CCRI Webinar:

Nuclear data evaluation for radionuclide metrology

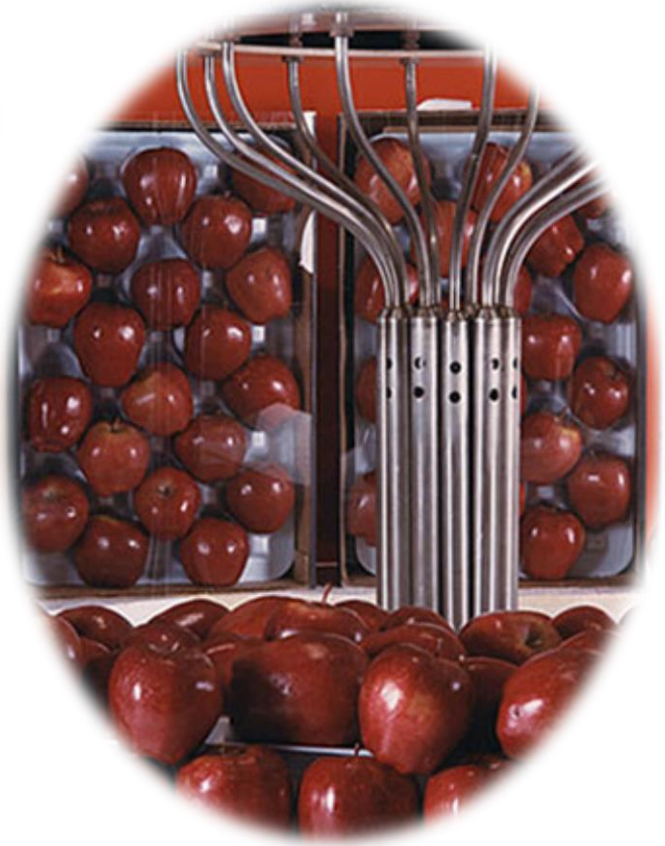
BIPM – 5 December 2024

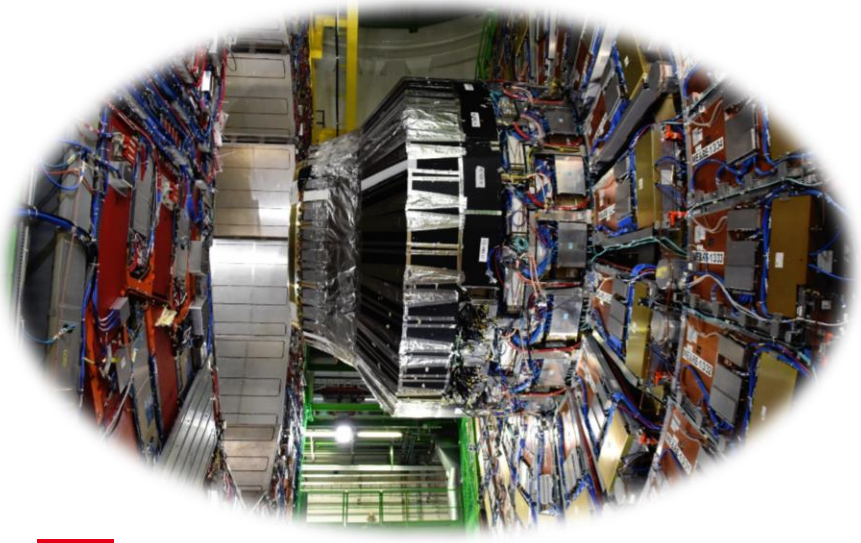
What is (the aim of) the Decay Data Evaluation Project?

X. Mougeot, CEA-LNHB (France)

Bureau International des Poids et Mesures

The need: use of radioactivity





The advent of nuclear data

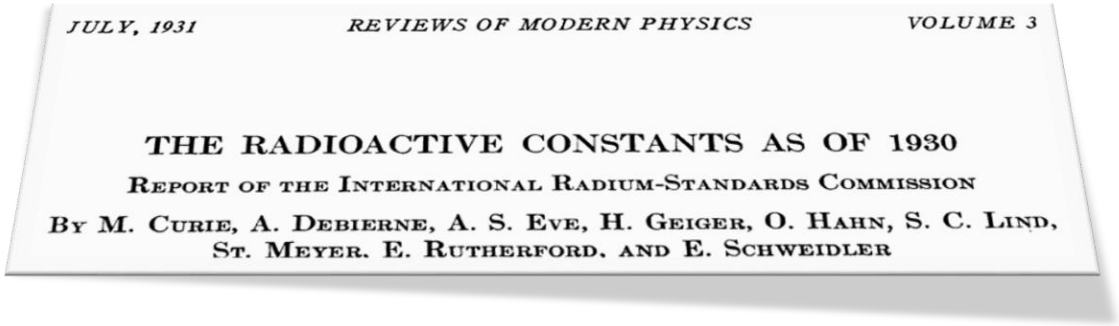
A critical need for many applications of nuclear physics

- Reliable and unbiased nuclear data.
- With a robust uncertainty estimation.

→ **Requires a rare expertise to evaluate both measurements and theoretical predictions**

- Nuclear Physics has been studied for more than a century.
- Usually many predictions / measurements are available.

First international recommendation of nuclear data in 1931.



JULY, 1931 REVIEWS OF MODERN PHYSICS VOLUME 3

THE RADIOACTIVE CONSTANTS AS OF 1930

REPORT OF THE INTERNATIONAL RADIUM-STANDARDS COMMISSION

BY M. CURIE, A. DEBIERNE, A. S. EVE, H. GEIGER, O. HAHN, S. C. LIND, ST. MEYER, E. RUTHERFORD, AND E. SCHWEIDLER

Many more quantities have been considered since then.

Nuclear data nowadays

Chinese Physics C Vol. 45, No. 3 (2021) 030002

The AME2020 atomic mass evaluation **

(I). Evaluation of input data, and adjustment procedures

W.J. Huang (黄文嘉)[1,2,3,4] Meng Wang (王猛)[1,5,*] F.G. Kondev[6] G. Audi (欧乔治)[3] S. Naimi[7]

NSDD

Nuclear Data Center
Japan Atomic Energy Agency

JENDL
Japanese Evaluated Nuclear Data Library

Evaluated Nuclear Data File (ENDF)

ENDF/B-VIII.0 released February 2, 2018

JEFF-3.3 NEA NUCLEAR ENERGY AGENCY

The Joint Evaluated Fission and Fusion File (JEFF) is an evaluated library produced via an international collaboration of NEA Data Bank participating countries.

And DDEP: the Decay Data Evaluation Project

At the origin of DDEP

LNHB has been involved in decay data evaluation for the last 50 years

- Critical for activity measurements in metrology.
- Published as internal reports, in the Table of radionuclides and in peer-reviewed journals.

DDEP is an international initiative started in the 1990s

- Specific needs of the metrology community: consistent decay schemes, nuclear and atomic data.
- Common evaluation methodology, comprehensive peer-review process.
- Initially, implication of metrology laboratories (LNHB, PTB) and ENSDF evaluators from USA.
- New evaluators come afterwards.

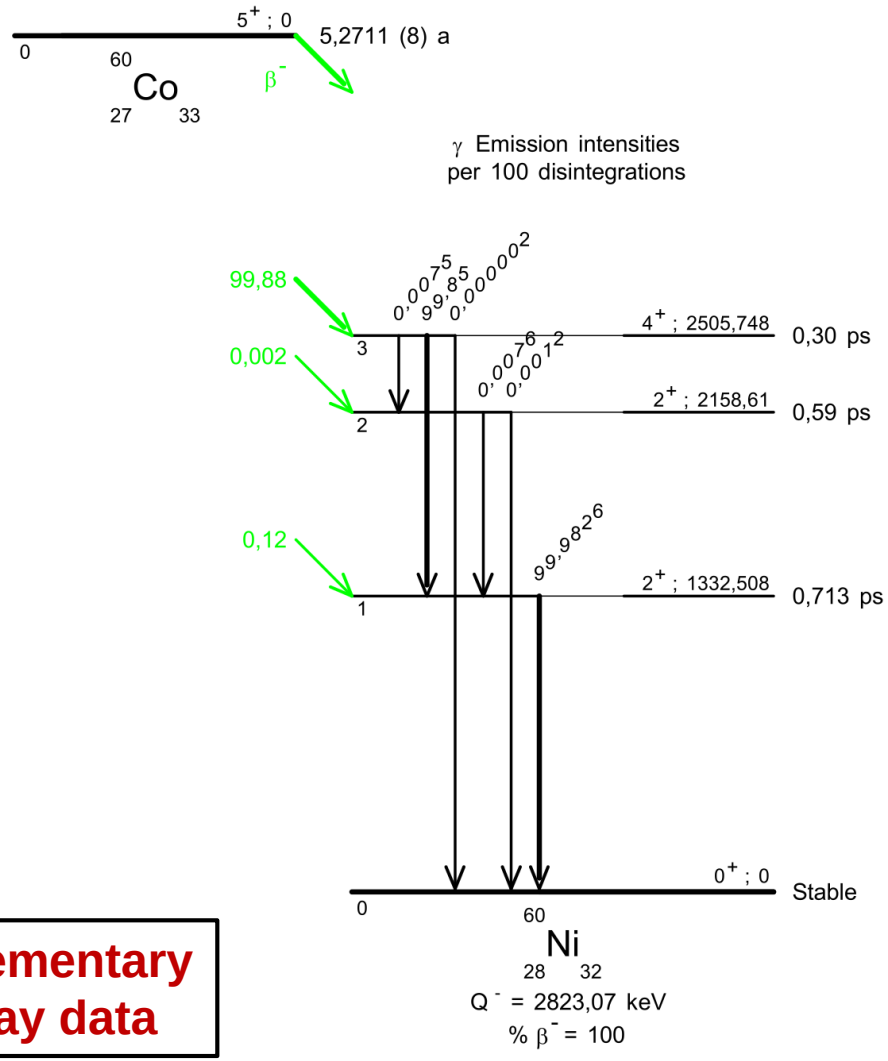
DDEP evaluations and data are officially recommended by the BIPM (International Bureau of Weights and Measures), through the Consultative Committee on Ionising Radiation, for being used by all metrology institutes.

DDEP – Missions

- **Provide recommended decay data to non-specialists**
  - ✓ Metrology
  - ✓ Fundamental physics (detector calibration)
  - ✓ Nuclear medicine
  - ✓ Nuclear industry

- **Main information of interest**
  - ✓ Half-life, Q-value
  - ✓ Decay scheme
  - ✓ Intensity and energies (transitions, emissions)
    - Alpha / beta / electron capture
    - Gamma and internal conversion
    - X-rays & Auger electrons

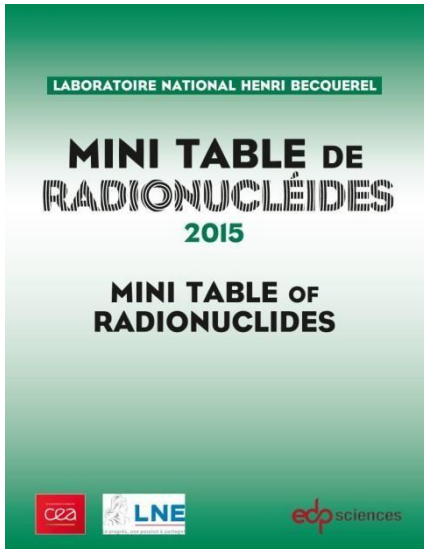
Symmetric uncertainties only



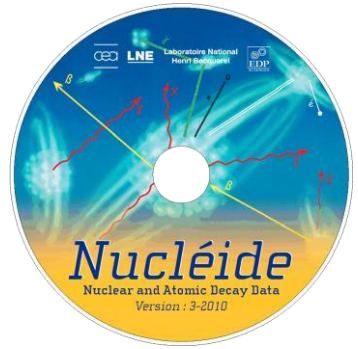
DDEP is complementary to ENSDF decay data

Publications

- ✓ **8 Tables of Radionuclides (BIPM Monographies)**
- ✓ **Mini Table of Radionuclides**



EDP Sciences



https://www.bipm.org/en/publications/monographies

LNHB website

- ✓ BIPM Monographies
- ✓ Nucleus Evaluation
- ✓ Comments file
- ✓ ENSDF file
- ✓ PenNuc input file
- ✓ BetaShape file

This introduction presents a brief description of the radioactivity physical processes, the enumeration of the evaluation rules leading to the recommended values, and a summary of the symbols and terms used in all the publications.

Explanation on recommended data and their evaluation (in various languages):

Please cite our evaluations using the following references:

Vol.	Publication	Year	ISBN	NSR	BibTeX
99	CEA Report – Table de Radionucléides	1999	2-7272-0200-8	1999BeZO	TabRad_v0.bib
1	Monographie BIPM-5 – Table of Radionuclides, vol. 1	2004	92-822-2206-3	2004BeZR	TabRad_v1.bib
2	Monographie BIPM-5 – Table of Radionuclides, vol. 2	2004	92-822-2207-1	2004BeZQ	TabRad_v2.bib
3	Monographie BIPM-5 – Table of Radionuclides, vol. 3	2006	92-822-2218-7	2006BeZL	TabRad_v3.bib
4	Monographie BIPM-5 – Table of Radionuclides, vol. 4	2008	92-822-2231-4	2008BeZV	TabRad_v4.bib
5	Monographie BIPM-5 – Table of Radionuclides, vol. 5	2010	978-92-822-2234-8	2010BeZO	TabRad_v5.bib
6	Monographie BIPM-5 – Table of Radionuclides, vol. 6	2011	978-92-822-2242-3	2011BeZW	TabRad_v6.bib
7	Monographie BIPM-5 – Table of Radionuclides, vol. 7	2013	978-92-822-2248-5	2013BeZP	TabRad_v7.bib
8	Monographie BIPM-5 – Table of Radionuclides, vol. 8	2016	978-92-822-2264-5	2016BeZX	TabRad_v8.bib
9	Monographie BIPM-5 – Table of Radionuclides, vol. 9	2020	to be published	-	-

Filter data:

Enter value

by Element by Atomic number (Z) by Mass number (A)

http://www.lnhb.fr/nuclear-data/nuclear-data-table/

LNHB website

- ✓ BIPM Monographies
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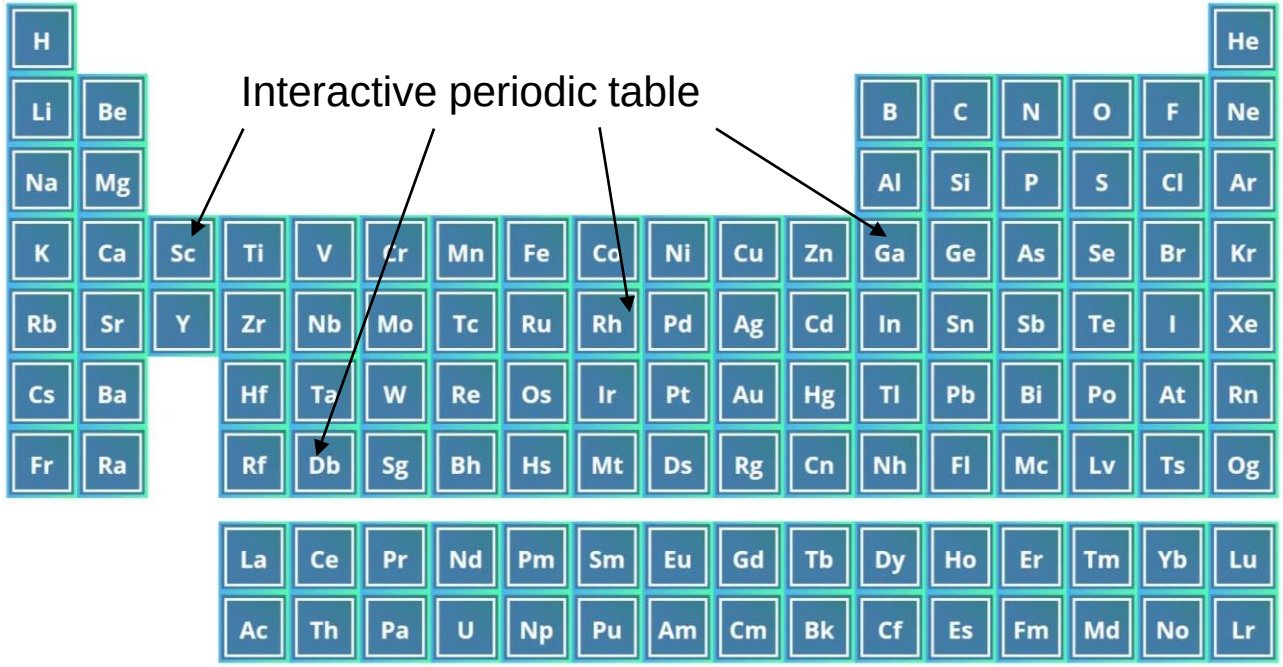


Sort by:

Atomic number

Additional files

E: ENSDF - P: PenNuc - L: Lara - B: BetaShape spectra

Nuclide		Z	Vol. (?)	UpDate	Type (?)	Table (?)	Comments (?)	ASCII files (?)
H-3	^{3}H	1	3	04/09/2006	1	T	C	E P L B
Be-7	^{7}Be	4	1	18/02/2004	1	T	C	E P L B

http://www.lnhb.fr/nuclear-data/nuclear-data-table/

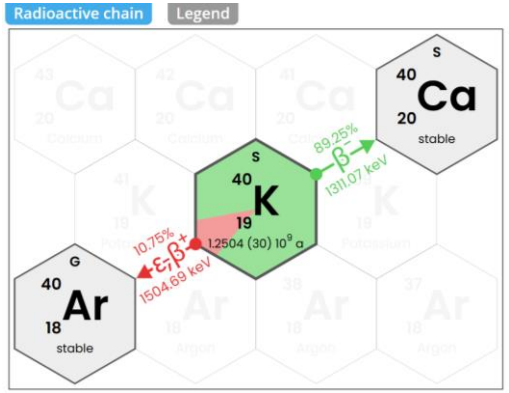
Laraweb

http://www.lnhb.fr/home/nuclear-data/module-lara/

Web interface with many features

- Easy access to decay data.
- Decay scheme plotting. Simplified based on selection criteria set by the user.

- Various utilities: energy / intensity queries, radioactive chain, etc.



Nucléide - Lara
Library for gamma and alpha emissions

Nuclide list: 3H, 6He, 7Be, 10Be, 11C

Nuclide, element or mass number search: 40K (e.g.: 57Co, Co-57, Co, 57)

Energy threshold (keV):
Intensity threshold (%):
Coincidence threshold (%): 10
Show γ-γ coincidences
Sort by decreasing intensity
Show daughter emissions
Sort by nuclide if in chain

Display: Data, Emissions, Tools, Scheme, Radioactive chain - Zoom (0.5 - 5): 1, Simplified chain - Threshold (%): 1

Emissions: X, Gamma, Alpha

Language: EN, EO, FR

Show all data | Show scheme only

Nuclide search criteria

Decay mode: β+,ε, β-, IT, α
(And, Or, XOr)
Emissions: X, Gamma, Alpha
Energies (or range):
E1: ± / - keV
E2: ± / - keV
E3: ± / - keV
And / Or
Intensity: - %
Mass number: - u
Atomic number: -
Q value: - keV
Half-life: a - a

Find nuclides

^{40}K - Decay data

Data | Emissions | Tools | Radioactive chain | Scheme

Data

Element: **Potassium** (Z=**19**)
Daughter(s): **Ar-40** (β+,ε, 10.75%), **Ca-40** (β-, 89.25%)
Q^+: **1504.69 keV**, Q^-: **1311.07 keV**
Half-life (T½): **1.2504 (30) 10^9 a** ≡ **39.46 (9) 10^{15} s**
Decay constant (λ): **17.566 (42) 10^{-18} s^{-1}**
Specific activity (Am): **264.5 (6) 10^3 $Bq.g^{-1}$**
Reference: **CEA/LNE-LNHB, INEEL - 2009**
Associated data files: Table - Comments - ENSDF - PenNuc - BetaShape
Data and emissions file (ASCII text format): K-40.lara.txt

Emissions

Emissions (**6** lines) sorted by increasing energy

Energy (keV)	Intensity (%)	Type	Origin*	Levels Start*	Levels End*
0.26545 (-)	0.003 (1)	X_L	Ar		
2.95566 (-)	0.299 (9)	$X_{Kα2}$	Ar		
2.95774 (-)	0.592 (17)	$X_{Kα1}$	Ar		
3.1905 (-)	0.096 (4)	$X_{Kβ1}$	Ar		
511 (-)	0.00200 (24)	γ±	Ar-40	-1	-1
1 460.822 (6)	10.55 (11)	γ	Ar-40	1	0

Tools

Activity ⇄ Mass conversion: 1000 Bq ⇄ 3.781E-3 g

Decay calculation: 1 calculation step(s)
: $t_1 \rightarrow t_2$ = 1.25E9 → 8.753E9 a
: $d_1 \rightarrow d_2$ = 12 03 2024 09:46:35 → 12 04 2024 09:46:35

Nuclide	(T½)	A_0	$A(t_1)$	$A(t_2)$	
^{40}K	(1.2504 10^9 a)	1000	500	7.8125	Bq

(d_2 - d_1 = d) Copy activity table to clipboard

DDEP data in the European JEFF database

Eur. Phys. J. A (2020) 56:181
https://doi.org/10.1140/epja/s10050-020-00141-9

THE EUROPEAN PHYSICAL JOURNAL A

Review

The joint evaluated fission and fusion nuclear data library, JEFF-3.3

A. J. M. Plompen[1,a], O. Cabellos[2], C. De Saint Jean[3], M. Fleming[4,5], A. Algora[6], M. Angelone[7], P. Archier[8], E. Bauge[3], O. Bersillon[3], A. Blokhin[9], F. Cantargi[10], A. Chebboubi[8,11], C. Diez[12], H. Duarte[3], E. Dupont[13], J. Dyrda[4], B. Erasmus[14], L. Fiorito[4,15], U. Fischer[16], D. Flammini[7], D. Foligno[8], M. R. Gilbert[5], J. R. Granada[10], W. Haeck[17], F.-J. Hambsch[1], P. Helgesson[18], S. Hilaire[3], I. Hill[4], M. Hursin[19], R. Ichou[17], R. Jacqmin[8], B. Jansky[20], C. Jouanne[21], M. A. Kellett[22], D. H. Kim[23], H. I. Kim[23], I. Kodeli[24], A. J. Koning[25], A. Yu. Konobeyev[16], S. Kopecky[1], B. Kos[24], A. Krása[15], J. C. Leal[17], N. Leclaire[17], P. Leconte[8], Y. O. Lee[23], H. Leeb[26], O. Litaize[8], M. Majerle[27]

Huge work performed by M. A. Kellett, O. Bersillon and A. L. Nichols on decay data.

- ✓ Complete update to all 900 evaluations coming from ENSDF Inclusion of IAEA actinide decay data (85 nuclei).
- ✓ Inclusion of IRDFF decay data library (~80 nuclei).
- ✓ Inclusion of updated UKPADD library (~50 additional nuclei), of new DDEP evaluations (~30 additional nuclei) and of TAGS results from Tain and Algora *et al.*
- ✓ Corrections based on limited feedback to JEFF-3.1.1

DDEP – Members

→ **None of the members are full-time-equivalent, far from it.**

- **DDEP Coordination**: Xavier Mougeot

- **LNHB Local team** (evaluation, review, edition, publication)
  - Sylvain Leblond
  - Xavier Mougeot
  - Mark A. Kellett (Special advisor)
  - Christophe Dulieu (IT support)

- **Decay data evaluators**
  - Alan L. Nichols* (Surrey University, UK)
  - Aurelian Luca (IFIN, Romania)
  - Brian E. Zimmerman (NIST, USA)
  - Rob Shearman (NPL, UK)
  - Xialong Huang (CIAE, China)
  - Nikolai Kuzmenko (KRI, Russia)

- **Additional support**
  - Tibor Kibédi* (BrIcc and BrIccMixing codes)
  - Balraj Singh*† (ENSDF collaboration)

* Retired.

† Deceased.

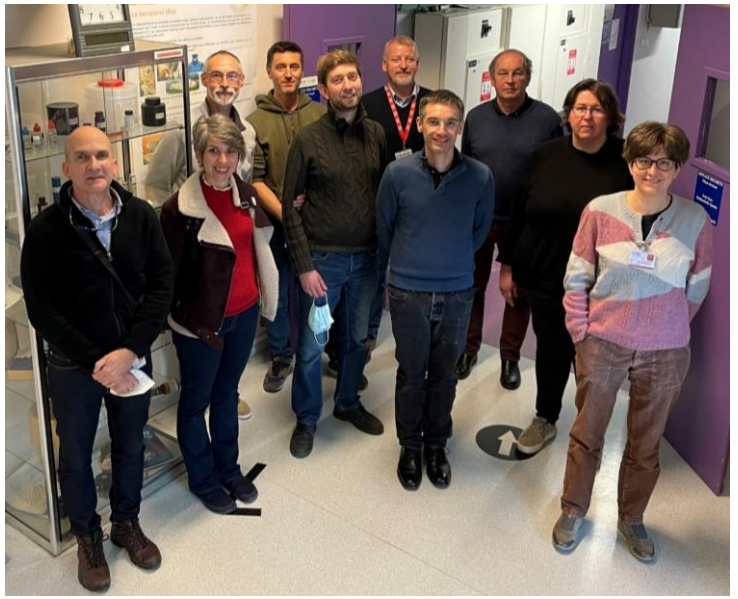
DDEP – Renewing the workforce

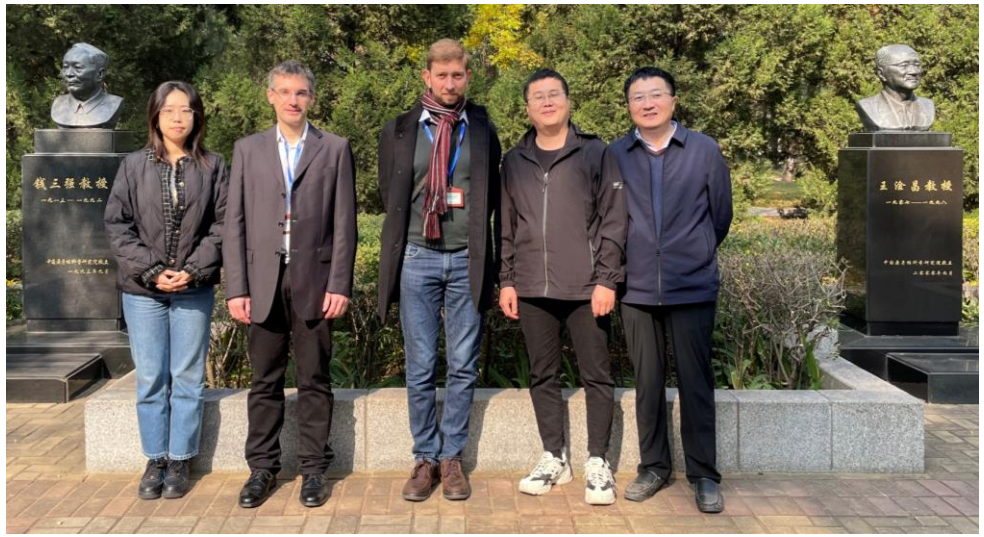
DDEP workforce remains limited. Actions engaged:

- ✓ 7th to 9th of March 2022: Organisation of a DDEP workshop dedicated to evaluator training.
- ✓ 21st to 28th of October 2023: Visit of China Nuclear Data Centre and National Institute of Metrology (Beijing, China).
- ✓ 7th to 11th of October 2024: Visit of China Nuclear Data Centre and National Institute of Metrology (Beijing, China).
- ✓ 21st to 25th of October 2024: Organisation of a DDEP workshop dedicated to evaluator training.

  14 participants from China, the US and Europe + local (LNHB) participants.

→ Efforts which require additional work and time, taken on availability dedicated to DDEP.





DDEP – Evaluations

- ✓ Since 2021, 17 evaluations published.
- ✓ Since latest BIPM vol. 8 monography (2016), 21 evaluations published.

Nuclide		Z	Vol. (?)	UpDate
Co-55	^{55}Co	27	9	04/09/2024
Rh-103m	^{103m}Rh	45	9	29/08/2024
Pd-103	^{103}Pd	46	9	29/08/2024
Ho-166	^{166}Ho	67	9	24/06/2024
Fe-55	^{55}Fe	26	9	19/03/2024
Sn-129m	^{129m}Sn	50	9	13/03/2024
Ac-225	^{225}Ac	89	9	20/12/2023
Cs-137	^{137}Cs	55	9	07/09/2023

Nuclide		Z	Vol. (?)	UpDate
Ba-137m	^{137m}Ba	56	9	07/09/2023
Sm-151	^{151}Sm	62	9	07/09/2023
He-6	^{6}He	2	9	10/11/2022
Al-26	^{26}Al	13	9	10/11/2022
Rb-87	^{87}Rb	37	9	24/05/2022
Cs-131	^{131}Cs	55	9	21/09/2021
I-124	^{124}I	53	9	20/07/2021
Mn-52	^{52}Mn	25	9	09/02/2021
Mn-52m	^{52m}Mn	25	9	09/02/2021

DDEP – Pending evaluations

Evaluations performed a few years ago, not yet reviewed nor published.

Updates are needed before review.

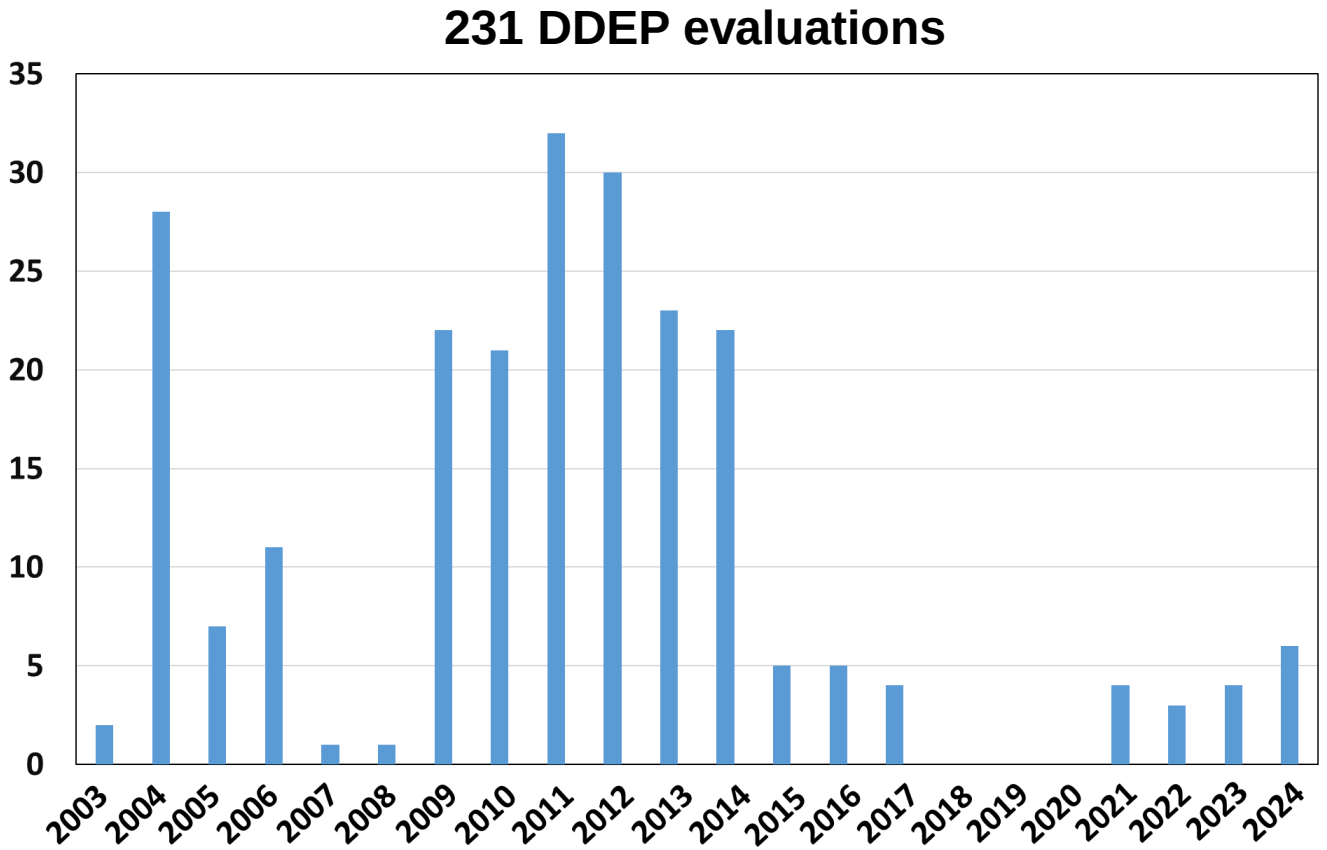
Nucleus	Laboratory	Evaluator	Reviewer
Ti-45	KRI, CIAE	V. Chechev, N. Kuzmenko, X. Huang	S. Leblond
Co-56	KRI, CIAE	V. Chechev, N. Kuzmenko, X. Huang	X. Mougeot
Ga-68	KRI	N. Kuzmenko	B. Zimmerman
Mo-99	Univ. Surrey	A. L. Nichols	
Tc-99m	Univ. Surrey	A. L. Nichols	
Cd-111m	Univ. Surrey	A. L. Nichols	
In-111	Univ. Surrey	A. L. Nichols	
I-120	Univ. Surrey	A. L. Nichols	
I-135	CTBTO	M. Galan	
I-133	CTBTO	M. Galan	

Nucleus	Laboratory	Evaluator	Reviewer
Xe-133	CTBTO	M. Galan	
Xe-135	CTBTO	M. Galan	
Xe-135m	CTBTO	M. Galan	
Pr-142m	Univ. Surrey	A. L. Nichols	
Ta-178	Univ. Surrey	A. L. Nichols	
Th-226	IFIN-HH	A. Luca	B. Singh
Th-227	CIAE	X. Huang	
Th-229	CIAE	X. Huang	B. Zimmerman
U-230	IFIN-HH	A. Luca	X. Huang, B. Singh
U-233	CIAE	X. Huang	

Conclusion

Lot of work to somehow maintain the situation

- Pending evaluations need to be finalized.
- New DDEP evaluators would be more than welcome.
- Updates of existing DDEP evaluations needed for a large number of nuclei. A good objective should be no evaluation older than 10 years, but it is very difficult.
- Complete renew of the database and related tools (physics, evaluation, checking, editing) is necessary. This requires time and technical expertise. Any help from anybody is welcome!



Thank you for attention