Status of the Decay Data Evaluation Project (DDEP)

Xavier Mougeot (on behalf of Mark A. Kellett)

NSDD 2019, Vienna, 8 – 12 April 2019

Outline

The Decay Data Evaluation Project (DDEP)

- Membership
- Data availability

Improvements to Beta Spectra: The MetroBeta Project

Conclusions

Decay Data Evaluation Project (DDEP)

A small number of decay data evaluation specialists, mainly from the metrology community:

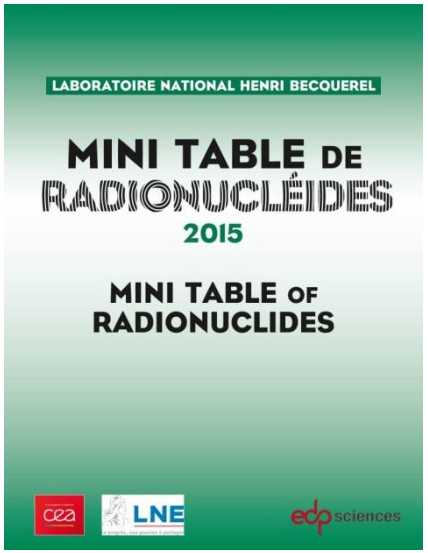
Mark A. Kellett (Coordinator) (to be replaced by Yann Kergadallan)	Xavier Mougeot **LNHB, France**	Christophe Dulieu (IT support)
Alan L. Nichols? **Surrey University, UK**	Aurelian Luca **IFIN, Romania**	Xiaolong Huang **CIAE, China**
Nikolai Kuzmenko **KRI, Russia**	Monica Galan **Consultant**	Andy Pearce & Arzu Arinc (to be replaced by Rob Shearman) **NPL, UK**

Members who joined in 2016:

Brian Zimmerman **NIST, USA**	Herbert Janssen? **PTB, Germany**	Haoran Liu **Metrology Institute, China**

Additional support: Tibor Kibédi (**ANU, Australia**) – *BrIcc & BrIccMixing codes* and others from the wider community who help in the review process, e.g. Balraj Singh

Publications of decay scheme data

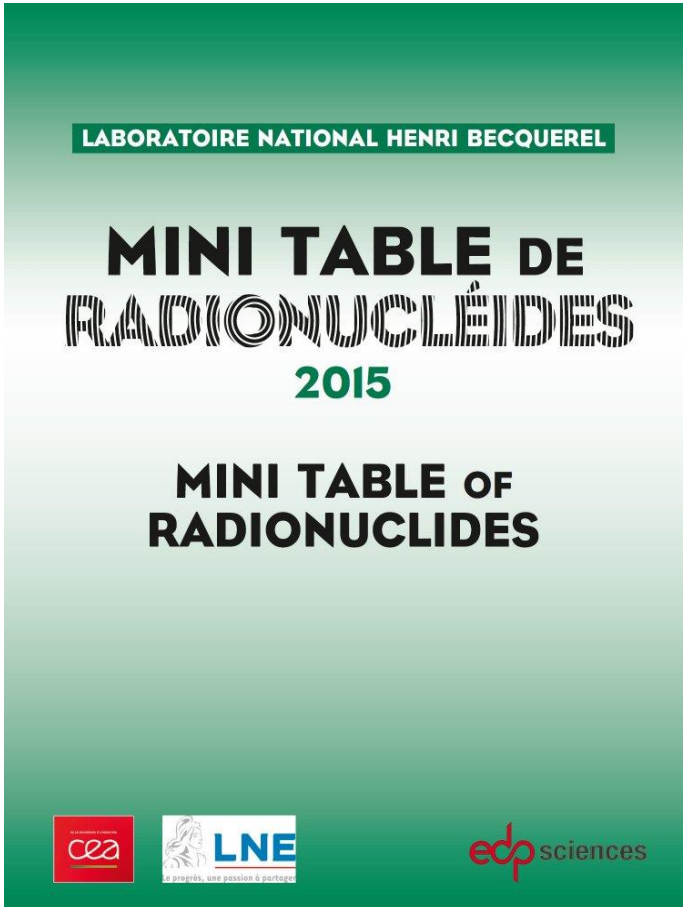


EDP Sciences

http://www.bipm.org/fr/publications/monographie-ri-5.html

Mini Table of Radionuclides 2015

Current edition of the Mini Table of Radionuclides - published in March 2015
Sold and distributed by EDP Sciences (25 €) ~2 000 copies sold to date



$^{61}_{29}$Cu — $T_{½}$: 3,366 (33) h — Copper / Cuivre

Descendant(s): (β^+, ε, 100 %) **Ni-61**
Q^+: 2237,5 keV

Electrons (10 lines) - $\Sigma(I_{e^-})$ omitted: 0,6 %

Energy (keV)	Intensity (%)	Type	Origin
0,6 – 1	51,2	Auger L	Ni-61
6,3 – 8,3	20,0	Auger K	Ni-61

Beta + (6 lines) - $\Sigma(I_{\beta^+})$ omitted: 0,035 %

E max. (keV)	*E* avg. (keV)	Intensity (%)
559,5	238,5	2,52
932,5	398,9	5,4
1 148,1	493,8	2,1
1 215,5	523,8	51,6

X (4 lines) - $\Sigma(I_X)$ omitted: 0,44 %

Energy (keV)	Intensity (%)	Type	Origin
7,46	4,33	$X_{Kα2}$	Ni-61
7,48	8,4	$X_{Kα1}$	Ni-61
8,3	1,76	$X_{K'β1}$	Ni-61

Gamma (34 lines) - $\Sigma(I_\gamma)$ omitted: 1,9 %

Energy (keV)	Intensity (%)	Type	Origin
67,41	4,0	γ	Ni-61
282,96	12,0	γ	Ni-61
373,05	2,09	γ	Ni-61
511	123	γ ±	
588,61	1,15	γ	Ni-61
656,01	10,4	γ	Ni-61
908,63	1,12	γ	Ni-61
1 185,23	3,6	γ	Ni-61

Production mode	Possible impurities
Ni-61 (p, n) Cu-61	-
Zn-64 (p, α) Cu-61	-
Cu-63 (γ, 2n) Cu-61	-

Reference: CEA/LNE-LNHB - 2013

$^{241}_{95}$Am — $T_{½}$: 432,6 (6) a — Americium / Américium

Descendant(s): (α, 100 %) **Np-237** (2,144 x 10^6 a)
Q^α: 5637,82 keV

Alpha (23 lines) - $\Sigma(I_\alpha)$ omitted: 0,7 %

Energy (keV)	Intensity (%)	Type	Origin
5 388,25	1,66	α	Am-241
5 442,86	13,23	α	Am-241
5 485,56	84,45	α	Am-241

Electrons (48 lines) - $\Sigma(I_{e^-})$ omitted: 2,6 %

Energy (keV)	Intensity (%)	Type	Origin
6,3	14	ec L	Np-237
6 – 13,5	33,4	Auger L	Np-237
13,2	15,9	ec L	Np-237
21,6	3,7	ec M	Np-237
23,4	8,8	ec L	Np-237
28,5	4,0	ec M	Np-237
32,2	1,08	ec N	Np-237
38,7	2,3	ec M	Np-237
39,5	30,2	ec L	Np-237
54,8	8,12	ec M	Np-237

X (9 lines) - $\Sigma(I_X)$ omitted < 0,01 %

Energy (keV)	Intensity (%)	Type	Origin
11,89	0,844	$X_{Lℓ}$	Np-237
13,85	13,02	$X_{Lα}$	Np-237
15,88	0,384	$X_{Lη}$	Np-237
16,96	18,58	$X_{Lβ}$	Np-237
21,16	4,83	$X_{Lγ}$	Np-237

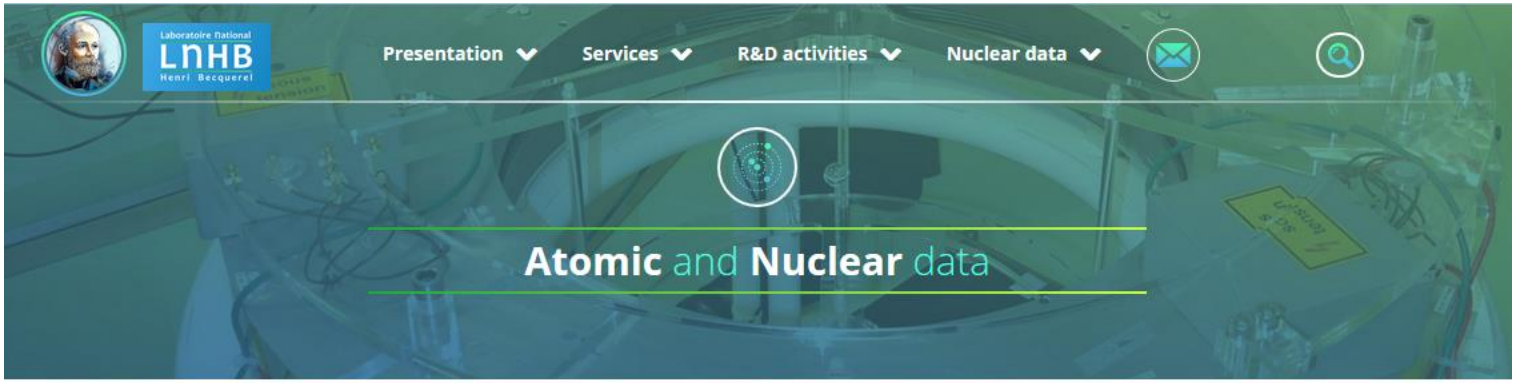
Gamma (179 lines) - $\Sigma(I_\gamma)$ omitted: 0,29 %

Energy (keV)	Intensity (%)	Type	Origin
26,34	2,31	γ	Np-237
59,54	35,92	γ	Np-237

Production mode	Possible impurities
Pu-241 (β^-) Am-241	T½ = 14,33 a

Reference: KRI - 2009

New website: http://www.lnhb.fr/en/



Filter data:

Enter value

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

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
			Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

New website: http://www.lnhb.fr/en/

Nuclide		Z	In (?)	UpDate	Type (?)	Table (?)	Comments (?)	ASCII files (?)
H-3	^{3}H	1	3	04/09/2006	1	T	C	E P L
Be-7	^{7}Be	4	1	18/02/2004	1	T	C	E P L
C-11	^{11}C	6	1	03/11/2011	2	T	C	E P L
C-14	^{14}C	6	7	22/11/2012	1	T	C	E P L
N-13	^{13}N	7	1	08/04/2004	1	T	C	E P L
O-15	^{15}O	8	1	01/06/2004	1	T	C	E P L
F-18	^{18}F	9	1	01/09/2014	2	T	C	E P L
Na-22	^{22}Na	11	5	06/08/2009	3	T	C	E P L
Na-24	^{24}Na	11	1	16/06/2014	2	T	C	E P L
Al-26	^{26}Al	13	99	24/07/2003	1	T	C	E P L
P-32	^{32}P	15	1	08/04/2004	1	T	C	E P L
P-33	^{33}P	15	1	08/04/2004	1	T	C	E P L
S-35	^{35}S	16	7	27/02/2012	N	T	C	E P L
Cl-36	^{36}Cl	17	7	04/06/2012	N	T	C	E P L
Ar-37	^{37}Ar	18	7	16/10/2012	N	T	C	E P L
Ar-41	^{41}Ar	18	6	04/05/2010	3	T	C	E P L
K-40	^{40}K	19	5	01/08/2012	2	T	C	E P L
Ca-41	^{41}Ca	20	8	24/04/2013	N	T	C	E P L
Ca-45	^{45}Ca	20	7	11/04/2012	N	T	C	E P L
Sc-44	^{44}Sc	21	1	27/04/2004	1	T	C	E P L
Sc-46	^{46}Sc	21	1	01/09/2014	2	T	C	E P L

PenNuc files

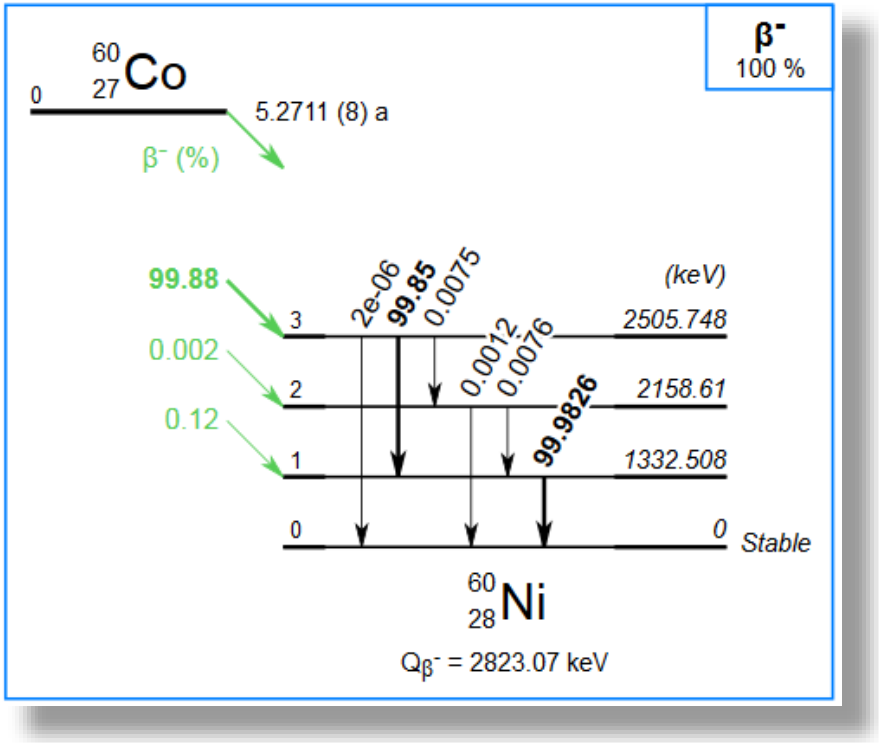
PenNuc add-on to PENELOPE

General problem: simulation of radioactive sources (beta +/-, gamma-rays, X-rays, Auger electrons).

Developed by CIEMAT and PENELOPE team.

Given a radionuclide, decay scheme can be obtained in pennuc format from LNHB website (DDEP evaluations).

- Allows easy evaluation of dose or energy spectrum deposited in a detection system (no need to implement all the decay scheme).
- Propagation of the uncertainties on the decay scheme parameters.
- Detector efficiency: already used to account for peak summing effects (e.g. ^{60}Co).
- Similar module in development at LNHB for Geant4, with metastable states and beta spectra from BetaShape.



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

^{60}Co - Emissions and decay scheme

Element: **Cobalt** (Z=**27**)
Daughter(s): **Ni-60** (β^-, 100 %)
Q: **2823.07 keV**
Possible parent(s): Co-60m (I.T., 99.75 %)
Half-life (T½): **5.2711 (8) a** ≡ **166.340 (25) 10^6 s**
Decay constant (λ): **4.1671 (6) 10^{-9} s^{-1}**
Specific activity (Am): **41.824 (6) 10^{12} $Bq.g^{-1}$**
Reference: **INEEL - 2006**
Associated data files: Table - Comments - ENSDF - PenNuc

Results file (ASCII text format): Co-60.txt

Mass ⇄ Activity conversion: 1.255E+8 Bq ⇄ 3E-6 g

Decay calculation:
$A(t_0)$=1000 Bq t_1=1.697E+0 a $A(t_1)$=800 Bq

Coincidence threshold: **10 %**
Emissions (**10** lines) sorted by increasing energy

Energy (keV)	Intensity (%)	Type	Origin*	Levels Start*	Levels End*	Possible coincidence with (keV) / Possible sum of (levels)
0.84 (-)	0.0002 (-)	X_L	Ni-60			
7.46097 (-)	0.00334 (12)	$X_{K\alpha 2}$	Ni-60			
7.47824 (-)	0.0065 (3)	$X_{K\alpha 1}$	Ni-60			
8.2967 (-)	0.00136 (5)	$X_{K'\beta 1}$	Ni-60			
347.14 (7)	0.0075 (4)	γ	Ni-60	3	2	
826.10 (3)	0.0076 (8)	γ	Ni-60	2	1	
1 173.228 (3)	99.85 (3)	γ	Ni-60	3	1	1 332.492 (Σ=2 505.720)
1 332.492 (4)	99.9826 (6)	γ	Ni-60	1	0	1 173.228 (Σ=2 505.720)
2 158.57 (3)	0.0012 (2)	γ	Ni-60	2	0	
2 505.692 (5)	0.0000020 (4)	γ	Ni-60	3	0	(3→1)+(1→0)

Nucléide - Lara
Library for gamma and alpha emissions

Nuclide list:
59Fe
59Ni
60Co
60Co-M
61Cu
63Ni
63Zn
64Cu

or Nuclide search: (e.g.: 99Xx or Xx-99)

Energy threshold (keV):
Intensity threshold (%):
Coincidence threshold (%): 10
Show γ-γ coincidences ☑
Sort by decreasing intensity ☐
Show simple decay tools ☑
Display: ☑ Data ☑ Emissions ☑ Scheme
Emission type: ☑ X ☑ gamma ☑ alpha

Language: ◉ EN ○ EO ○ FR

Show data

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

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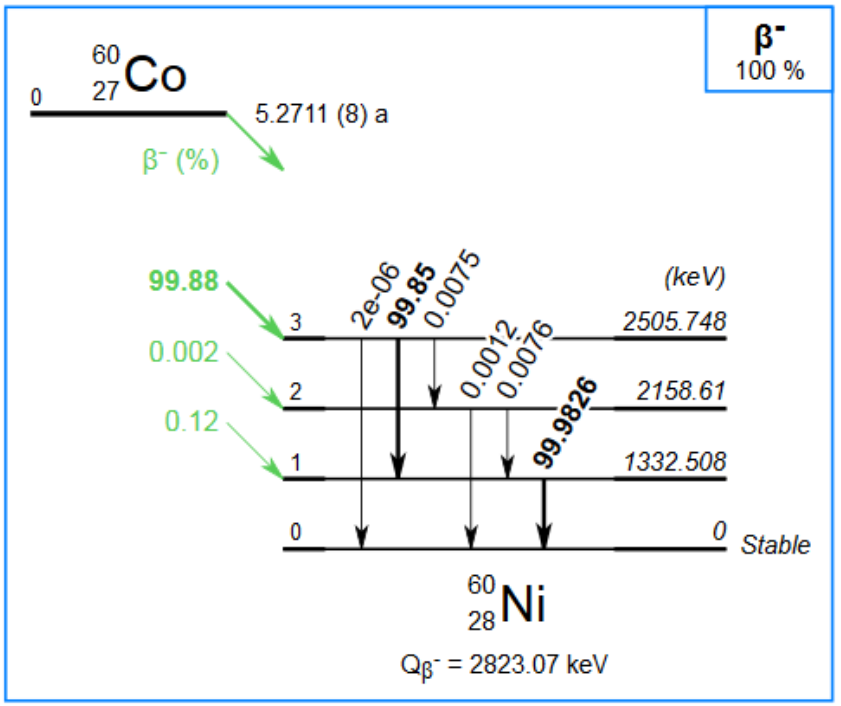

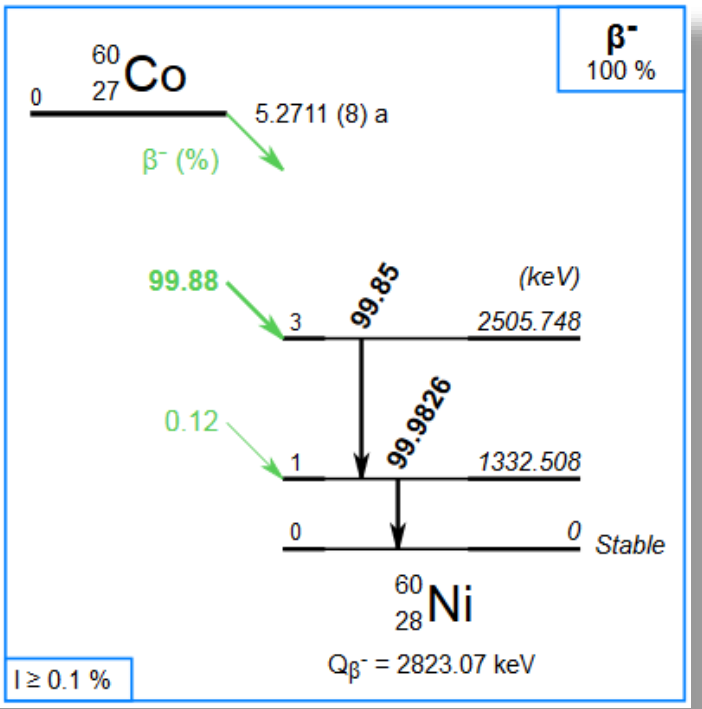

The BetaShape code

- First release in 2016. Beta transitions are calculated from ENSDF file as input. Modelling improved compared with LogFT. Database of experimental shape factors. Provides beta spectra (single, total), mean energies, log *ft* values. Officially adopted by DDEP.
- New version will be released in June 2019. Small bugs fixed, change in uncertainty treatment. Improved radiative corrections from Towner and Hardy (unitarity of CKM matrix).
- Inclusion of electron captures with an improved modelling compared with LogFT. Provides capture and capture-to-positron probability ratios for each subshell, splitting of the branch between capture and beta plus, log *ft* values.
- Possible on-the-fly update of the Q-values with AME2016 (already implemented). ENSDF format for continuous data will be included.
- Nuclear Data Week at NNDC (5-9 November, 2018).
- Technical Meeting on the Improvement of Analysis Codes for Nuclear Structure and Decay Data Evaluations (3-7 December, 2018).

The MetroBeta Project

EMPIR

EURAMET

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

http://metrobeta-empir.eu/

Short Name	Organisation legal full name	Country
CEA	Commissariat à l'énergie atomique et aux énergies alternatives	France
CMI	Cesky Metrologicky Institut Brno	Czech Republic
PTB	Physikalisch-Technische Bundesanstalt	Germany
Gonitec	Gonitec BV	Netherlands
UHEI	Ruprecht-Karls-Universitaet Heidelberg	Germany
UMCS	Uniwersytet Marii Curie-Sklodowskiej	Poland
CHUV	University Hospital of Lausanne	Switzerland

The MetroBeta Project

WP No	Work Package Title	Active Partners
WP1	Theoretical calculations of beta spectra	CEA; UMCS
WP2	High-resolution beta spectrometry based on Metallic Magnetic Calorimeters (MMCs)	PTB; CEA; UHEI
WP3	Measurements of beta spectra with other methods	CHUV; CMI; Gonitec
WP4	Comparison and validation of measurements	PTB; CEA; CHUV
WP5	Creating impact	CMI; all partners
WP6	Management and coordination	CEA; all partners

Improve the calculations of beta spectra and inclusion of nuclear structure.

Measure new high resolution beta spectra for low (< 100 keV) and intermediate (< 1 MeV) end-point energy pure beta emitters ^{151}Sm, ^{14}C, ^{99}Tc and ^{36}Cl.

The MetroMMC Project

EMPIR

EURAMET

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

εtrMMC

Measurement of fundamental nuclear decay data using Metallic Magnetic Calorimeters

http://empir.npl.co.uk/metrommc/

Short Name	Organisation legal full name	Country
CEA	Commissariat à l'énergie atomique et aux énergies alternatives	France
NPL	National Physical Laboratory	United Kingdom
PTB	Physikalisch-Technische Bundesanstalt	Germany
KRISS	Korean Research Institute of Standards and Science	South Korea
UHEI	Ruprecht-Karls-Universitaet Heidelberg	Germany
UNL	Universidade Nova de Lisboa	Portugal
CNRS	Centre National de la Recherche Scientifique	France

The MetroMMC Project

WP No	Work Package Title	Active Partners
WP1	Improvement of experimental techniques for spectrometry based on novel cryogenic detectors for radionuclide metrology in the energy range of 20 eV - 100 keV	PTB, CEA, NPL, UHEI, KRISS
WP2	Determination of fractional electron capture probabilities of selected radionuclides by means of spectrometry based on novel cryogenic detectors with high energy resolution and very low energy threshold using sources embedded in the detector absorber	CEA, PTB, KRISS
WP3	Measurement of absolute X-ray emission intensities of selected radionuclides (^{54}Mn, ^{65}Zn, ^{59}Ni, ^{109}Cd, ^{125}I) by using a combination of high-resolution spectrometry based on novel cryogenic detectors using external sources and accurate primary activity determination	NPL, PTB, CEA
WP4	Improvement of theoretical models of the electron capture process and subsequent atomic relaxation	CEA, NPL, PTB, CNRS, UHEI, UNL
WP5	Creating impact	NPL; all partners
WP6	Management and coordination	PTB; all partners

Improve the calculations of electron captures and atomic relaxation.

Measure new high-precision capture probabilities and X-ray emission intensities for a set of radionuclides (^{41}Ca, ^{54}Mn, ^{59}Ni, ^{65}Zn, ^{109}Cd, ^{125}I).

Conclusions

The CCRI of the BIPM endorse the use of DDEP recommended data.

The DDEP has expertise in evaluating atomic and nuclear decay data.

Publication of reference data in collaboration with the BIPM and provision of a database in order to disseminate these reference data.

Provision of information concerning the details of each evaluation, including recommendations for new measurements.

Three new evaluators from National Metrology Institutes have recently joined.

Other additional data related projects, e.g. MetroBeta and MetroMMC, are on-going.

THANK YOU FOR YOUR ATTENTION

Commissariat à l'énergie atomique et aux énergies alternatives
Institut List | CEA SACLAY NANO-INNOV | BAT. 861 – PC142
91191 Gif-sur-Yvette Cedex - FRANCE
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