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Dissemination and visualisation of reference decay data from Decay Data Evaluation Project (DDEP)

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Abstract. As a primary laboratory in the field of ionising radiation metrology, the Laboratoire National Henri Becquerel (LNE-LNHB), CEA Saclay, is involved in measurements, evaluations and dissemination of radioactive decay data.

Data measurements undertaken by various laboratories are evaluated by an international commission of experts (Decay Data Evaluation Project) coordinated by LNHB staff in order to establish a set of recommended decay scheme data.

New nuclide evaluations are regularly added to our website, the NUCLÉIDE database, published in the BIPM-5 Monographie series and uploaded to our web application LARAWEB, a dedicated tool for alpha and gamma spectrometry. The Mini Table of Radionuclides is produced from time-to-time with data extracted from our database.

Various publications are described, along with new search criteria and decay scheme visualisation in LARAWEB.

1. Introduction

Evaluation of nuclear decay data at the Laboratoire National Henri Becquerel (LNHB), CEA, began in 1974 and many publications on this topic have been released. In order to facilitate the management and distribution of these data, a computerized database called NUCLÉIDE was developed, as well as many tools for both evaluators and users.

All necessary data are stored in one single database, NUCLÉIDE, which is used as an entry point and has allowed the development of specific software to maintain and update this database. The LNHB is therefore able to offer a variety of tools related to reference nuclear decay data for users in many fields such as nuclear medicine, reactor monitoring and shielding, spectrometry, environmental studies, etc. We present some of the publications and tools we distribute, and more specifically the latest enhancements of LARAWEB which is our web application for alpha and gamma spectrometry.

2. Data evaluation

New or updated nuclide evaluations are regularly added to the NUCLÉIDE database through the work of evaluators from the Decay Data Evaluation Project (DDEP) [1]. These evaluations are undertaken when new measurements are published or special interest for a new nuclide emerges. All published measurements and data are analysed and compiled by a DDEP evaluator and a set of recommended decay data is established. After a review procedure among evaluators, these data are inserted in the NUCLÉIDE database and made available to the users through multiple media: electronic files on our website, printed publications, and our web applications.

3. LNHB website

In the atomic and nuclear data section of our website, one can find a variety of information concerning evaluated nuclides, mainly in the form of PDF or text files. Thus, the recommended data and decay scheme relative to a nuclide, and information concerning the way the evaluation was achieved, are available as PDF files. Decay data are also available in the ENSDF file format [2] and as a simple text file. A specific PenNuc text file, intended to be used for Penelope Monte Carlo simulation, has recently been added that describes the complete decay scheme of a nuclide to be used as a radioactive source in a simulation process.

As of today, nearly 220 nuclides are available, and the website is regularly updated when new evaluations become available. The main LNHB website can be found at: http://www.nucleide.org/ with the Atomic and Nuclear Data Section at: http://www.nucleide.org/ NucData.htm.

4. Monographie BIPM-5 series

All the latest evaluated nuclides are periodically published in a printed monograph under the auspices of the BIPM (Bureau International des Poids et Mesures) [3], as well as electronically in a PDF file format available on the BIPM website [4]. The eighth volume in the series has been published by the end of 2016 and contains 32 nuclide evaluations. Comments on how these evaluations were conducted is available online as PDF files.

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Figure 1. Extract of recommended decay data from the LNHB website.



Figure 2. Extract of nuclide data from Monographie BIPM-5.

5. Mini Table of Radionuclides

At the end of 2015, the LNHB published a new and updated edition of its booklet version of the Table of Radionuclides known as the "Mini Table of Radionuclides". This work presents, in a concise way, the parameters characterizing each radionuclide; the half-life and the main alpha, beta, gamma and X-ray emissions, and daughters for a selection of about 300 nuclides of particular interest in the fields of spectrometry, medicine and practical industrial applications [5].

6. LARAWEB/NUCLÉIDE – LARA

LARAWEB is a web-based application designed for spectrometry purposes. It contains information relating to ≈ 450 nuclides of particular interest in the field of alpha, X- and gamma-ray spectrometry. The main data presented



Figure 3. Nuclide decay scheme extracted from Monographie BIPM-5.

¹²⁷ ₅₄ X	7%: 36 Xenon /	,358 (3 Xénon	1) d	$^{128}_{_{53}}\mathbf{I}$	7½ : 24,99 (2 lodine / lode	2) min	
Desc.: (ε, 100 ° Q*: 662,3 keV	%) I-127			Desc.: (β*, ε, 6 (β*, 93,	5,9 %) Te-128, 1 %) Xe-128		
Electrons (32	lines) - Σ(le-) o	mitted: 3,	3%	Q [*] : 1252 keV,	Q ⁻ : 2119 keV		
Energy (keV)	Intensity (%)	Туре	Origin	Beta - (5 lines) - Σ(Iβ-) omitted	1: 0,30 9	6
2,4 - 5,1	96,4	Auger L	I-127	E max. (keV	E avg. (keV	Inter	nsity (%)
24,44	4,02	ec K	I-127	1 150	408,8		1,6
22,7 - 33,1	11,8	Auger K	I-127	1 676	635,7		14,5
112,08	1,510	ec K	I-127	2 119	834,1		76,7
138,96	3,62	ec K	I-127	X (10 lines) - 3	E(I _v) omitted: 1.6	5%	
169,69	6,60	ec K	I-127	Energy (keV)	Intensity (%)	Type	Origin
X (5 lines) - Σ(I	v) omitted: 10	16		27.20	1.45	Xxa	Te-128
Enormy (kol/)	Intoneity (%)	Turno	Origin	27.47	27	Xvat	Te-128
28.32	25 0	Yre	L127			PARMAN	
20,52	25,0 A6.5	AKii2	1-127	Gamma (9 lin	es) - Σ(I ₇) omitte	d: 0,8 %	6
20,01	40,5	AKat	1 127	Energy (keV)	Intensity (%)	Туре	Origin
32,30	2.02	Акрі	1 127	442,90	15,8	Y	Xe-128
33,11	3,03	AK/j2	1-121	511	0,007	γ±	
Gamma (6 line	s) - Σ(I _γ) omitte	d: 0,014	%	526,56	1,5	γ	Xe-128
Energy (keV)	Intensity (%)	Type	Origin	Production	node Pos	sible im	purities
57,61	1,272	Y	I-127	1-127 (n. v) I-	128 none		
145,25	4,23	γ	I-127	Peference: Cl		1008	
172,13	25,53	γ	I-127	reiefence. Ci	LACTUC-LINED	1000	
202,86	68,45	Y	I-127				
374,99	17,26	γ	I-127				
Production m	ode Pos	sible imr	urities				
I-127 (p. n) Xe	-127m Xe-1	122. Xe-1	25				
I-127 (d. 2n) X	e-127m I-12	6					
Xe-126 (n v)	(e-127m -						
Xe-127m (IT)	Xe-127 T%	= 69 s					
Xe-126 (n v))	(e-127 Xe-1	129m Xe	-131m				
- 160 (ii, 1) /		2040					

Figure 4. Extract from the Mini Table (2015 version).

are half-life, decay constant, daughters, Q values, possible parents, specific activity and, most importantly, alpha, X and gamma emissions for each selected nuclide.

6.1. Decay data display

Energy and intensity thresholds can be set to restrict the displayed data to the most intense emissions. Multiple nuclides can be selected at the same time for comparison. When available, starting and ending levels of each emission are also displayed. Such information now allows the user to interactively display the nuclide decay scheme,



Figure 5a. Main LARAWEB window ①. selection of nuclides to be displayed. ②: optional thresholds settings. ③: selection of information to be displayed.



Figure 5b. LARAWEB data window. ①: Main data relating to the selected nuclide(s). ②: associated emissions according to thresholds.



Figure 5c. LARAWEB decay scheme plot. Left: complete scheme. Right: reduced scheme based on selected thresholds.

according to the selected thresholds. Thus, only the most intense or energetic emissions are displayed, offering a simplified view of the decay scheme.

LARAWEB can display the possible coincidences between to cascading nuclides, based on their respective intensities. This feature, combined with the possibility to plot a simplified decay scheme, makes it a convenient tool for spectrometrists.

Element: Fluor	ine (Z=9)
Daughter(s): O	-18 (β*,ε, 100 %)
Q*: 1655.9 keV	/
Half-life (T½): 1	.82890 (23) h ≡ 6.5840 (8) 10 ³ s
Decay constan	t (λ): 105.277 (13) 10 ⁻⁶ s ⁻¹
Specific activity	y (Am): 3.52218 (44) 10 ¹⁸ Bq.g ⁻¹
Reference: LNI	HB, KRI - 2014
Associated dat	a files: Table - Comments - ENSDF - PenNuc
Results file (AS	Cll text format): <u>F-18.txt</u>

Figure 6. Mass to activity conversion, and simple decay calculation tools in LARAWEB.

	Nuclide search criter	Selection results				
Decay r (O Ar Emissio Energy 511	mode: $\forall \beta^+, \epsilon \forall \beta^-$ and \circledast Or \circ XOr) on type: $\exists X \forall gammatrian 1 (or range): \pm 1 - 1$	☑ IT □ α na □ alpha keV	3 nuclides disintegrating by β^+ , ϵ or β^- or I.T. giving 6 gamma emissions where Energy 1: $\epsilon = 511 \pm 1 \text{ keV}$ Energy 2: $\epsilon = 850 \pm 50 \text{ keV}$ Intensity: $l \ge 5 \%$ Half-life: $T_{y_2} \ge 1 \text{ d}$			
And en	ergy 2 (or range):	keV	Energy / Intensity (nuclide):			
And on	± / - 50	ĸev	511 5.14E+1 (84Rb) ^			
And en	ergy 5 (or range):	key	511 3.92E+1 (56Co)			
	±/-	Rev	810,7602 9,94F+1 (58Co)			
Intensi	ty range:		846.7638 9.99E+1 (56Co)			
5		%	881.61 6.90E+1 (84Rb) -			
Half-life	e range: d • -	u a •	Nuclide (half-life): 56Co (77.236 d) 58Co (70.85 d) 84Rb (32.82 d) Energy threshold (keV): Intensity threshold (%): 5			
			Show emissions			



6.2. Conversion and decay tools

New calculation tools have also been added to the application. A mass to activity converter calculates the activity of a sample for a given mass and nuclide, considered as pure, and vice versa. A decay tool gives the activity of a nuclide after a time t_1 knowing the activity at t_0 or reciprocally, the time t_1 needed to obtain a given activity.

6.3. Advanced search engine

An integrated search engine allows all nuclides to be found which correspond to a range of chosen search criteria, such as; decay mode $(\beta^+/\varepsilon, \beta^-, IT, \alpha)$, emission type (alpha, X or gamma), emission energies (up to three individual energies or ranges may be specified), emission intensity, mass number and half-life. The user can then select one or more nuclides amongst the resulting list in order to display the complete information. Emissions meeting the search criteria are then highlighted, along with other significantly intense emissions.

This tool can be used to quickly identify the originating radionuclide of an alpha or gamma ray in a spectrum when the energies of the peaks are known.

LARAWEB is available through the Atomic and Nuclear Data section of the LNHB website: http://www. nucleide.org/NucData.htm or directly at the following address: http://www.nucleide.org/Laraweb.

⁵⁶ Co - Emission	S				
Element: Cobalt (Z=2)	7)				
Daughter(s): Fe-56 (β	',ε, 100 %)				
Q ⁺ : 4566 keV					
Possible parent(s): Ni	<u>-56</u> (β ⁺ ,ε, 100 %)				
Half-life (T½): 77.236 (26) d ≡ 6.6732 (22)	10 ⁶ s			
Decay constant (λ): 10)3.870 (35) 10 ⁻⁹ s ⁻¹				
Specific activity (Am):	1.11700 (38) 10 ¹⁵ B	q.g ⁻¹			
Reference: LBNL, NPI	- 2005				
Associated data files:	Table - Comments -	ENSDE	- PenNue	<u>c</u>	
Intensity threshold: 5	%				
Gamma emissions (8	lines out of 47) sort	ed by ir	ncreasing	energy	
Emissions meeting se	earch criteria Other	r signific	antly inte	ense em	issions
Energy (keV)	Intensity (%)	Туре	Origin*	Lev Start*	els <u>End</u> *
511 (-)	39.21 (22)	γ±	Fe-56	-1	-1
846.7638 (19)	99.9399 (23)	Y	Fe-56	1	0
1 037.8333 (24)	14.03 (5)	У	Fe-56	5	2
1 238.2736 (22)	66.41 (16)	У	Fe-56	2	1
1 771.327 (3)	15.45 (4)	У	Fe-56	8	2
2 034.752 (5)	7.741 (13)	У	Fe-56	11	2
2 598.438 (4)	16.96 (4)	У	Fe-56	7	1
3 253.402 (5)	7.87 (3)	У	Fe-56	10	1
⁵⁸ Co - Emission	S				
Element: Cobalt (Z=2)	7)				
Daughter(s): Fe-58 (β	, ε, 100 %)				
Q ⁺ : 2307.9 keV					
Possible parent(s): <u>Co</u>	-58m (I.T., 100 %)				
Half-life (T½): 70.85 (3) d ≡ 6.1214 (26) 10 ⁴	⁶ s			
Decay constant (λ): 11	3.233 (48) 10 ⁻⁹ s ⁻¹				
Specific activity (Am):	1.17570 (50) 10 ¹⁵ B	q.g ⁻¹			
Reference: CEA/LNE-L	NHB - 2013				
Reference: CEA/LNE-I Associated data files:	NHB - 2013 Table - Comments -	ENSDE	- <u>PenNu</u>	<u>c</u>	
Reference: CEA/LNE-L Associated data files: Intensity threshold: 5	-NHB - 2013 Table - <u>Comments</u> - %	ENSDE	- <u>PenNu</u>	2	
Reference: CEA/LNE-I Associated data files: Intensity threshold: 5 Gamma emissions (2	.NHB - 2013 Table - Comments - % lines out of 4) sorte	ENSDF	- <u>PenNu</u>	<u>c</u> energy	
Reference: CEA/LNE-I Associated data files: Intensity threshold: 5 Gamma emissions (2 Emissions meeting so	.NHB - 2013 Table - Comments - % lines out of 4) sorte earch criteria Other	d by ind	- <u>PenNue</u> creasing e	energy	issions
Reference: CEA/LNE-I Associated data files: Intensity threshold: 5 Gamma emissions (2 Emissions meeting so	.NHB - 2013 Table - <u>Comments</u> - % lines out of 4) sorte <i>earch criteria</i> <u>Other</u>	d by ind	- <u>PenNu</u> creasing e cantly inte	energy ense em Lev	<i>issions</i> els
Reference: CEA/LNE-I Associated data files: Intensity threshold: 5 Gamma emissions (2 <i>Emissions meeting su</i> Energy (keV)	.NHB - 2013 <u>Table - Comments -</u> % lines out of 4) sorte <i>earch criteria Other</i> Intensity (%)	d by ind r signific Type	- <u>PenNue</u> creasing e cantly inte Origin [*]	energy ense em Leve Start [*]	<i>issions</i> els End*
Reference: CEA/LNE-I Associated data files: Intensity threshold: 5 Gamma emissions (2 <i>Emissions meeting su</i> Energy (keV) 511 (-)	NHB - 2013 <u>Table</u> - <u>Comments</u> - % lines out of 4) sorte <i>earch criteria</i> Other Intensity (%) 29.88 (32)	d by ind r signific Type Y±	- <u>PenNue</u> creasing e cantly inte Origin* Fe-58	energy ense em Lev Start*	<i>issions</i> els <u>End</u> * -1

Figure 7b. LARAWEB search engine: associated data, with relevant emissions highlighted.

7. Conclusions

Data evaluation and dissemination is a continuous process in which the LNHB is deeply involved. We are permanently updating data and tools and developing new ones to fulfil the needs of decay data users and evaluators. Over a period of 10 years, about 100 new nuclide evaluations have been added to our database and published in six volumes of the Monographie BIPM-5, and an updated pocket-sized reference guide entitled the Mini Table of Radionuclides issued in 2015.

Many new developments have been implemented in the online tool LARAWEB, including information on γ - γ coincidences and the ability to plot decay schemes. In particular, the use of intensity thresholds allows the main decay radiations to be displayed and a simplified decay scheme to be plotted, which is unique to LARAWEB.

We would like to express our sincere thanks to all members of the Decay Data Evaluation Project, past and present, without whose dedication this work would not have been possible. A full list is available from our website at: http://www.nucleide.org/DDEP_WG/DDEPadresses.htm.

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