IAEA 60 Years
Atoms for Peace and Development

Status of TENDL

Arjan Koning, IAEA
Dimitri Rochman, PSI

WPEC-33 Meeting, May 13-14 2021, NEA, Boulogne-Billancourt

Contents

- TENDL: Global info (6 very quick slides)
- Software to support TENDL
- TENDL-2021 developments
- Conclusions

“The split”: IAEA Meeting on long term nuclear data needs (2011)

An Alternative Future: An International Evaluated Nuclear Database (“ENDF/I” or “WENDF” or “WEF or …”)

M.B. Chadwick

X-CP Computational Physics Division, LANL,

What users need: nuclear data libraries of the highest possible quality for all nuclides, incident particles, energies, reaction channels, including uncertainties:

A plea for reproducibility

Arjan Koning

CIELO

All effort on 6 most important isotopes

Successful collaboration between experimentalists, nuclear modelers, evaluators and validators

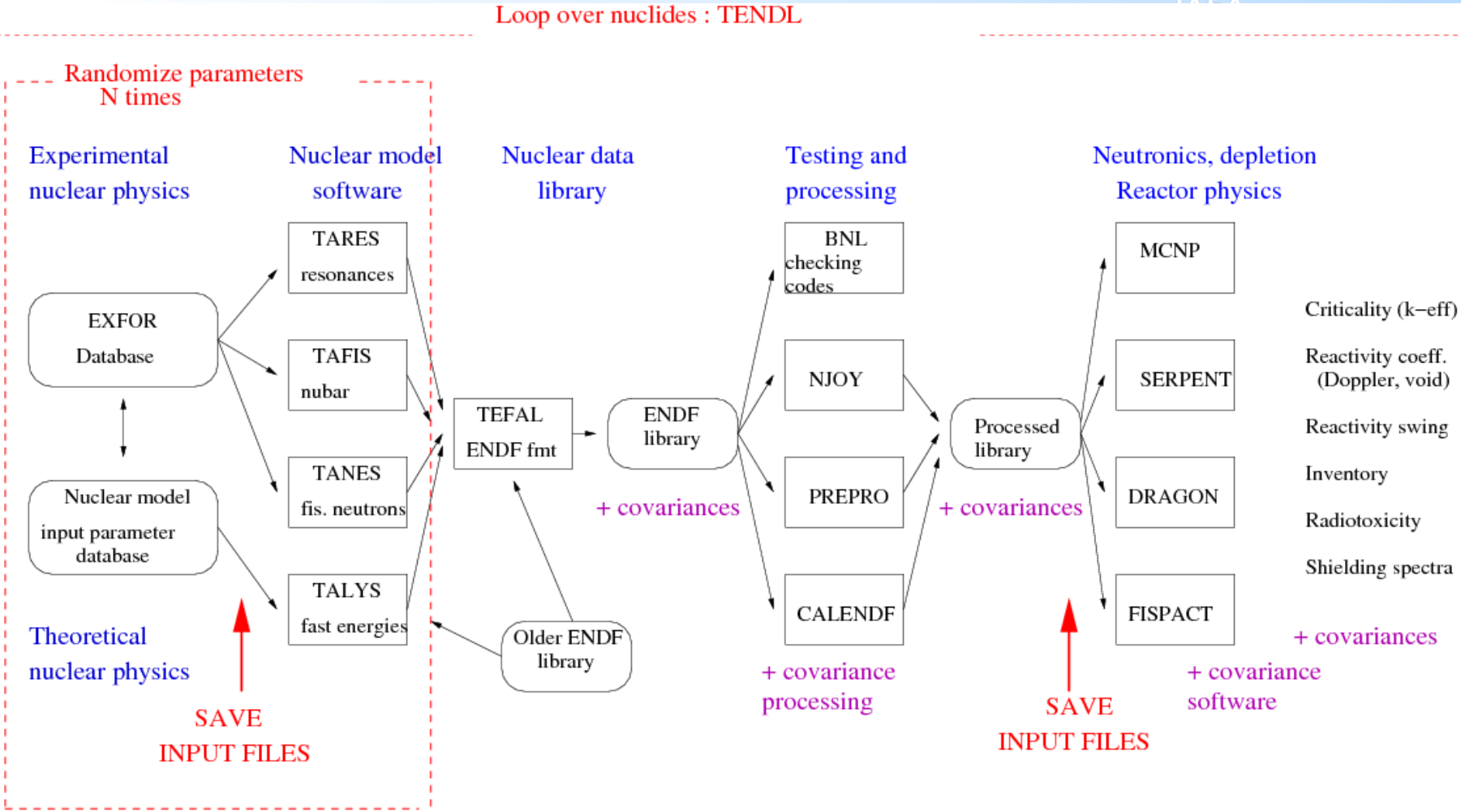
No change in evaluation/validation paradigms

TENDL

All effort distributed among everything

Automated use of “all knowledge up to now”: EXFOR, TALYS, existing libraries CIELO (challenging!), AK + DR

Reproducibility and completeness


Loop over nuclides : TENDL
Randomize parameters
N times
Experimental
nuclear physics
Nuclear model
software
Nuclear data
library
Testing and
processing
Neutronics, depletion
Reactor physics
EXFOR
Database
Nuclear model
input parameter
database
Theoretical
nuclear physics
TARES
resonances
TAFIS
nubar
TANES
fis. neutrons
TALYS
fast energies
SAVE
INPUT FILES
TEFAL
ENDF fmt
Older ENDF
library
ENDF
library
+ covariances
BNL
checking
codes
NJOY
PREPRO
CALENDF
+ covariance
processing
Processed
library
+ covariances
SAVE
INPUT FILES
MCNP
SERPENT
DRAGON
FISPACT
+ covariance
software
Criticality (k−eff)
Reactivity coeff.
(Doppler, void)
Reactivity swing
Inventory
Radiotoxicity
Shielding spectra
+ covariances

TENDL-2019

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TALYS-based evaluated nuclear data library

Home | Reference & us | Citations | Feedback | TALYS

"We believe that our great goal can be achieved with systematism and reproducibility. We are so outside the box, that the box is a point"

How to reference

Sub-library files

1. Neutron
2. Proton
3. Deuteron
4. Triton
5. He3
6. Alpha
7. Gamma

Application libraries & tar

Random files

1. Random fission yields
2. Random thermal scattering
3. Random ENDF-6 files
4. Random ACE files

V&V

TENDL-2019: (release date: December 31, 2019)

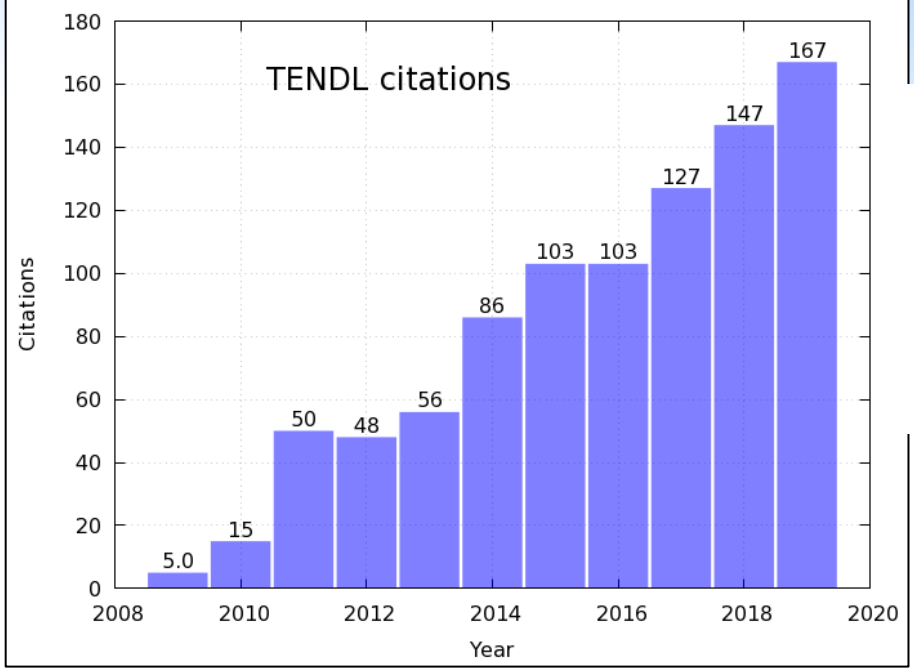
Last update: 13 December 2019

TENDL is a nuclear data library which provides the output of the **TALYS** nuclear model code system for direct use in both basic physics and applications. The 10th version is **TENDL-2019**, which is based on both default and adjusted **TALYS** calculations and data from other sources (previous releases can be found here: 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, and 2017).

Up to 2014, TENDL was produced at NRG Petten. Since 2015, TENDL is mainly developped at PSI and the IAEA (Nuclear Data Section). Still, many people contributes to TENDL with the testing and processing of the files.

TENDL contains evaluations for seven types of incident particles, for all isotopes living longer than 1 second: Z=1 ^{1}H to Z=115 ^{291}Mc (about 2800 isotopes), up to 200 MeV, with covariances.

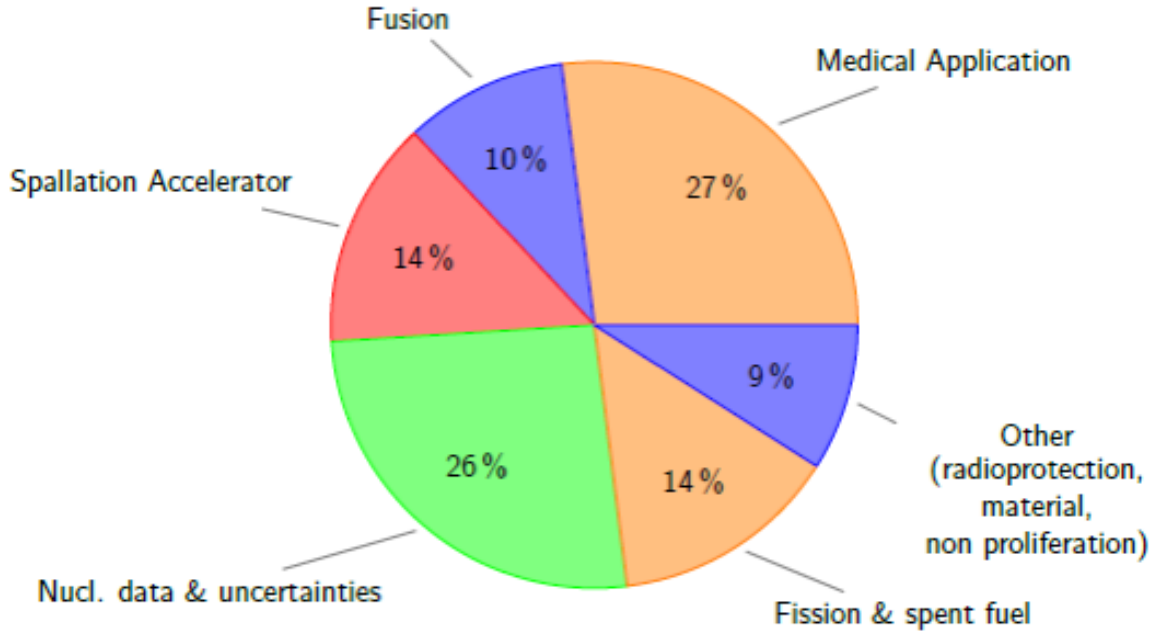
TENDL is not a default or shadow library. Not a single neutron evaluation is based on default calculations. With the HFR approach, all resonances follow statistical hypothesis. For major isotopes, greater care was used during the evaluation process.



Available online at www.sciencedirect.com
ScienceDirect
Nuclear Data Sheets
Nuclear Data Sheets 155 (2019) 1–55
www.elsevier.com/locate/nds

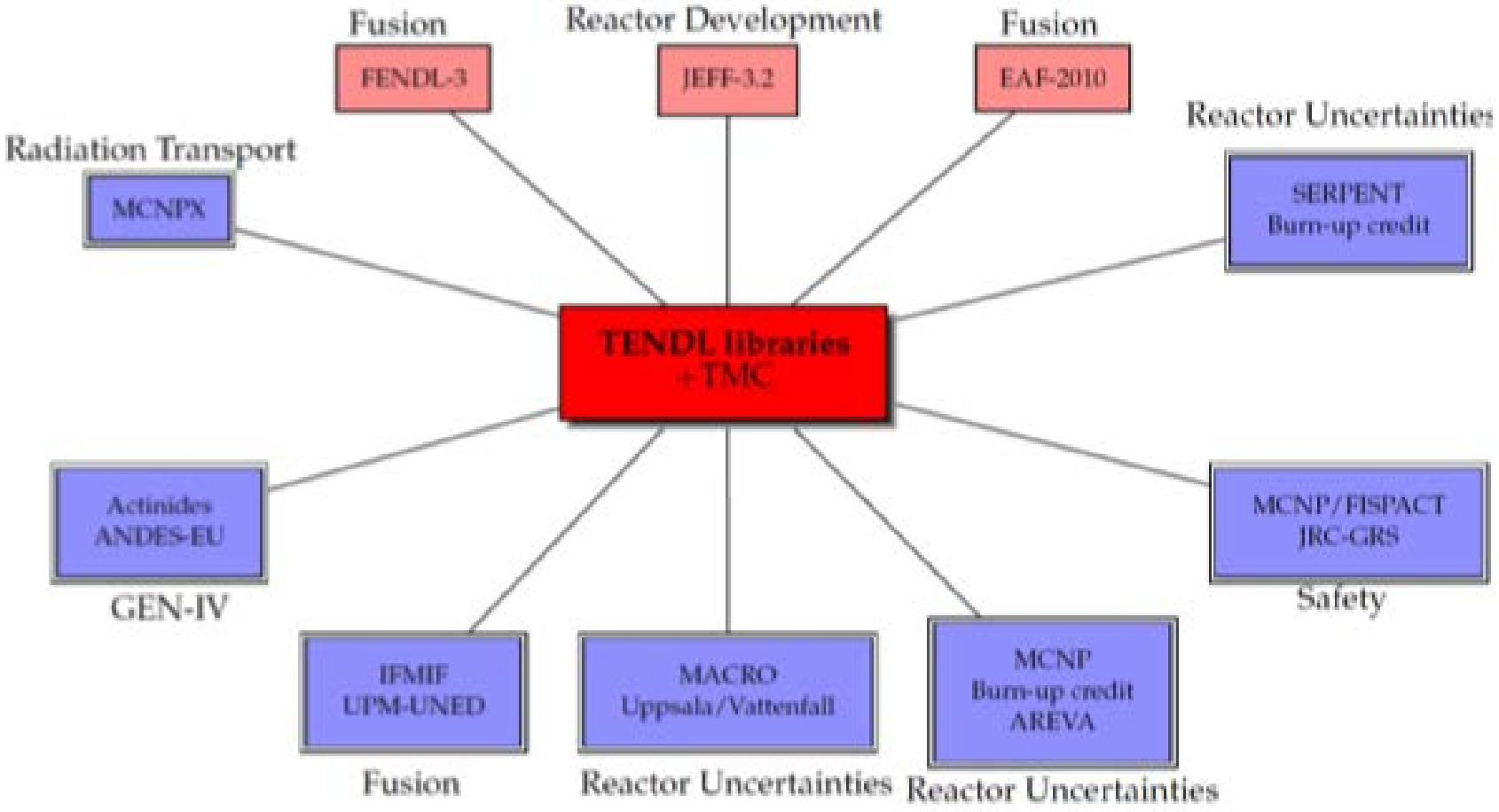
TENDL: Complete Nuclear Data Library for Innovative Nuclear Science and Technology

A.J. Koning,[1,2,*] D. Rochman,[3] J.-Ch. Sublet,[1] N. Dzysiuk,[4,5] M. Fleming,[6,7] and S. van der Marck[4]



What is the TENDL project ?

- Fully implemented in FISPACT-II, part of GEANT, CASMO…,
- Used in fission, fusion applications, medical isotope productions



TENDL-2019

- Similar structure as the previous TENDL libraries
  - 2813 isotopes, 200 MeV
  - Incident neutrons, protons, deuterons, tritons, He3, alphas, and gammas
  - Uncertainty Quantification based on Bayesian Monte Carlo
  - Complete for secondary distributions: ang. dis, DDX, recoils, discrete and continuum gamma's
  - Complete for covariance data for all that ENDF format allows (MF31-40)
  - ACE, multi group
  - ENDF-6 files in different options (MF3 MT5 at 0, 20 or 60 MeV, EAF files)
  - MF32 and/or MF33 for resonance range
  - Automated plots versus EXFOR and other world libraries
  - Random files for use in Total Monte Carlo

TALYS-Related Software and Databases

TALYS and the TALYS-related packages are open source software and datasets (GPL License) for the simulation of nuclear reactions.

Coming soon, still available here

TALYS

Arjan Koning, Stephane Hilaire, Stephane Goriely

Nuclear reaction model code.

Download TALYS-1.95
Download previous versions
Read Tutorial

Created at NRG CEA ULB UNIVERSITÉ LIBRE DE BRUXELLES IAEA

EXFORTABLES

Arjan Koning

Experimental nuclear reaction database based on EXFOR.

Download EXFORTABLES-1.0
Read Tutorial

RESONANCETABLES

Arjan Koning, Dimitri Rochman

Database for thermal cross sections, MACS and average resonance parameters.

Download RESONANCETABLES-1.0
Read Tutorial

Created at IAEA PSI

ENDFTABLES

Arjan Koning

Code to translate ENDF nuclear data libraries into tabular format.

Download ENDFTABLES-1.0
Read Tutorial (Chapter 2)

Libraries-2020

Arjan Koning

Evaluated nuclear data libraries and EXFOR in tabular format.

Libraries-2020 [15GB]
Read Tutorial (Chapter 3)

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nds.iaea.org/talys

TASMAN, TEFAL, and Tools for TALYS (“T6”, TENDL) soon to follow

Contribution to WPEC: SG49 on reproducibility of nuclear data Evaluation

SG50 on curated computer-readable experimental database (based on EXFOR)

Direct-access plotting tool under development

Automation and relation with AI/ML

- Strictly controlled dataflows for TENDL particularly well suited for AI/ML
- T6 package IS a pipeline

Available online at www.sciencedirect.com

ScienceDirect

Nuclear Data Sheets 173 (2021) 239–284

Nuclear Data Sheets

www.elsevier.com/locate/nds

Conception and Software Implementation of a Nuclear Data Evaluation Pipeline

G. Schnabel,[1,*] H. Sjöstrand,[2] J. Hansson,[2] D. Rochman,[3] A. Koning,[1] and R. Capote[1]

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[2] *Uppsala University, Department of Physics and Astronomy, Uppsala, Sweden*
[3] *Paul Scherrer Institut, 5232 Villigen, Switzerland*

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TENDL automation and portability

- Essentially depends on **direct** (non-GUI) access to all data of EXFOR and the most important ENDF libraries:
  - TENDL supports SG-49 on reproducibility
  - TENDL supports SG-50 on readable exp. database
- Is produced by the **autotalys** command from the 'T6' package, e.g.:

  autotalys –proj n –element Am –mass 242 –Liso 1 –njoy –recoils etc. (+ another 5-10 flags)
- Challenge: Finalize documentation and modularity of T6, and motivate users other than AK and DR to produce evaluations (JEFF-4)

Under construction for TENDL-2021: Fission yields and TSL

TENDL-2021

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Fission yields

Last update: 12 May 2021

The following fission yield files (nominal and random) were produced with the GEF code, version 2019 (see more details about GEF here).

For more questions, please contact D. Rochman at PSI.

List of isotopes

• Z=90, ^{229}Th	(06/05/2021)	0.0253 eV, nominal ENDF and 100 random ENDF files (2 Mb)
• Z=90, ^{231}Th	(06/05/2021)	0.0253 eV, nominal ENDF and 100 random ENDF files (2 Mb)
• Z=90, ^{233}Th	(06/05/2021)	0.0253 eV, nominal ENDF and 100 random ENDF files (2 Mb)
• Z=91, ^{232}Pa	(07/05/2021)	0.0253 eV, nominal ENDF and 100 random ENDF files (2 Mb)

For more questions, please contact D. Rochman at PSI. This work was possible thanks to G. Noguere, J.I. Marquez, M. Hursin and V. Saligno.

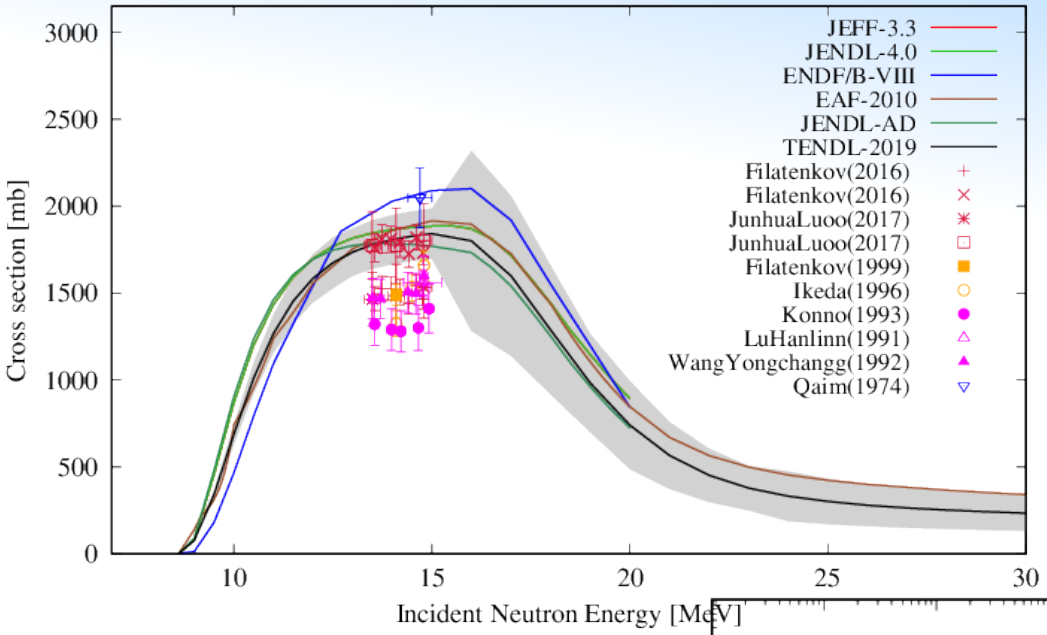
H in H_2O at many temperatures (preliminary files)

• LEAPR files	(11/05/2021)	nominal and 150 random files (6 Mb)
• ENDF files	(06/05/2021)	nominal and 30 random files (800 Mb)
• ACE files (293.60 K)	(11/05/2021)	nominal xsdir,ace and 150 random files (800 Mb)
• ACE files (600 K)	(11/05/2021)	nominal xsdir,ace and 150 random files (800 Mb)
• ACE files (900 K)	(11/05/2021)	nominal xsdir,ace and 150 random files (800 Mb)

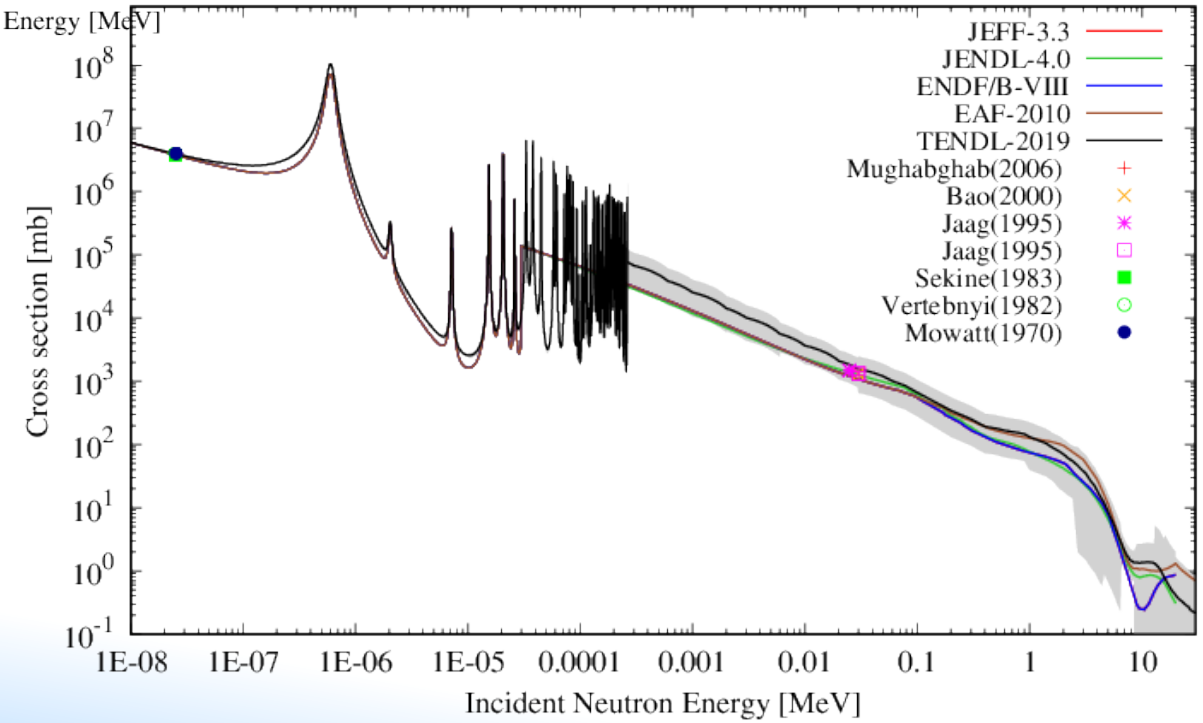
Other developments for TENDL-2021

- New RR evaluations for JEFF: $Ag^{107,109}$, $Eu^{151,153\text{-}155}$, Pm^{148m}, $Lu^{173,175,176}$ (David Bernard and Gilles Noguere, CEA-CAD), have been integrated by DR in 'T6' for TENDL-2021 and JEFF-4. AK will revise fast range.
- Deuteron library improvement, for medical isotope production and fusion (IFMIF):
  - M. Avrigeanu model for deuteron break-up
  - P. Sauvan's extension of Kalbach systematics for break-up angular distributions

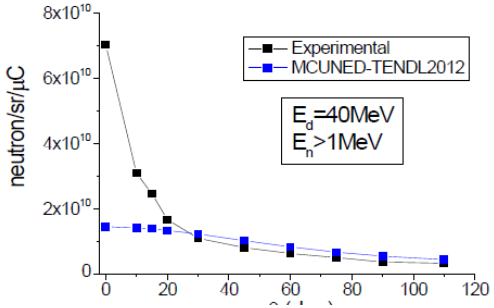
$^{153}Eu(n,2n)^{152}Eu$



$^{155}Eu(n,\gamma)^{156}Eu$



(d,xn data)



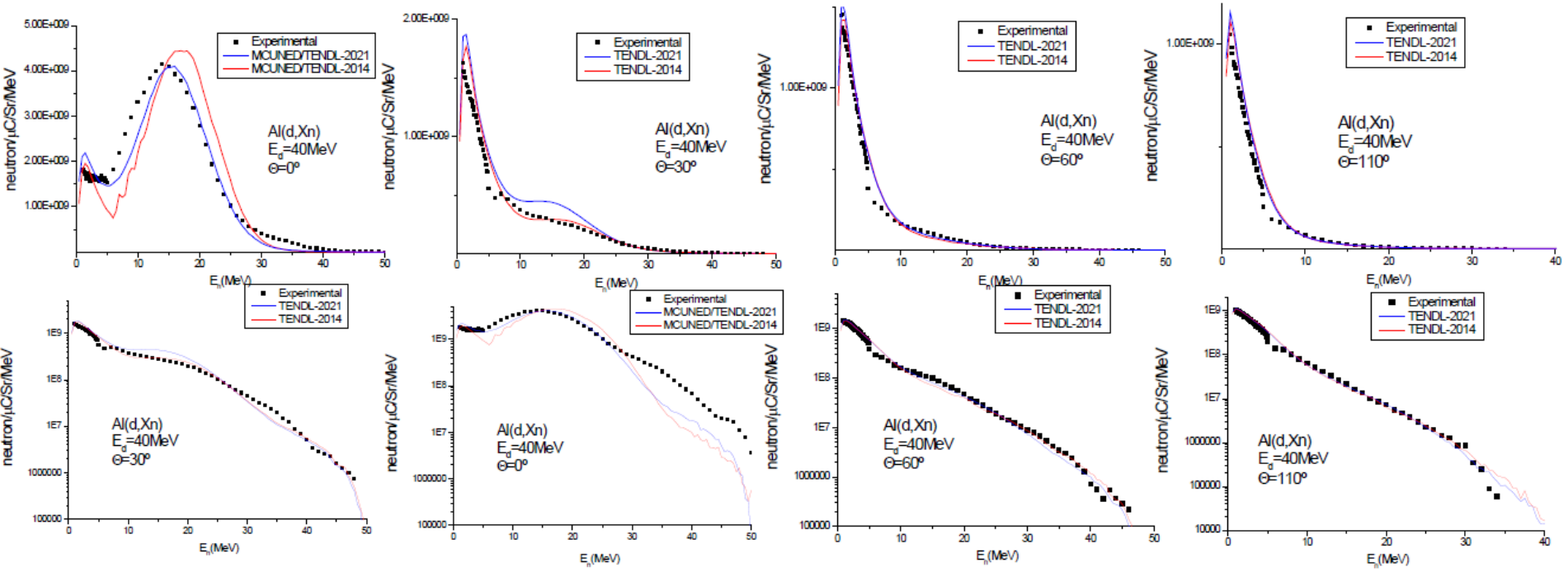
Peaked forward cannot be reproduced with the Kalbach distribution (commonly used in charged particle libraries)

Preliminary results : Neutron yield from deuteron interaction with thick target

P. Sauvan, JEFF Eurofusion meeting April 2021

UNED ETS de Ingenieros Industriales

- 40 MeV deuteron on Aluminum target
- Simulation performed with modified version of MCUNED

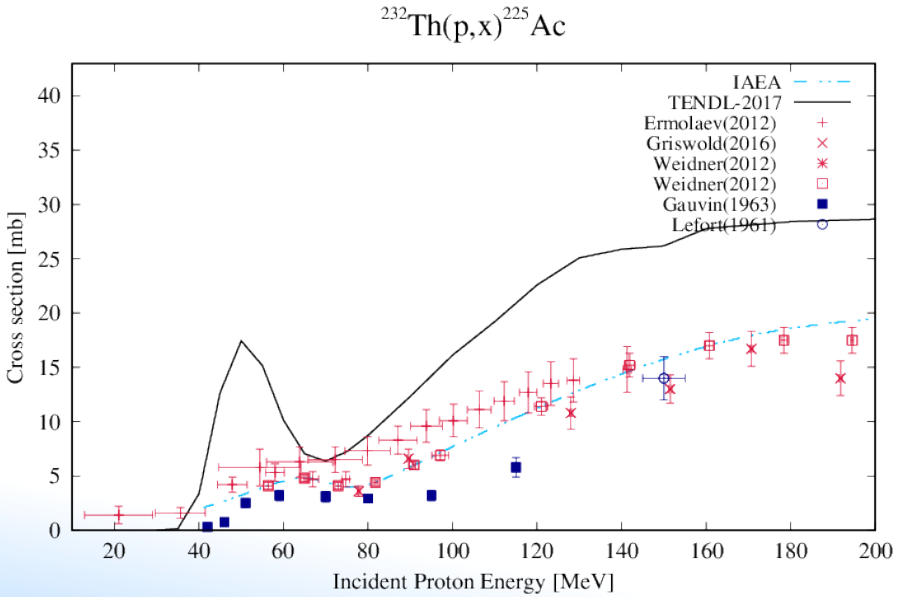


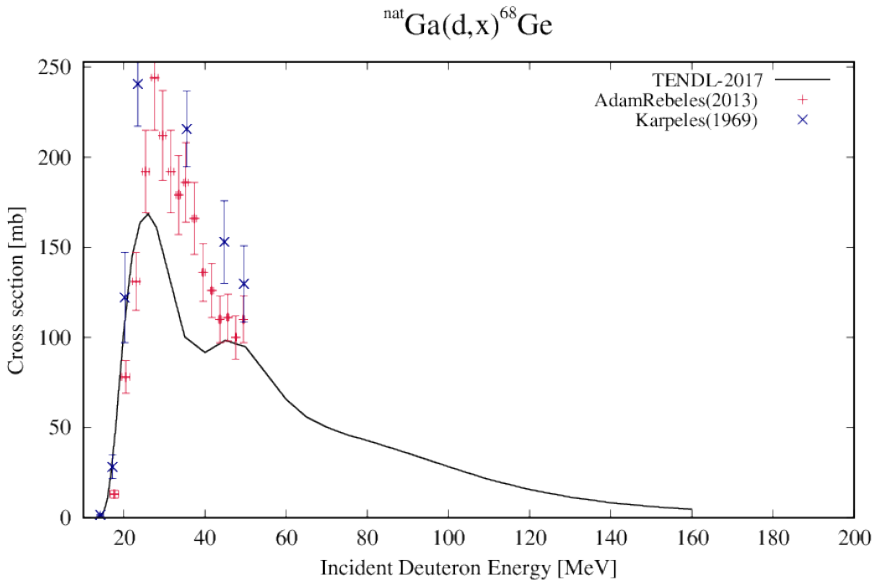
Medical isotope data library: combine the best with the most complete

IAEA high-quality evaluations (150 reaction channels)

TENDL-2021

IAEA-201 Medical Isotope Data Library





Next: Add neutron reactions (for research reactors) and photonuclear route to Medical Isotope Browser

Conclusions

- At least one more….: TENDL-2021
- Focus on more different output formats, more applications do not require/want ENDF format
  - Straight from TALYS + TARES to GNDS (TAGNDS, C. Mattoon)
  - Tables with human/machine readable covariance data
- Automate validation as much as evaluation (challenging!). Now:
  - Criticality validation by van der Marck
  - Decay heat and activation validation by UKAEA (Gilbert et al)
  - Scattered results from other places in 1-2 years after release
- Strong coupling with Machine Learning, SG49, EXFOR usability (SG50)
- Release T6, the system that produces (among others) TENDL

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Thank you!