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DE LA RECHERCHE À L'INDUSTRIE

## Status of the DDEP collaboration

24<sup>th</sup> of October 2022

S. Leblond, C. Dulieu, M.A. Kellett

on the behalf of X. Mougeot



➤ **Providing recommended decay data to non-specialists**

- Metrology
- Nuclear Physics
- Nuclear Medicine
- Nuclear Power
- ...



➤ **Information of interest**

- Half-life
- Q-value
- Decay scheme
- Properties of nuclear radiations
  - Energy
  - Intensity
- Atomic radiations
  - X-rays
  - Conversion electrons
  - Auger electrons

➤ **History**

- Initiated in 1993 by LNHB (France) & PTB (Germany)
- Joined by international evaluators from USA and others in 1994
- Data quickly recommended by BIPM



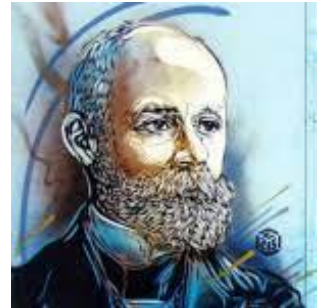
The goal is **not** to compete with the Nuclear Structure and Decay Data Evaluator's Network (ENSDF evaluators) **but to complement** their efforts in providing the relevant recommended data for our community

## Coordinator

Mark A. Kellett (2016-2020) → **Xavier Mougeot (2020 to present)**

### ➤ LNHB local team (evaluation, review, edition process, code development)

- Sylvain Leblond (since oct. 2020)
- Xavier Mougeot
- Mark A. Kellett (Special advisor)
- Christophe Dulieu (IT support)



### ➤ Decay data evaluation specialists (evaluation, review)

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



### ➤ Additional support

- Tibor Kibédi (BrIcc and BrIccMixing codes)
- ENSDF collaboration (joint evaluation) – Special thanks to Balraj Singh

**Lack of manpower**

## ➤ LNHB website

- 225 evaluations available
- Evaluations & comments in pdf format
- Export: ENSDF, PENNUC, BetaShape...
- In 2021
  - ~ 130 access per day
  - ~ 20 download per day
  - ~ 20 countries
- Increasing success:  
7 times more access in 5 years

## ➤ Laraweb

- ~ 450 nuclei available
- Interactive online interface
- Multi-criteria search tool
- In 2021
  - ~ 3000 users per day
  - ~ 60 countries

The screenshot shows the LNHB website interface. At the top, there is a navigation bar with 'Presentation', 'Services', 'R&D activities', and 'Nuclear data'. Below this is a periodic table of elements. Underneath the periodic table is a table of nuclides with columns for Nuclide, Z, Vol. (?), Update, Type (?), Table (?), Comments (?), and ASCII files (?). The table lists nuclides from H-3 to P-33. Below the table is a 'Sort by:' dropdown menu with 'Atomic number' selected.

Nuclide	Z	Vol. (?)	Update	Type (?)	Table (?)	Comments (?)	ASCII files (?)
H-3	<sup>3</sup> H	1	3	04/09/2006	1	T	C E P L B
Be-7	<sup>7</sup> Be	4	1	18/02/2004	1	T	C E P L B
C-11	<sup>11</sup> C	6	1	03/11/2011	2	T	C E P L B
C-14	<sup>14</sup> C	6	7	22/11/2012	1	T	C E P L B
N-13	<sup>13</sup> N	7	1	06/04/2004	1	T	C E P L B
O-15	<sup>15</sup> O	8	1	01/06/2004	1	T	C E P L B
F-18	<sup>18</sup> F	9	1	01/09/2014	2	T	C E P L B
Na-22	<sup>22</sup> Na	11	5	06/08/2009	3	T	C E P L B
Na-24	<sup>24</sup> Na	11	1	16/06/2014	2	T	C E P L B
Al-26	<sup>26</sup> Al	13	99	24/07/2003	1	T	C E P L B
P-32	<sup>32</sup> P	15	1	06/04/2004	1	T	C E P L B
P-33	<sup>33</sup> P	15	1	06/04/2004	1	T	C E P L B

The screenshot shows the 'Nuclide - Lara' website interface. It features a search bar, a 'Nuclide list' dropdown, and various search criteria like 'Energy threshold', 'Intensity threshold', and 'Coincidence threshold'. The interface is divided into several sections: 'Data', 'Tools', 'Emissions', and 'Scheme'. The 'Data' section shows the element Cobalt (Z=27) and its daughter(s) Ni-60. The 'Tools' section shows activity and mass conversion options. The 'Emissions' section shows a table of gamma emissions. The 'Scheme' section shows a decay scheme diagram for <sup>60</sup>Co.

**60Co - Emissions and decay scheme**

**Data**

Element: Cobalt (Z=27)  
 Daughter(s): Ni-60 (β<sup>+</sup>; 100%)  
 Q: 2823.07 keV  
 Possible parents: Co-60m (I.T., 99.75%)  
 Half-life (T<sub>1/2</sub>): 5.2711 (8) a = 166.340 (25) 10<sup>6</sup> s  
 Decay constant (λ): 4.1671 (6) 10<sup>-8</sup> s<sup>-1</sup>  
 Specific activity (A<sub>m</sub>): 41.824 (6) 10<sup>12</sup> Bq.g<sup>-1</sup>  
 Reference: INEEL - 2006  
 Associated data files: Table - Comments - ENSDF - PenNuc  
 Data and emissions file (ASCII text format): Co-60.txt

**Tools**

Activity = Mass conversion: 1000 Bq = 2.391E-11 g  
 Decay calculation: t<sub>1</sub> → t<sub>2</sub> = 5.271E0 → 5.271E1 a → 1 steps  
 Nuclide (T<sub>1/2</sub>) A<sub>0</sub> A(t<sub>1</sub>) A(t<sub>2</sub>)  
<sup>60</sup>Co (5.2711 a) 1000 500 0.9765625 Bq  
 Copy table to clipboard

**Emissions**

Energy threshold: 10 keV  
 Intensity threshold: 2%  
 Coincidence threshold: 10%  
 Gamma emissions (2 lines out of 6) sorted by increasing energy

Energy (keV)	Intensity (%)	Type	Origin*	Levels Start* End*	Possible coincidence with (keV) / Possible sum of (levels)
1.173,228 (3)	99.85 (3)	Y	Ni-60	3	1 1332.492 (Z+2 505.720)
1.332,492 (4)	99.9826 (6)	Y	Ni-60	1	0 1173.228 (Z+2 505.720)

**Scheme**

Decay scheme diagram for <sup>60</sup>Co showing transitions to <sup>60</sup>Ni. The diagram includes energy levels and transition probabilities.

**64Cu - Emissions and decay scheme**

**Data**

### ➤ Lean years between 2017 and 2020

- Mainly due to lack of manpower at LNHB
- Accumulation of unpublished evaluated data

### ➤ Since 2021

- Recruitment at LNHB to support DDEP
- Slowly recovering...

#### ❖ Published

- $^{52}\text{Mn}$ ,  $^{52\text{m}}\text{Mn}$  (ENSDF 2015)
- $^{124}\text{I}$  (ENSDF 2008)
- $^{131}\text{Cs}$  (ENSDF 2006)
- $^{87}\text{Rb}$  (ENSDF 2015)

#### ❖ Under Review

- $^{68}\text{Ga}$  (ENSDF 2012)
- $^{103}\text{Pd}$  /  $^{103\text{m}}\text{Rh}$  (ENSDF 2009) - publication expected in 2022
- $^{226}\text{Th}$  (ENSDF 2011)
- $^{137}\text{Cs}$  (ENSDF 2007) - publication expected in 2022

#### ❖ Evaluations in progress

- $^{166}\text{Ho}$ ,  $^{151}\text{Sm}$ ,  $^{40}\text{K}$ ,  $^{55}\text{Fe}$ ,  $^{99}\text{Mo}$ ,  $^{99\text{m}}\text{Tc}$ ,  $^{111}\text{In}$ ,  $^{111\text{m}}\text{Cd}$ ,  $^{120}\text{I}$ ,  $^{137}\text{Cs}$ ,  $^{142\text{m}}\text{Pr}$ ,  $^{178}\text{Ta}$

#### ❖ Still pending

- $^{45}\text{Ti}$ ,  $^{55}\text{Co}$ ,  $^{56}\text{Co}$ ,  $^{135}\text{I}$ ,  $^{133}\text{Xe}$ ,  $^{135}\text{Xe}$ ,  $^{135\text{m}}\text{Xe}$ ,  $^{227}\text{Th}$ ,  $^{229}\text{Th}$ ,  $^{230}\text{U}$ ,  $^{233}\text{U}$

Nuclide	Z	Vol. (?)	UpDate	Type (?)	Table (?)	Comments (?)	ASCII files (?)				
All Nuclides			25/05/2022	N	T	C	E	P	L	B	
Rb-87	$^{87}\text{Rb}$	37	9	24/05/2022	N	T	C	E	P	L	B
Cs-131	$^{131}\text{Cs}$	55	9	21/09/2021	N	T	C	E	P	L	B
I-124	$^{124}\text{I}$	53	9	20/07/2021	N	T	C	E	P	L	B
Mn-52	$^{52}\text{Mn}$	25	9	09/02/2021	N	T	C	E	P	L	B
Mn-52m	$^{52\text{m}}\text{Mn}$	25	9	09/02/2021	N	T	C	E	P	L	B
Sn-113	$^{113}\text{Sn}$	50	99	20/10/2017	2	T	C	E	P	L	B
Br-76	$^{76}\text{Br}$	35	9	04/10/2017	N	T	C	E	P	L	B
Co-57	$^{57}\text{Co}$	27	9	03/03/2017	1	T	C	E	P	L	B
Xe-133m	$^{133\text{m}}\text{Xe}$	54	9	03/03/2017	2	T	C	E	P	L	
Pr-142	$^{142}\text{Pr}$	59	9	03/02/2017	N	T	C	E	P	L	B
Y-88	$^{88}\text{Y}$	39	8	04/10/2016	1	T	C	E	P	L	B
La-138	$^{138}\text{La}$	57	8	15/06/2016	N	T	C	E	P	L	B
Ba-133	$^{133}\text{Ba}$	56	8	24/03/2016	3	T	C	E	P	L	B
Ba-140	$^{140}\text{Ba}$	56	8	24/03/2016	3	T	C	E	P	L	B

➤ Collaboration between DDEP and ENSDF

➤ Updating the  $\beta$ -decay  $^{137}\text{Cs} \rightarrow ^{137}\text{Ba}$

○ Previous DDEP

- R.G. Helmer (1998)
- V.P. Chechev (2007)

○  $T_{1/2} = 30.05 (8) \text{ a}$

○  $I_{\beta}(\text{g.s.} \rightarrow \text{g.s.}) = 5.64 (28) \%$

○ Previous Mass evaluation  $A = 137$  (2007BR23)

- E. Browne
- J.K. Tuli

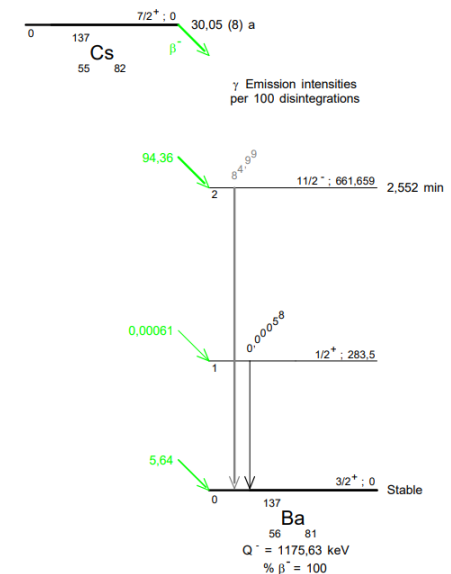
○  $T_{1/2} = 30.08 (9) \text{ a}$

○  $I_{\beta}(\text{g.s.} \rightarrow \text{g.s.}) = 5.3 (2) \%$

➤ Jointly performed by T. Kibédi, C. Nesaraja and S. Leblond under B. Singh guidance

➤ More than 150 publications have been investigated

➤ S. Leblond nearing completion (under reviewing by A. Nichols)



### ➤ IAEA Coordinated Research Projects (CRP)

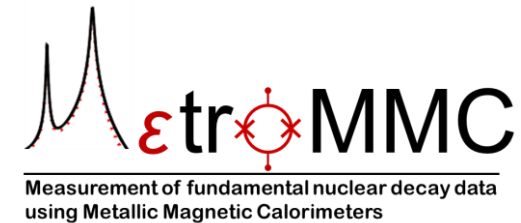
- *Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production (2019)*
  - $^{52}\text{Mn}$ ,  $^{52\text{m}}\text{Mn}$ ,  $^{76}\text{Br}$

### ➤ Evaluations for *Comprehensive Nuclear-Test-Ban Treaty Organisation (CTBTO)*

- $^{133}\text{Xe}$ ,  $^{133\text{m}}\text{Xe}$ ,  $^{135}\text{Xe}$ ,  $^{135\text{m}}\text{Xe}$ ,  $^{133}\text{I}$ ,  $^{135}\text{I}$   
(by Mónica Galán -- to be published)

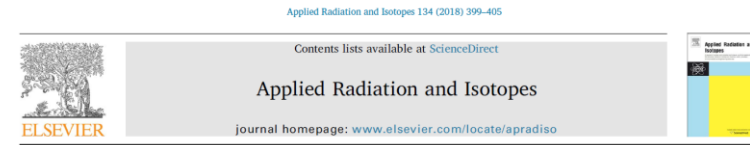
### ➤ European Research Project (EMPIR Euramet)

- MetroMMC (2018-2021)
  - Fractional EC probabilities:  $^{54}\text{Mn}$ ,  $^{59}\text{Ni}$ ,  $^{65}\text{Zn}$ ,  $^{109}\text{Cd}$ ,  $^{125}\text{I}$
- Prima-LTD (2021-2024)
  - Measurements to be performed:  $^{55}\text{Fe}$ ,  $^{129}\text{I}$



### ➤ CEA INSNU project (Reactor safety)

- $^{103}\text{Pd}$  /  $^{103\text{m}}\text{Rh}$  X-rays intensity measurements
- Updated evaluation under review



Measurement of absolute K X-ray emission intensities in the decay of  $^{103\text{m}}\text{Rh}$

J. Riffaud<sup>1,a</sup>, P. Cassette<sup>2</sup>, D. Lacour<sup>3</sup>, V. Lourenço<sup>3</sup>, I. Tartès<sup>3</sup>, M.A. Kellett<sup>4</sup>, M. Corbel<sup>5</sup>, M.-C. Lépy<sup>6</sup>, C. Domergue<sup>5</sup>, C. Destouches<sup>5</sup>, H. Carcreff<sup>7</sup>, O. Vigneau<sup>4</sup>



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<https://doi.org/10.1140/epja/s10050-020-00141-9>

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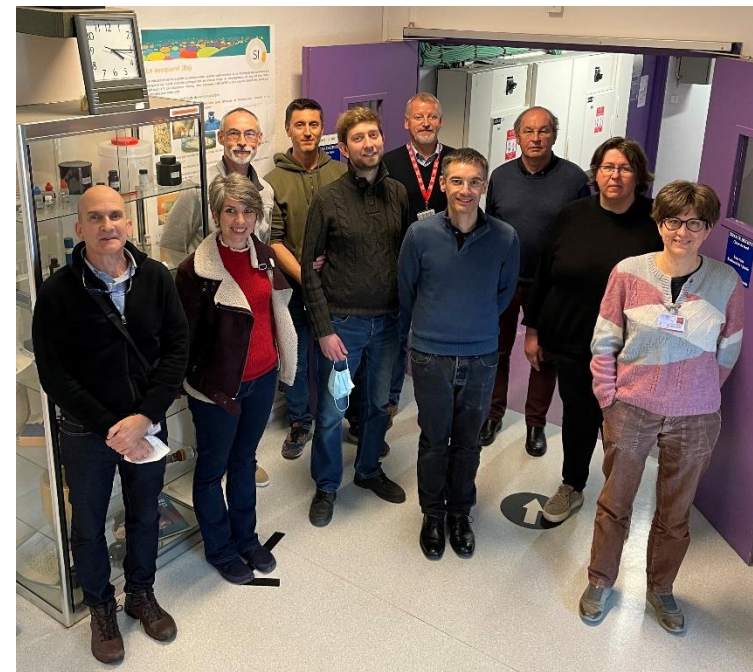
Review

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

A. J. M. Plompen<sup>1,a</sup>, O. Cabello<sup>2</sup>, C. De Saint Jean<sup>3</sup>, M. Fleming<sup>4,5</sup>, A. Algora<sup>6</sup>, M. Angelone<sup>7</sup>, P. Archier<sup>8</sup>, E. Bauge<sup>3</sup>, O. Bersillon<sup>3</sup>, A. Blokhin<sup>9</sup>, F. Cantargi<sup>10</sup>, A. Chebboubi<sup>8,11</sup>, C. Diez<sup>12</sup>, H. Duarte<sup>3</sup>, E. Dupont<sup>13</sup>, J. Dyrda<sup>14</sup>, B. Erasmussen<sup>14</sup>, L. Fiorito<sup>4,15</sup>, U. Fischer<sup>16</sup>, D. Flammini<sup>7</sup>, D. Foligno<sup>8</sup>, M. R. Gilbert<sup>5</sup>, J. R. Granada<sup>10</sup>, W. Haack<sup>17</sup>, F.-J. Hambach<sup>1</sup>, P. Helgesson<sup>18</sup>, S. Hilaire<sup>3</sup>, I. Hill<sup>4</sup>, M. Hursin<sup>19</sup>, R. Ichou<sup>17</sup>, R. Jacquini<sup>8</sup>, B. Jansky<sup>20</sup>, C. Journe<sup>21</sup>, M.A. Kellett<sup>22</sup>, D.H. Kim<sup>23</sup>, H.L. Kim<sup>23</sup>, I. Kodeli<sup>24</sup>, A.J. Koning<sup>25</sup>, A. Yu. Konobeyev<sup>16</sup>, S. Kopecky<sup>1</sup>, B. Koz<sup>24</sup>, A. Kráeš<sup>15</sup>, L.C. Loati<sup>17</sup>, N. Lohr<sup>17</sup>, P. Lecoq<sup>8</sup>, V.O. Lou<sup>23</sup>, H. Loh<sup>26</sup>, O. Litaize<sup>8</sup>, M. Maithe<sup>27</sup>

## ➤ Recruiting new members

- 7<sup>th</sup> to 9<sup>th</sup> of March 2022: organisation of a DDEP workshop dedicated to evaluator training
  - Vanessa VALLET (CEA Cadarache)
  - David BERNARD (CEA Cadarache)
  - Muriel FALLOT (SUBATECH)
  - Amanda PORTA (SUBATECH)
  - Lydie GIOT (SUBATECH)
  - Alejandro ALGORA (Instituto de Física Corpuscular)
  - Philippe CASSETTE (Sofia University)
  
- Participation to the 2022 Joint ICTP-IAEA Workshop on Nuclear Structure and Decay Data
  - Vanessa VALLET
  - Sylvain LEBLOND
  - Xavier MOUGEOT (Lecturer)
  
- 2021: Publication of Dr Brian Zimmerman (NIST) first DDEP evaluation ( $^{124}\text{I}$ )
  
- Listening to the needs of the users / evaluators
  - Inclusion of TAGS measurements related to the pandemonium effect?
  - Inclusion of beta-delayed neutron data?





### ➤ Improving Laraweb

- Decay chain tools
  - Parent / Daughters activity calculation
  - Calculation of radiation emission intensities
- BetaShape on the web (released recently)  
[http://www.lnhb.fr/Laraweb/BetaShape\\_web/](http://www.lnhb.fr/Laraweb/BetaShape_web/)

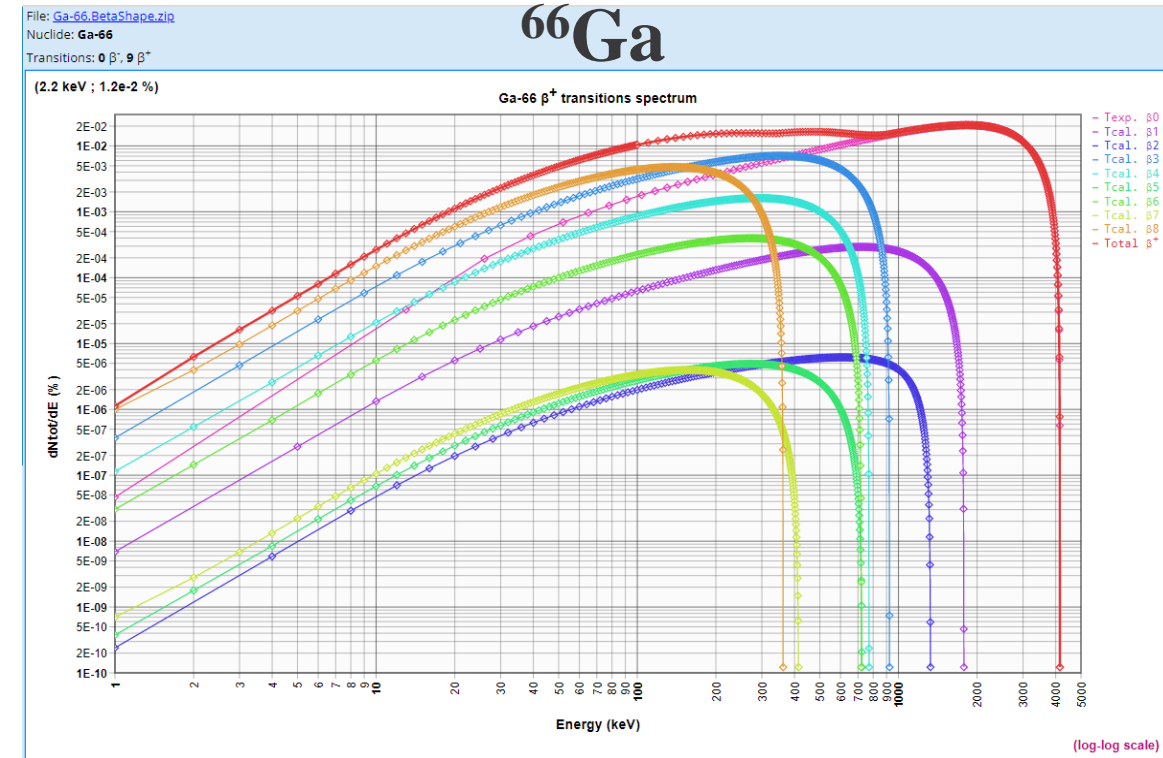
### ➤ Development of libraries for Monte-Carlo simulations

- PENNUC for PENELOPE
- Nuclide++ for Geant4

### ➤ Software developments (SAISINUC)

- New Installation Manual and User Guide
- Direct integration of calculations codes (BetaShape, BrIcc, Alpha-rad)
- Removal of obsolete functions
- Improved process of gamma multipolarity and mixing ratio

**Discussions are ongoing regarding the future of SAISINUC**



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Contents lists available at ScienceDirect  
**Applied Radiation and Isotopes**

journal homepage: <http://www.elsevier.com/locate/apradiso>



Nuclide++: A C++ module to include DDEP recommended radioactive decay Data in Geant4

C. Thiam<sup>a,\*</sup>, C. Dulieu<sup>a</sup>, X. Mougeot<sup>a</sup>, A. Nair<sup>b</sup>, C. Bobin<sup>a</sup>, M.A. Kellett<sup>a</sup>



- **DDEP: an international collaboration complementary to ENSDF to provide recommended decay data**
- **Involved in many collaborations to be as close a possible to the user needs**
- **Effort is continuously made to ensure the effective distribution of recommended decay data**
  - Publications: BIPM Monographies
  - Online: Improved website, Laraweb
  - Codes: PENELOPE, GEANT4
- **After few lean years, evaluations are back on track**
  - 4 evaluations published in 2021, 4 additional expected at the end of 2022
  - But manpower remains limited...
- **Various actions are being undertaken to renew DDEP**
  - Recruitment of one evaluator at LNHB in 2020
  - Evaluation workshop organized in March 2022 to train new evaluators
  - Participation to the Joint ICTP-IAEA Workshop on Nuclear Structure and Decay Data in October 2022
  - Various developments around SAISINUC / Laraweb

**Any comments, requests or ideas  
are gladly welcome**