu-239 | U-233 | **Fe isotopes** | Si isotopes | Mn-55 | Cr isotopes | O-16 and O-18

These are the current best files (post-ENDF/B-VIII.0). New RRR fits compatible with the Fe-56 and Fe-57 files will be very desirable. Fe-57 update was related to the increase in the average inelastic cross section in the RRR.

Data files available for downloading:

The main change compared to the original Fe-56 CIELO evaluation (equal to ENDF/B-VIII.0) is the reduction of the inelastic cross section. Near threshold, the elastic and the inelastic cross sections determine the total cross section, since the capture cross section is small. New measurements of the elastic cross section at Geel (Pirovano et al) indicate that recent measurements of the inelastic cross sections are probably too high from the threshold up to about 7 MeV of the neutron incident energy.

Small ad-hoc changes were made to increase the elastic cross section minima in the resolved resonance range to improve the performance of the file for deep penetration problems like the leakage spectra measurements from thick iron spheres with a Cf-252 source in the centre.

Specific features:

"r41" Thermal capture was increased from 2.39 barn in r39 (Firestone et al value) to 2.577 barn (JEFF-3.1.1 value) as the lower value was rejected in CEA MINERVE benchmarking.
"r39" Standard angular distribution fit of Kinney (above 0.85 MeV) and Smith (from 2.5 to 4 MeV) was adopted, equivalent to that used in ENDF/B-VIII.0.

$n+^{54,56,57}Fe$

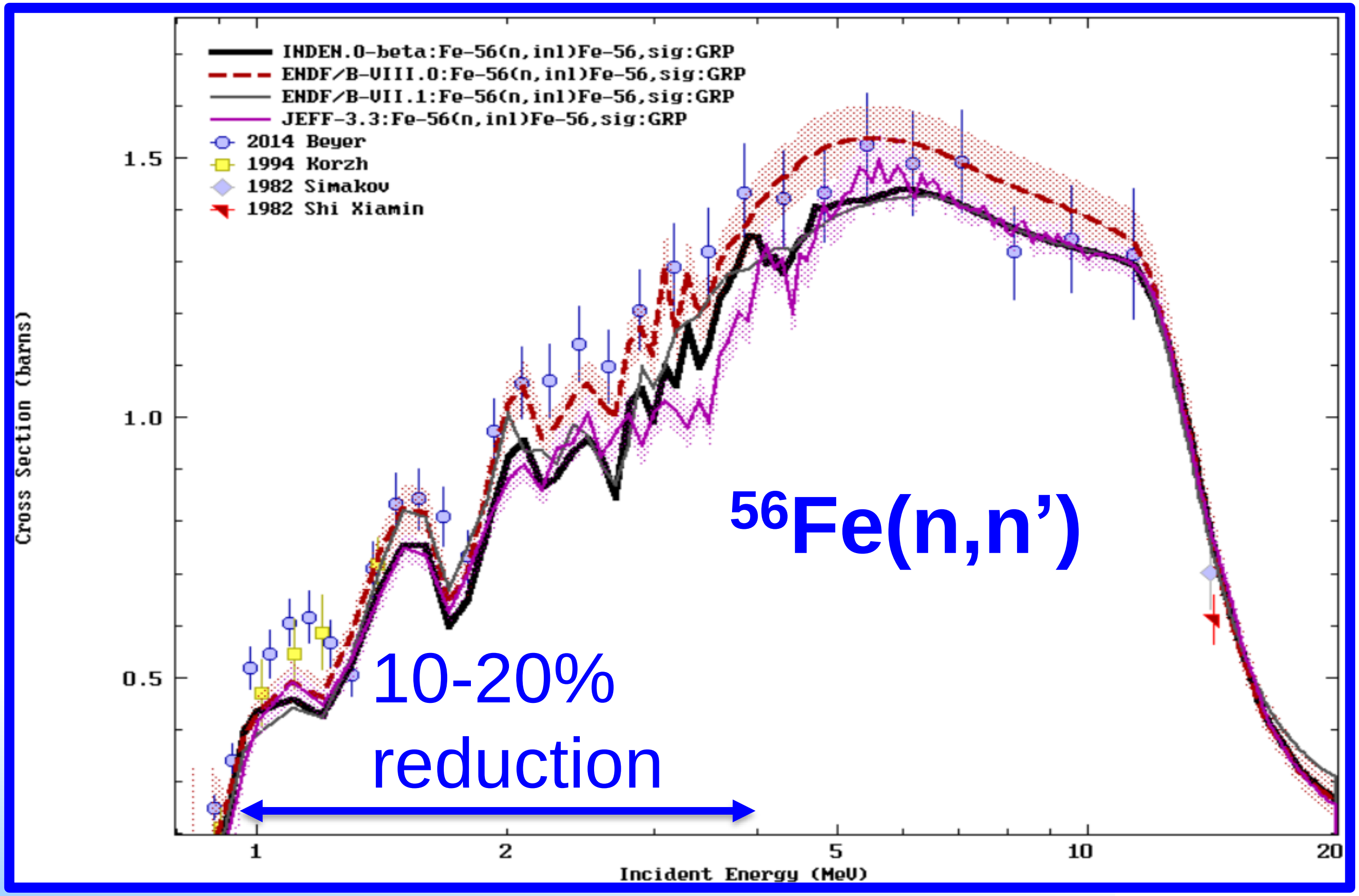
#	Nuclide	Version	Format	Link	Documents
1	Fe-56	fe56e80X29r41	ENDF	zip	10-Feb-2021
2			ACE	zip	
3	Fe-56	fe56e80X29r39	ENDF	zip	27-Jan-2020
4			ACE	zip	
5	Fe-54	fe54e80o	ENDF	zip	25-Apr-2018
6			ACE	zip	25-Apr-2018
7	Fe-57	fe57e80j	ENDF	zip	23-Apr-2018
8			ACE	zip	23-Apr-2018

Int. ND Evaluation Network (INDEN-SM)

INDEN-SM: Evaluated Data of Structural Materials

Focus: evaluations of neutron induced reactions on medium and heavy mass targets

INDEN Fe: new experiment justified



Int. ND Evaluation Network (INDEN-SM)

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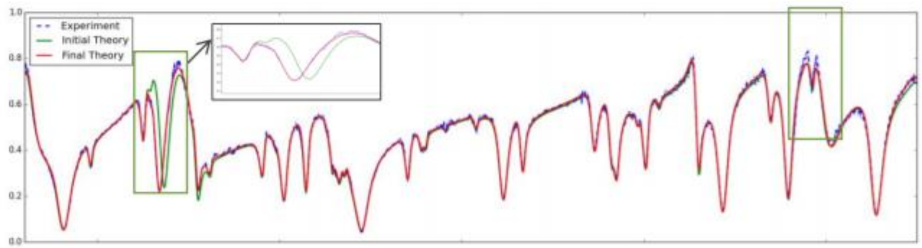
INDEN-SM: Evaluated Data of Structural Materials

Focus: evaluations of neutron induced reactions on medium and heavy mass targets

cea

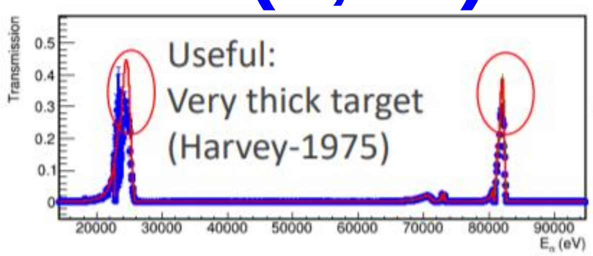
ISSUES UP TO 850keV (TRANSMISSION DATA)

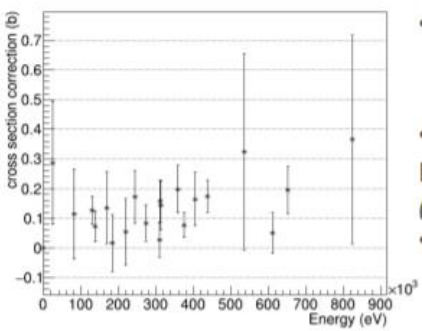
- Small issues identified,
new RRP values obtained up to 850keV



- **TOTAL CROSS SECTION MINIMA:**
We investigated the reproduction of Fe-nat total cross section minima with JEFF 3.1.1 at the different datasets

^{56}Fe(n,tot)





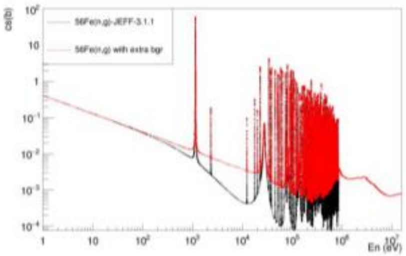
- Big standard deviation among experiments BUT indication of a **need of cs increase at the minima**
- Already proposed by:
Neutron transport experiment through natural iron:
(B.Jansky, JEFDOC 1918, 2018)
- Further work: Where does this come from?
(shape elastic and/or external levels,
other Fe isotopes….)

Int. ND Evaluation Network (INDEN-SM)

INDEN-SM: Evaluated Data of Structural Materials

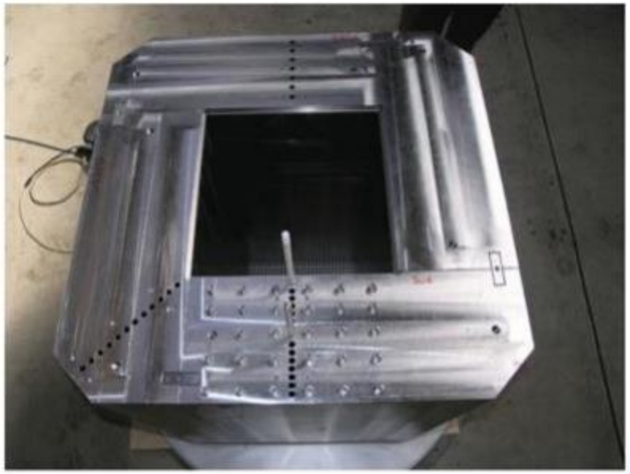
Focus: evaluations of neutron induced reactions on medium and heavy mass targets

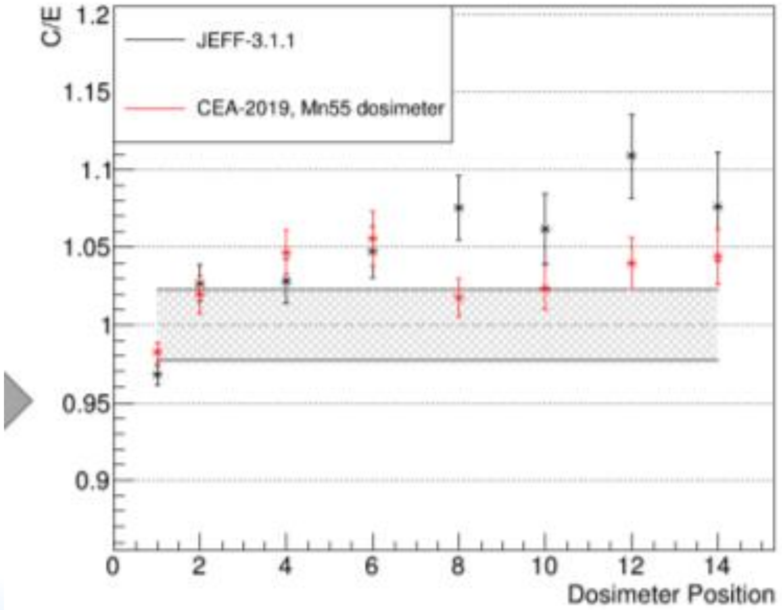
- Background added (CIELO-ENDF/B-VIII.0*) to better reproduce integral data, we did the same:



Test this correction with integral measurement: PERLE (CEA Cadarache)

*Nucl. Data Sheets **148**(2018) 214-253.





* E. Brun et al, Annals of Nuclear Energy, Volume 82, pp. 151-160, 2015

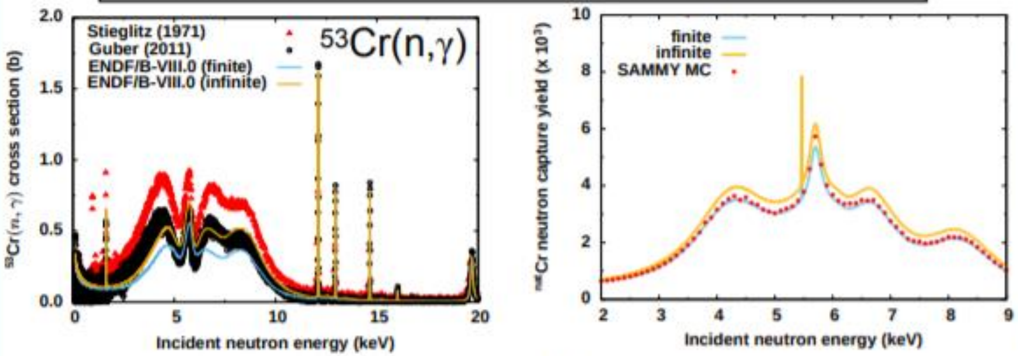
Int. ND Evaluation Network (INDEN-SM)

INDEN-SM: Evaluated Data of Structural Materials

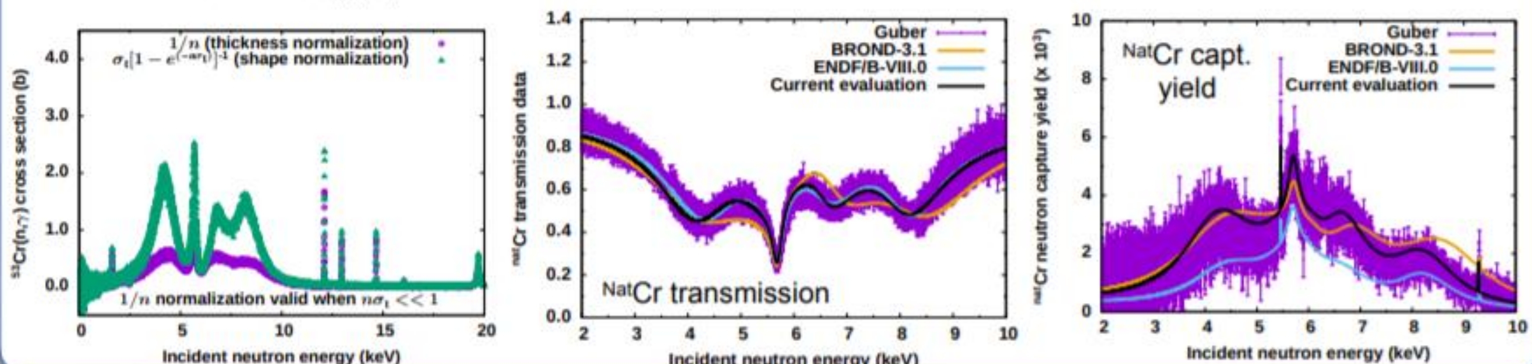
Addressing the exp. discrepancy

- Discrepancy between ^{53}Cr capture sets from Stieglitz and Guber
- ENDF/B-VIII.0 and BROND follow different improper corrections when converting data from yields to cross section
- Used ^{Nat}Cr transmission data to constrain the normalization of isotopic capture data

Normalized the neutron capture yield by the inverse of the sample thickness and tested for finite and infinite slab approximations.



- Experimental validation of normalization of capture data
- Significantly increase in capture relative to ENDF/B-VIII.0
- Increased capture improves performance in criticality benchmarks
- BROND evaluation is not supported by data



Int. ND Evaluation Network (INDEN-SM)

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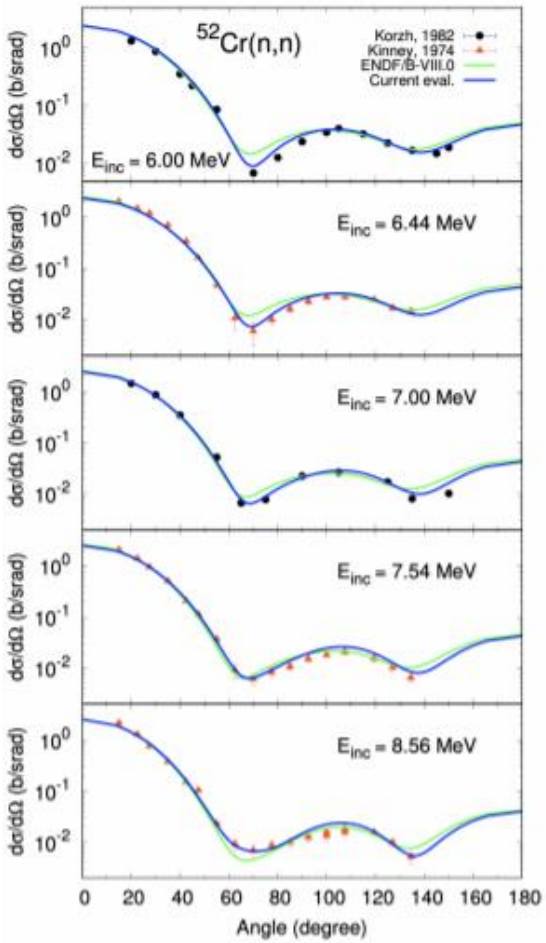
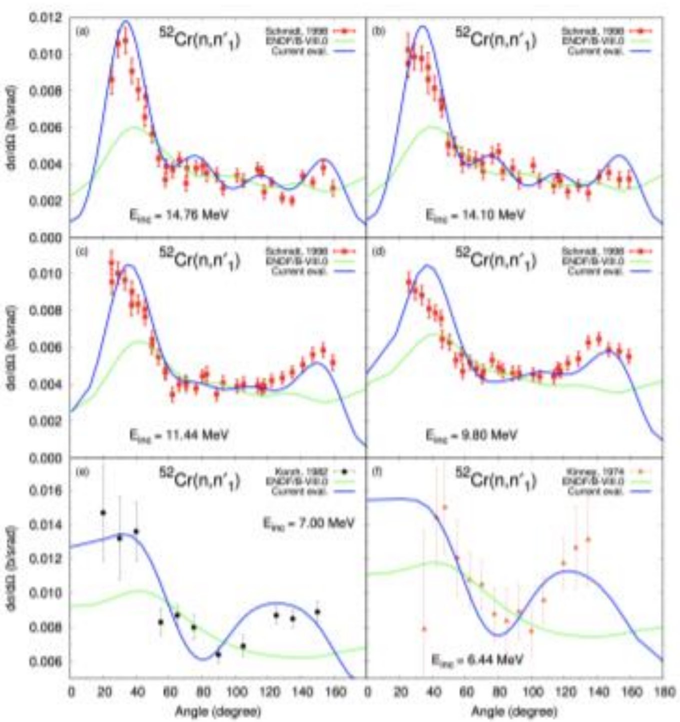
INDEN-SM: Evaluated Data of Structural Materials

Angular distributions



- Improvements in descriptions of elastic and inelastic angular distributions is direct consequence of the more realistic optical potential



Int. ND Evaluation Network (INDEN-RR)

International Atomic Energy Agency
Atoms for Peace and Development

INDEN-RR: Actinide evaluations in the Resonance Region

Major actinide PFNS, nubar and resonance parameters, URR

CM #3: 17-19 December 2020 (virtual), INDC(NDS)-0818
CM #2: 21-24 October 2019, Vienna, IAEA, INDC(NDS)-0804
CM #1: 8-11 May 2018, Vienna, IAEA, INDC(NDS)-0760

Int. ND Evaluation Network (INDEN-RR)

INDEN-RR: Actinide evaluations in the Resonance Region

Available Materials

U-235 | Pu-239 | U-233 | Fe isotopes | Si isotopes | Mn-55 | Cr isotopes | O-16 and O-18

This is WORK IN PROGRESS.
The main updates to the U-235 evaluation (suffix "zn") include

- Detailed shape of the fission cross section that follows better the measured data in the unresolved resonance range and above..
- Spurious cross-reaction covariance elements between the resonance and the fast energy ranges were removed because they gave rise to negative eigenvalues.
- Cross-covariances between nu-bar and fission cross section were removed for the same reason.

Additional work was performed on the resonance analysis to improve agreement with the measurements of the fission and capture cross sections below 20 eV. This work resulted in version "zt". Note that the integral of the fission cross section from 7.8 to 11 eV in this version is higher than the recommended standard value. This is work in progress.

$n+^{235}U$

Data files available for downloading:

#	Version	Description of changes	Format	Link	Documents
1	u235ib46o28t6DNcnu5ef0STzn	Fission x.s., covariance data (IAEA)	ENDF	zip	22-Nov-2019
2			ACE	zip	22-Nov-2019
3	u235ib46o28t6DNcnu5ef0STzt	zn + updated res. par. below 20 eV (ORNL+IAEA)	ENDF	zip	28-Oct-2020
4			ACE	zip	28-Oct-2020

Int. ND Evaluation Network (INDEN-RR)

INDEN-RR: Actinide evaluations in the Resonance Region

n+^{235}U

C/E

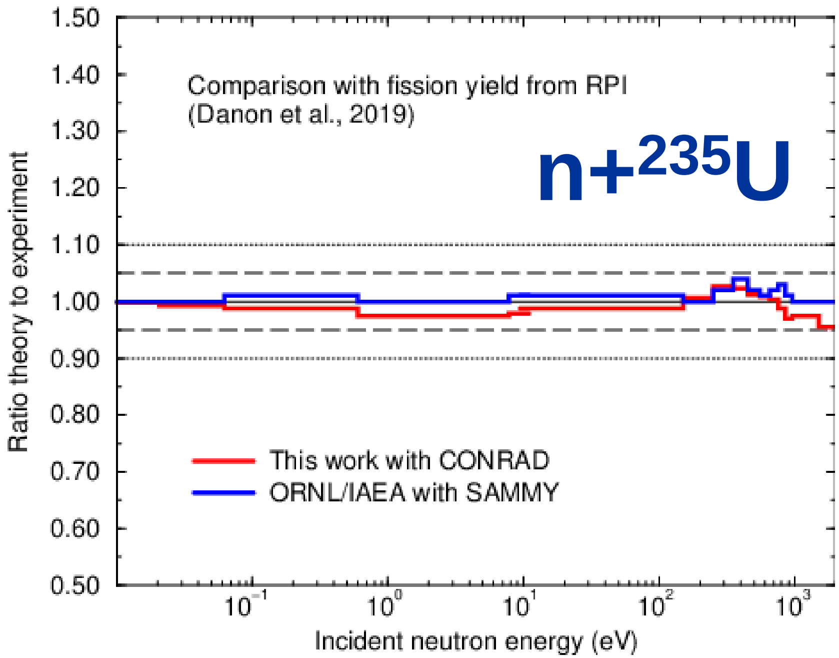
- The C/E are ratios of grouped yields which are approximately ratios of grouped cross sections (more accurate for small yields)
- **The IAEA evaluation shows improvement over ENDF-8.0 in the low energy range (E<11 eV).**
- Systematic uncertainty on fission is 2% and 3% for capture

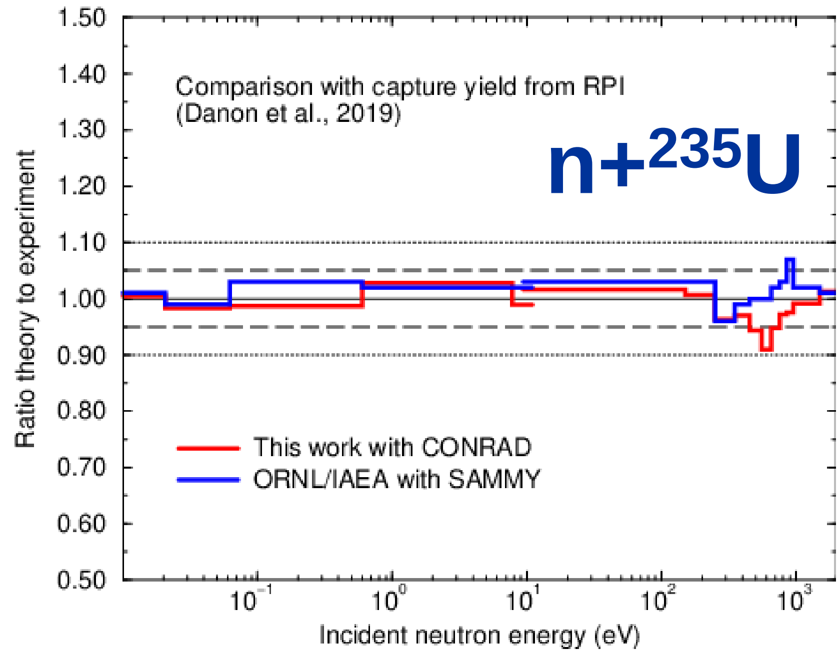
			C/E Fission Yield			C/E Capture Yield		
	E1	E2	ENDF 7.1	ENDF 8.0	IAEA 2020	ENDF 7.1	ENDF 8.0	IAEA 2020
From Thermal Experiment								
	0.01	0.0206	1.01	1.00	1.00	1.02	1.01	1.01
	0.02	0.03	1.00	1.00	1.00	0.99	0.99	0.99
	0.0206	0.0623	1.00	1.00	1.00	0.98	0.99	0.99
	0.0623	0.6	0.99	1.01	1.01	0.99	1.05	1.03
	0.6	7.8	0.97	0.99	1.00	0.99	1.05	1.02
	0.0253	9.4	0.98	0.99	1.01	0.99	1.06	1.02
	7.8	11	0.98	0.98	1.01	1.00	1.10	1.02
From Epi Thermal Experiment								
	9.4	150	1.02	1.01	1.01	1.04	1.03	1.03
	150	250	1.02	1.00	1.00	1.07	1.03	1.03
	250	350	1.04	1.02	1.02	1.06	0.96	0.96
	350	450	1.03	1.04	1.04	1.12	0.99	0.99
	450	550	1.02	1.02	1.02	1.17	1.00	1.00
	550	650	1.03	1.01	1.01	1.18	1.00	1.00
	650	750	1.03	1.02	1.02	1.17	1.02	1.02
	750	850	1.03	1.03	1.03	1.17	1.03	1.03
	850	950	1.00	1.01	1.01	1.17	1.07	1.07
	950	1500	1.02	1.00	1.00	1.25	1.02	1.02
	1500	2000	1.03	1.00	1.00	1.45	1.01	1.01

Int. ND Evaluation Network (INDEN-RR)

INDEN-RR: Actinide evaluations in the Resonance Region

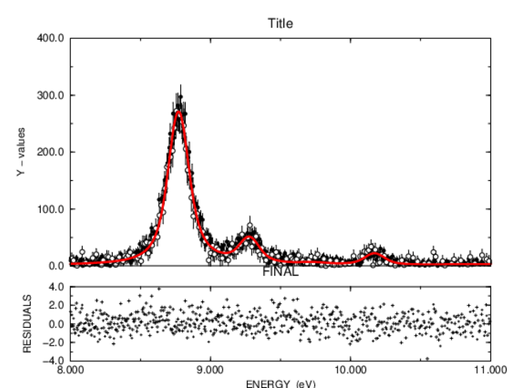
Convergence of CEA and ORNL/IAEA evaluations in the RRR





n+^{235}U eval

n_TOF capture yield



Int. ND Evaluation Network (INDEN-RR)

INDEN-RR: Actinide evaluations in the Resonance Region

Available Materials

U-235 | **Pu-239** | U-233 | Fe isotopes | Si isotopes | Mn-55 | Cr isotopes | O-16 and O-18

This is WORK IN PROGRESS.
The main updates to the ENDF/B-VIII.0 Pu-239 evaluations (suffix "p16" and "p17") include

- p16: Use of the LANL (D. Neudecker) Pu-239 PFNS evaluation that include thermal, ChiNu and CEA data (preliminary). The thermal PFNS average energy of Eav=2.08 MeV agrees with the one of the IAEA PFNS evaluation (ENDF/B-VIII.0 value ~2.12 MeV).
- p17: Use of the IAEA Pu-239 PFNS for thermal neutrons with average energy Eav=2.08 MeV (ENDF/B-VIII.0 value ~2.12 MeV). The PFNS for neutron incident energies of 500 keV and above is taken from Talou et al evaluation (IAEA PFNS CRP).
- Adjustment of thermal cross sections and nubar to agree with TNC from IAEA Standards 2017.
- Increase of the capture-to-fission ratio near and below the first resonance of Pu-239 to decrease the criticality in high leakage PST (ATLF>0.4).
- A rigid-rotor RIPL 2408 neutron potential with extended coupling was used in EMPIRE calculations (to be updated).
- New EMPIRE calculation in the fast neutron range tuned to describe ENDF/B-VIII.0 fission and capture cross section; (n,2n) well reproduced.
- Fission and capture cross sections in the fast range adopted from ENDF/B-VIII.0. Therefore, only changes in elastic/inelastic are relevant.

n+^{239}Pu

Data files available for downloading:

#	Version	Description of changes	Format	Link	Documents
1	pu239p10	ORNL + IAEA, IAEA PFNS thermal, Talou et al PFNS fast	ENDF	zip	17-05-2019
2			ACE	zip	17-05-2019
3	pu239p16	ORNL+IAEA(RRR), IAEA(fast), LANL PFNS based on ChiNU+CEA + thermal data	ENDF	zip	23-11-2020
4			ACE	zip	23-11-2020
5	pu239p17	ORNL+IAEA(RRR), IAEA(fast), IAEA PFNS thermal, Talou et al PFNS fast	ENDF	zip	23-11-2020
6			ACE	zip	23-11-2020

Int. ND Evaluation Network (INDEN-RR)

INDEN-RR: Actinide evaluations in the Resonance Region

Available Materials

U-235 | Pu-239 | **U-233** | Fe isotopes | Si isotopes | Mn-55 | Cr isotopes | O-16 and O-18

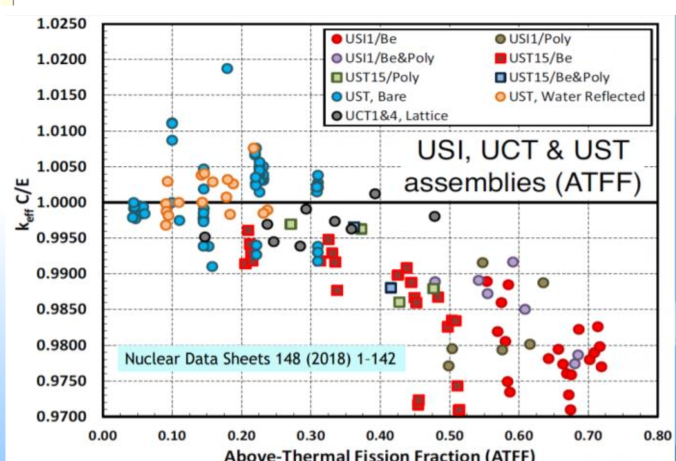
This is WORK IN PROGRESS.
See IAEA report INDC(SLO)-0004 on "On the Analysis of Benchmarks with 233U fuel and Be or Polyethylene reflectors".
The main updates to the ENDF/B-VIII.0 U-233 evaluation (suffix "a506b-c") include

- Use of the IAEA U-233 PFNS for thermal neutrons with average energy Eav=2.030 MeV (ENDF/B-VIII.0 value ~2.074 MeV). Talou et al PFNS evaluation (IAEA PFNS CRP) is used in the fast region.
- Adjustment of thermal cross sections to agree with TNC from IAEA Standards 2017.
- Introduction of energy dependence for nubar below 30eV from Reed et al data.
- Resonance parameters were refitted adding new experimental data (Berthomieux, Calviani).

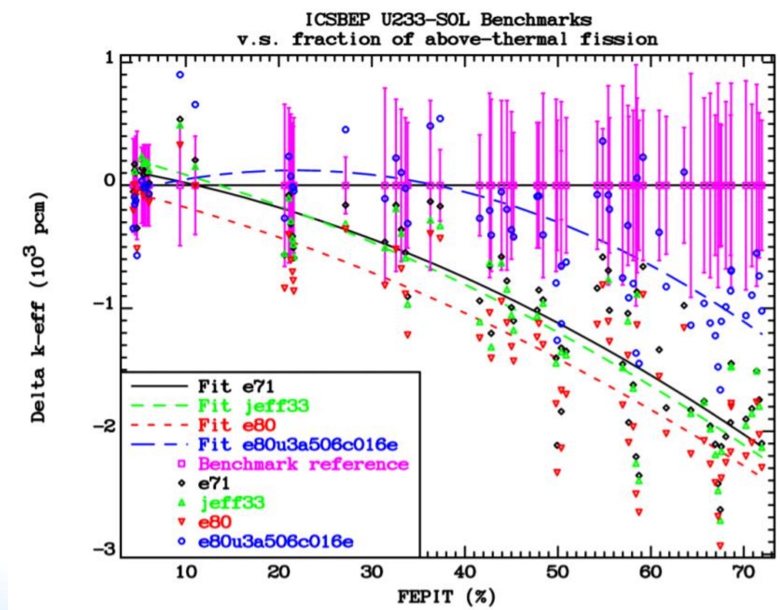
This file is a preliminary one, but the criticality dependence on ATLF for U-233 solution benchmarks as shown in this document is significantly improved for FEPIT<0.6 using the new PFNS.

Data files available for downloading:

#	Version	Description of changes	Format	Link	Documents
1	u233a506b-c	ORNL + IAEA	ENDF	zip	15-05-2020
2			ACE	zip	15-05-2020



n+^{233}U

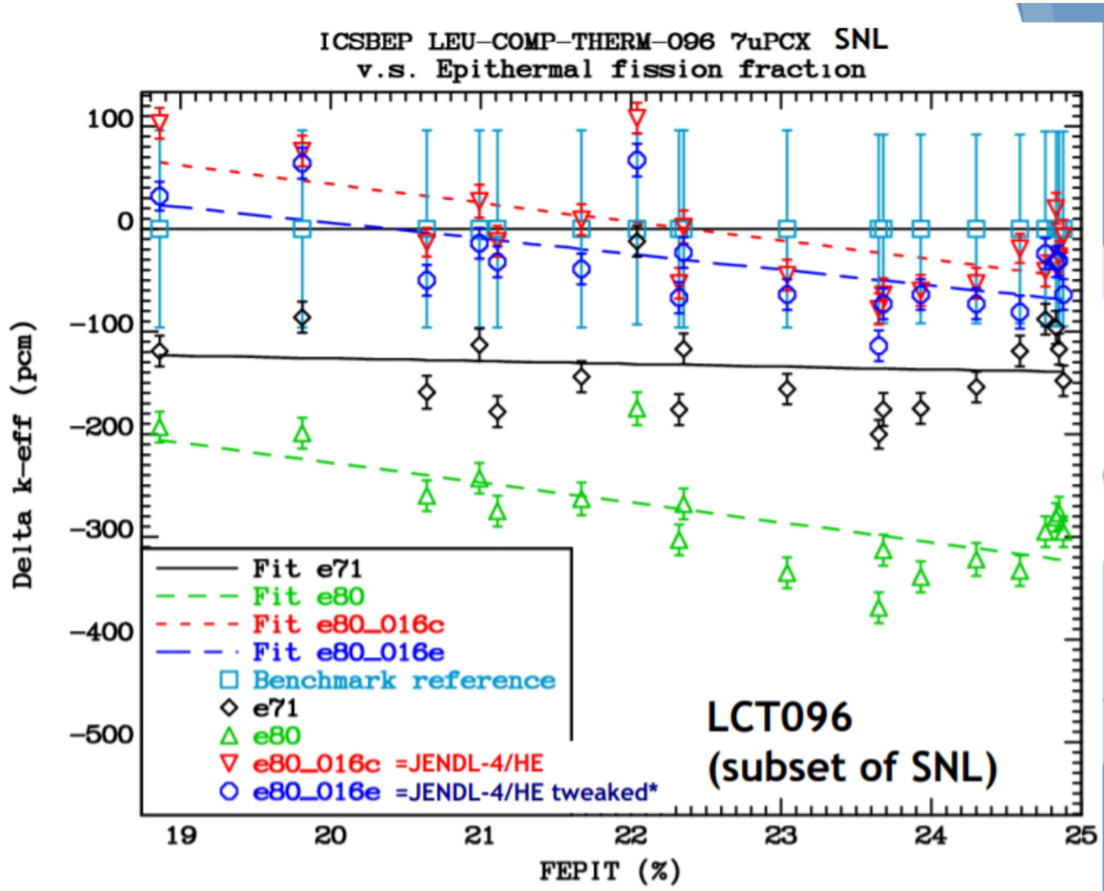


Int. ND Evaluation Network (INDEN-RR)

INDEN-RR: Actinide evaluations in the Resonance Region

Integral feedback to oxygen evaluation (HST, PST, UST)

Different n+^{16}O evaluations tested



Int. ND Evaluation Network (INDEN)

International Network of Nuclear Data Evaluators

nds.iaea.org/INDEN/

INDEN list of on-going evaluations (March 2021)

Light elements:
Be-9; N-14,15; O-16,17,18; Na-23; Si-28,29,30
Structural elements:
Cr, Fe, Ni, Pb, Zr isotopes
Actinides:
U-233,235,238; Pu-239;

Re-evaluations (due to identified issues):

- **Fe-54,56,57** (issues in (n,el), (n,inl) and $d\sigma/d\Omega_{el}(\theta)$ cross sections from 0.85-6 MeV)
- **Cr isotopes** (new RR evaluation of Cr-50,Cr-53; new fast evaluations)
- **Si isotopes** (updated thermal capture, direct capture included)
- **Mn-55** (correction of thermal capture gammas)
- **Pu-239** (New PFNS, thermal nubar, resonance region)
- **U-233** (New PFNS, thermal nubar, resonance region)
- **U-238** (14 MeV leakage issues due to inelastic spectra, PFNS for E_n=5-8 MeV)
- **O-16** (Preliminary update for benchmarking)

Int. ND Evaluation Network (INDEN)

Si evaluations (ORNL/IAEA) - Status

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

New information from integral testing since ENDF/B-VIII.0 release & publications

Criticality performance: any new/unexpected findings? ***Yes, Si-28 thermal capture too low***

Neutron transmission: any new/unexpected findings? ***No*** ***(169 mb -> 186mb)***

(n,xn) activations: any new/unexpected findings? ***No***

Known deficiencies/gaps:

Si-28: **Thermal capture increased by ~10% up to 186 mb (Firestone et al, IAEA EGAF)**

Author (Year)	Value (mb)
Islam (1990)	207±4
Kennett (1992)	171±3
Raman (1992)	169±3
Mughabghab (2006)	177±4

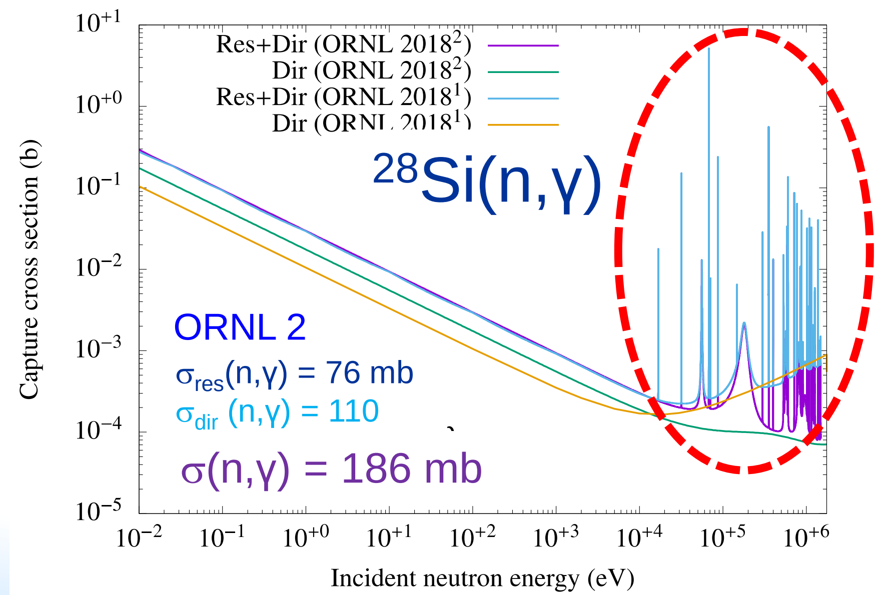
ORNL (2002)	168.9	103.1	65.8
IAEA (2007)	186±3	N/A	N/A
ENDF/B-VIII.0 (2018)	169.1	169.1	0
ORNL (20181)	184.5	131.9	52.6
ORNL (20182)	186.01	76	110

- ORNL new RRR evals for ^{28,29,30}Si with direct capture (TEDCA- ORNL I & CUPIDO- ORNL II)

. CUPIDO calculations (G. Arbanas) needed to be decreased by 5% to match the $\boldsymbol{\sigma_\gamma(E_{th}) = 110}$ mb

. Both ORNL I and ORNL II give improved performance

. Inclusion of a complex component for the channel radii (new feature) can be used to describe the direct capture component within R-matrix formalism. This allows to produce resonance parameters and related reconstructed cross sections in full unitary regime



ORNL 2 has better physics (improved modelling of direct capture)

Int. ND Evaluation Network (INDEN)

Si evaluations (ORNL/IAEA) - Status

Si-28 **Thermal capture increased by ~10% following Firestone et al, IAEA EGAF**

Direct capture considered by CUPIDO (ORNL) and new consistent ORNL evals

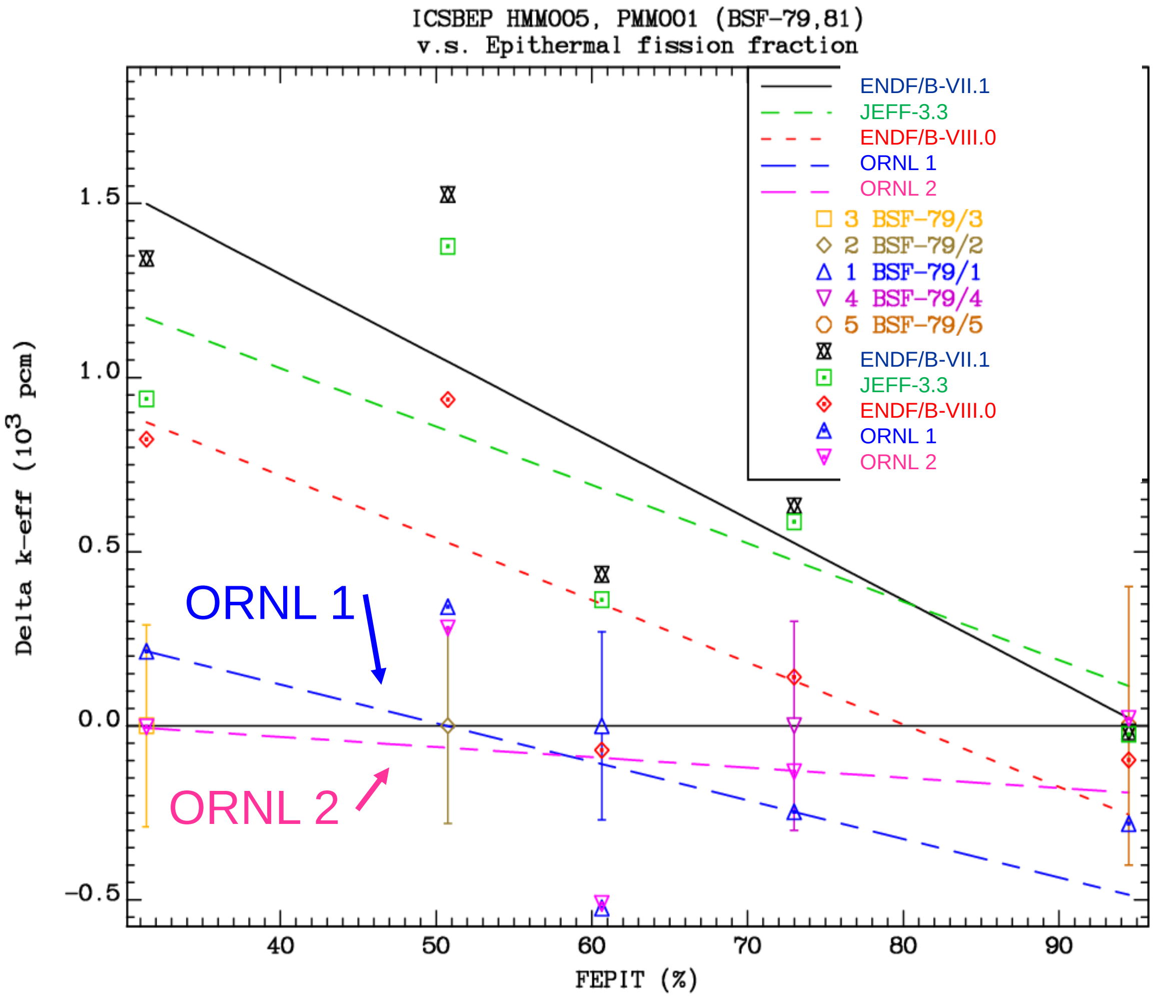
-> Criticality impact ~ -800 pcm in thermal assemblies (e.g., hmm005.3)

ORNL 2: Criticality is independent of the epithermal fraction in spectra (~zero slope) !!

Better physics & criticality performance improved in new evaluations

Consistent unitarity in R-matrix treatment

New evaluations READY !



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Thank you!