Berkeley Nuclear Database Projects

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25th Technical Meeting of the International Newtwork of Nuclear Structure and Decay Data Evaluators,
IAEA Headquarters, Vienna, Austria

April 15 – 19, 2024

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1868

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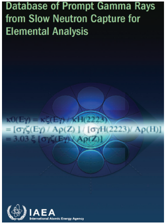
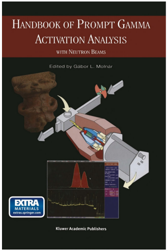
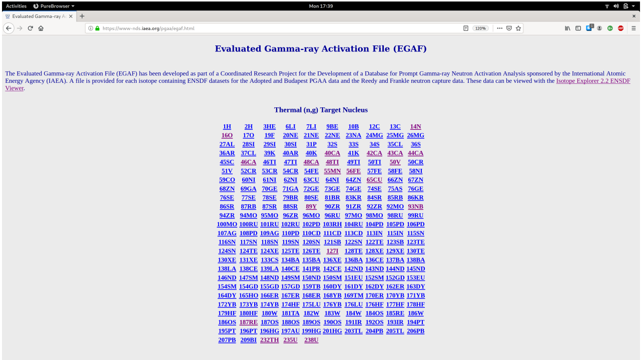
https://nucleardata.berkeley.edu/databases/

EGAF disseminated in printed form and through the IAEA

https://www-nds.iaea.org/pgaa/egaf.html







Evaluated Gamma-ray Activation File (EGAF)

The Evaluated Gamma-ray Activation File (EGAF) has been developed as part of a Coordinated Research Project for the Development of a Database for Prompt Gamma-ray Neutron Activation Analysis sponsored by the International Atomic Energy Agency (IAEA). A file is provided for each isotope containing ENSDF datasets for the Adopted and Budapest PGAA data and the Reedy and Frankle neutron capture data. These data can be viewed with the Isotope Explorer 2.2 ENSDF Viewer.

Thermal (n,g) Target Nucleus

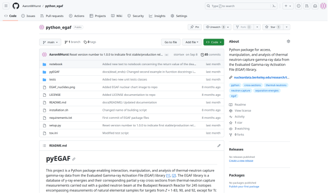
1H	2H	3HE	6LI	7LI	9BE	10B	12C	13C	14N
16O	17O	19F	20NE	21NE	22NE	23NA	24MG	25MG	26MG
27AL	28SI	29SI	30SI	31P	32S	33S	34S	35CL	36S
36AR	37CL	39K	40AR	40K	40CA	41K	42CA	43CA	44CA
45SC	46CA	46TI	47TI	48CA	48TI	49TI	50TI	50V	50CR
51V	52CR	53CR	54CR	54FE	55MN	56FE	57FE	58FE	58NI
59CO	60NI	61NI	62NI	63CU	64NI	64ZN	65CU	66ZN	67ZN
68ZN	69GA	70GE	71GA	72GE	73GE	74GE	74SE	75AS	76GE
76SE	77SE	78SE	79BR	80SE	81BR	83KR	84SR	85RB	86KR
86SR	87RB	87SR	88SR	89Y	90ZR	91ZR	92ZR	92MO	93NB
94ZR	94MO	95MO	96ZR	96MO	96RU	97MO	98MO	98RU	99RU
100MO	100RU	101RU	102RU	102PD	103RH	104RU	104PD	105PD	106PD
107AG	108PD	109AG	110PD	110CD	111CD	113CD	113IN	115IN	115SN
116SN	117SN	118SN	119SN	120SN	121SB	122SN	122TE	123SB	123TE
124SN	124TE	124XE	125TE	126TE	127I	128TE	128XE	129XE	130TE
130XE	131XE	133CS	134BA	135BA	136XE	136BA	136CE	137BA	138BA
138LA	138CE	139LA	140CE	141PR	142CE	142ND	143ND	144ND	145ND
146ND	147SM	148ND	149SM	150ND	150SM	151EU	152SM	152GD	153EU
154SM	154GD	155GD	157GD	159TB	160DY	161DY	162DY	162ER	163DY
164DY	165HO	166ER	167ER	168ER	168YB	169TM	170ER	170YB	171YB
172YB	173YB	174YB	174HF	175LU	176YB	176LU	176HF	177HF	178HF
179HF	180HF	180W	181TA	182W	183W	184W	184OS	185RE	186W
186OS	187RE	187OS	188OS	189OS	190OS	191IR	192OS	193IR	194PT
195PT	196PT	196HG	197AU	199HG	201HG	203TL	204PB	205TL	206PB
207PB	209BI	232TH	235U	238U					

Source ENSDF-formatted datasets @ IAEA

Open-source Python library pyEGAF on GitHub

https://github.com/AaronMHurst/python_egaf

- Translated all 245 ENSDF-formatted EGAF datasets to a new `JSON` format.
- Generated RIPL-format EGAF for reaction calculations.
- Developed suite of Python modules enabling interaction, analysis, and visualization of the EGAF (n,γ) data.
- Docstrings provided for all methods.
- JSON schema keys documented extensively in `README`.
- 224 unit tests (multiple virtual `Python3` environments).
- Installation, testing scripts, and `Jupyter Notebooks` provided.
- `ENSDF`, `RIPL`, and `JSON` files bundled with software.
- Over 800 downloads.



python_egaf Public

AaronMHurst Reset version number to 1.0.0 to indicate first stable/production rel... 050f0d4 on Sep 8 85 commits

notebook	Added new text to notebook concerning the return value of the dea...	last month
pyEGAF	docs(dead_ends): Changed second example in fucntion docstrings i...	last month
tests	Added two new unit tests classes	last month
EGAF_nuclides.png	Added EGAF nuclear chart image to repo	8 months ago
LICENSE	Added LICENSE documentation to repo	8 months ago
README.md	docs(README): Updated documentation	last month
installation.sh	Changed name of building script	8 months ago
requirements.txt	First commit of EGAF package files	8 months ago
setup.py	Reset version number to 1.0.0 to indicate first stable/production rel...	last month
tox.ini	Modified test script	last month

README.md

pyEGAF

This project is a Python package enabling interaction, manipulation, and analysis of thermal-neutron capture gamma-ray data from the Evaluated Gamma-ray Activation File (EGAF) library [1], [2]. The EGAF library is a database of γ-ray energies and their corresponding partial γ-ray cross sections from thermal-neutron capture measurements carried out with a guided neutron beam at the Budapest Research Reactor for 245 isotopes encompassing measurements of natural elemental samples for targets from Z = 1-83, 90, and 92, except for Tc

About

Python package for access, manipulation, and analysis of thermal neutron-capture gamma-ray data from the Evaluated Gamma-ray Activation File (EGAF) library.

nucleardata.berkeley.edu/research/t...

python cross-sections thermal-neutrons neutron-capture separation-energies egaf

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No packages published
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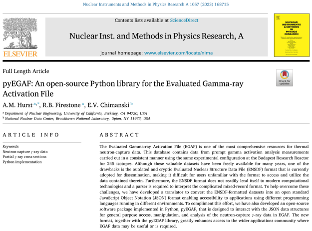

Nuclear Instruments and Methods in Physics Research A 1057 (2023) 168715

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Full Length Article

pyEGAF: An open-source Python library for the Evaluated Gamma-ray Activation File

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[b] National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY 11973, USA

ARTICLE INFO

Keywords:
Neutron-capture γ-ray data
Partial γ-ray cross sections
Python implementation

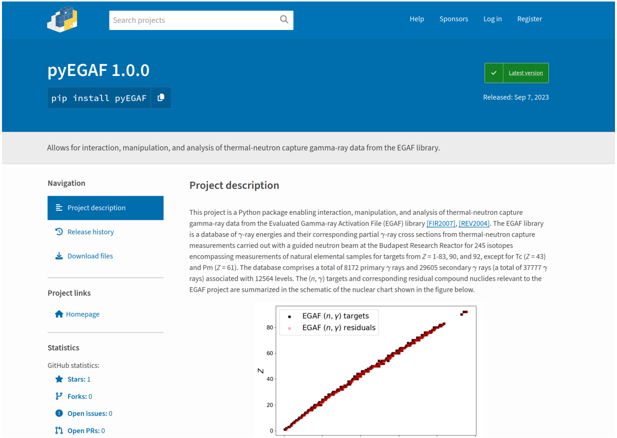
ABSTRACT

The Evaluated Gamma-ray Activation File (EGAF) is one of the most comprehensive resources for thermal neutron-capture data. This database contains data from prompt gamma activation analysis measurements carried out in a consistent manner using the same experimental configuration at the Budapest Research Reactor for 245 isotopes. Although these valuable datasets have been freely available for many years, one of the drawbacks is the outdated and cryptic Evaluated Nuclear Structure Data File (ENSDF) format that is currently adopted for dissemination, making it difficult for users unfamiliar with the format to access and utilize the data contained therein. Furthermore, the ENSDF format does not readily lend itself to modern computational technologies and a parser is required to interpret the complicated mixed-record format. To help overcome these challenges, we have developed a translator to convert the ENSDF-formatted datasets into an open standard JavaScript Object Notation (JSON) format enabling accessibility to applications using different programming languages running in different environments. To compliment this effort, we have also developed an open-source software package implemented in Python, pyEGAF, that is designed to interact with the JSON data structures for general purpose access, manipulation, and analysis of the neutron-capture γ-ray data in EGAF. The new format, together with the pyEGAF library, greatly enhances access to the wider applications community where EGAF data may be useful or is required.

```
git clone https://github.com/AaronMHurst/python_egaf.git
```

pyEGAF on the Python Package Index (PyPI) repository

https://pypi.org/project/pyEGAF/



pyEGAF 1.0.0

`pip install pyEGAF`

Released: Sep 7, 2023

Allows for interaction, manipulation, and analysis of thermal-neutron capture gamma-ray data from the EGAF library.

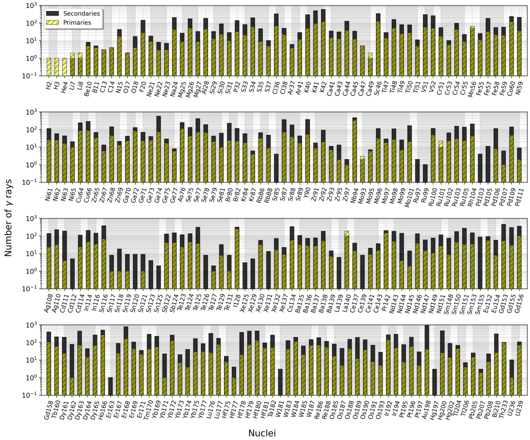
Project description

This project is a Python package enabling interaction, manipulation, and analysis of thermal-neutron capture gamma-ray data from the Evaluated Gamma-ray Activation File (EGAF) library [FIR2007], [REV2004]. The EGAF library is a database of γ-ray energies and their corresponding partial γ-ray cross sections from thermal-neutron capture measurements carried out with a guided neutron beam at the Budapest Research Reactor for 245 isotopes encompassing measurements of natural elemental samples for targets from $Z = 1$-83, 90, and 92, except for Tc ($Z = 43$) and Pm ($Z = 61$). The database comprises a total of 8172 primary γ rays and 29605 secondary γ rays (a total of 37777 γ rays) associated with 12564 levels. The (n, γ) targets and corresponding residual compound nuclides relevant to the EGAF project are summarized in the schematic of the nuclear chart shown in the figure below.

- `pip install pyegaf`
- pyEGAF 1.0.0: Production/stable development release.
- FreeBSD License.

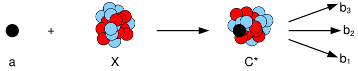
What data is in EGAF?

And what else do we need?



- Courtesy: *E.V. Chimanski, BNL*
- 8,172 primary γ rays.
- 29,605 secondary γ rays.
- 12,564 levels.
- Cross sections: σ_γ, σ_0
- Associated nuclear structure properties, e.g., J^π, I_γ . . .
- α, δ_γ, λL for improved RIPL and ENDF libraries.

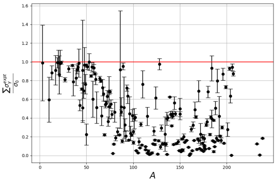
Assess completeness of capture-γ data using pyEGAF

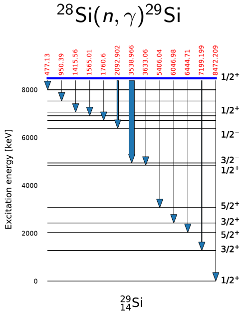


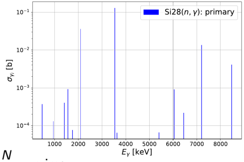
- The cross section for fusion in entrance channel (a) is given by the sum of cross sections for decay to all final channels (b_i):

$$\sigma_F(a) = \sum_{b_i}^{N} \sigma^{C}_{a\to b_i} \quad \therefore \quad \sigma_0 = \sum_{i=1}^{N} \sigma^{\text{primary}}_{\gamma_i}.$$

- Compare $\sum_{i=1}^{N} \sigma^{\text{primary}}_{\gamma_i}$ from `pyEGAF` to σ_0.



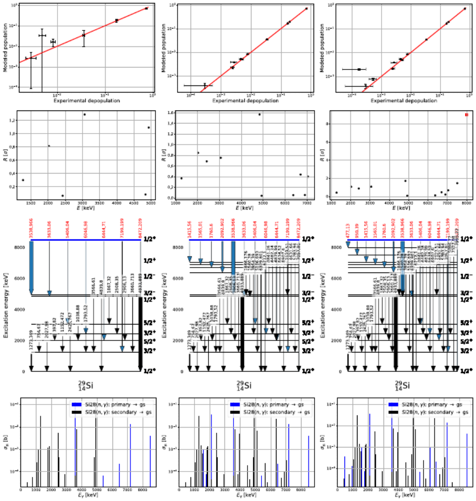




$$\sum_{i=1}^{N} \sigma^{\text{primary}}_{\gamma_i} = 0.185(2)\ \text{b [pyEGAF]}$$

$$\sigma_0 = 0.177(5)\ \text{b [Adopted]}$$

Modeling the (n,γ) reaction using pyEGAF methods

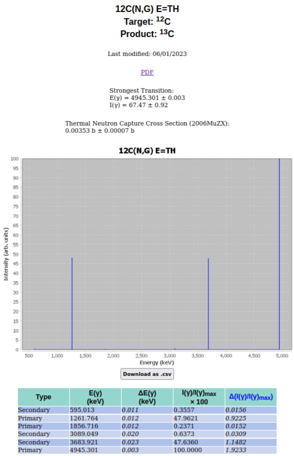


(a) $E_c = 4934.339$ keV (b) $E_c = 7057.94$ keV (c) $E_c = 7996.4$ keV

- Statistical-model analysis of (n,γ) reaction, e.g., ^{28}Si(n,γ).
- Compare modeled population of levels to experimental data.
- Establish critical energy E_c.

CapGam cf. pyEGAF::capgam

CapGam



12C(N,G) E=TH
Target: ^{12}C
Product: ^{13}C

Last modified: 06/01/2023

PDF

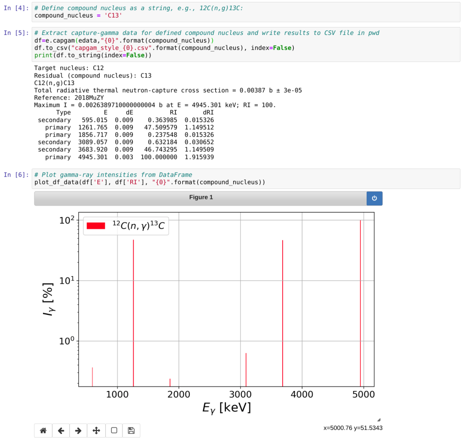
Strongest Transition:
E(γ) = 4945.301 ± 0.003
I(γ) = 67.47 ± 0.92

Thermal Neutron Capture Cross Section (2006MuZX):
0.00353 b ± 0.00007 b

12C(N,G) E=TH

Type	E(γ) (keV)	ΔE(γ) (keV)	I(γ)/I(γ)max × 100	Δ(I(γ)/I(γ)max)
Secondary	595.013	*0.011*	0.3557	*0.0156*
Primary	1261.764	*0.012*	47.9621	*0.9225*
Primary	1856.716	*0.012*	0.2371	*0.0152*
Secondary	3089.049	*0.020*	0.6373	*0.0309*
Secondary	3683.921	*0.023*	47.6360	*1.1482*
Primary	4945.301	*0.003*	100.0000	*1.9233*

pyEGAF



In [4]:
```
# Define compound nucleus as a string, e.g., 12C(n,g)13C:
compound_nucleus = 'C13'
```

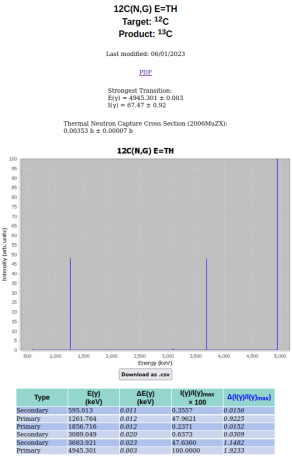
In [5]:
```
# Extract capture-gamma data for defined compound nucleus and write results to CSV file in pwd
df=e.capgam(edata,"{0}".format(compound_nucleus))
df.to_csv("capgam_style_{0}.csv".format(compound_nucleus), index=False)
print(df.to_string(index=False))
```

```
Target nucleus: C12
Residual (compound nucleus): C13
C12(n,g)C13
Total radiative thermal neutron-capture cross section = 0.00387 b ± 3e-05
Reference: 2018MuZY
Maximum I = 0.0026389710000000004 b at E = 4945.301 keV; RI = 100.
      Type        E     dE          RI       dRI
 secondary   595.015  0.009    0.363985  0.015326
   primary  1261.765  0.009   47.509579  1.149512
   primary  1856.717  0.009    0.237548  0.015326
 secondary  3089.057  0.009    0.632184  0.030652
 secondary  3683.920  0.009   46.743295  1.149509
   primary  4945.301  0.003  100.000000  1.915939
```

In [6]:
```
# Plot gamma-ray intensities from DataFrame
plot_df_data(df['E'], df['RI'], "{0}".format(compound_nucleus))
```

CapGam cf. `pyEGAF::capgam`

CapGam



12C(N,G) E=TH
Target: ^{12}C
Product: ^{13}C

Last modified: 06/01/2023

PDF

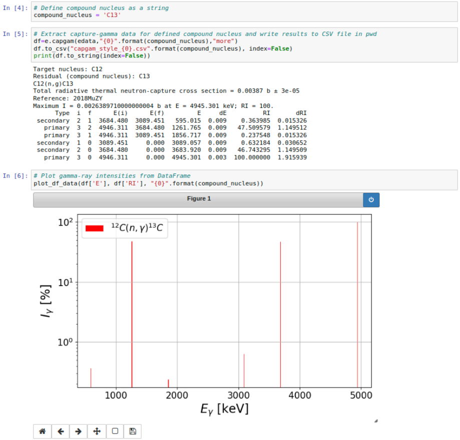
Strongest Transition:
E(γ) = 4945.301 ± 0.003
I(γ) = 67.47 ± 0.92

Thermal Neutron Capture Cross Section (2006MuZX):
0.00353 b ± 0.00007 b

12C(N,G) E=TH

Type	E(γ) (keV)	ΔE(γ) (keV)	$I(\gamma)/I(\gamma)_{max} \times 100$	$\Delta(I(\gamma)/I(\gamma)_{max})$
Secondary	595.013	*0.011*	0.3557	*0.0156*
Primary	1261.764	*0.012*	47.9621	*0.9225*
Primary	1856.716	*0.012*	0.2371	*0.0152*
Secondary	3089.049	*0.020*	0.6373	*0.0309*
Secondary	3683.921	*0.023*	47.6360	*1.1482*
Primary	4945.301	*0.003*	100.0000	*1.9233*

pyEGAF: ‘`more`’



In [4]:
```
# Define compound nucleus as a string
compound_nucleus = 'C13'
```

In [5]:
```
# Extract capture-gamma data for defined compound nucleus and write results to CSV file in pwd
df=e.capgam(edata,"{0}".format(compound_nucleus),"more")
df.to_csv("capgam_style_{0}.csv".format(compound_nucleus), index=False)
print(df.to_string(index=False))
```

```
Target nucleus: C12
Residual (compound nucleus): C13
C12(n,g)C13
Total radiative thermal neutron-capture cross section = 0.00387 b ± 3e-05
Reference: 2018MuZY
Maximum I = 0.0026389710000000004 b at E = 4945.301 keV; RI = 100.
      Type  i  f     E(i)     E(f)        E     dE         RI       dRI
 secondary  2  1  3684.480  3089.451   595.015  0.009    0.363985  0.015326
   primary  3  2  4946.311  3684.480  1261.765  0.009   47.509579  1.149512
   primary  3  1  4946.311  3089.451  1856.717  0.009    0.237548  0.015326
 secondary  1  0  3089.451     0.000  3089.057  0.009    0.632184  0.030652
 secondary  2  0  3684.480     0.000  3683.920  0.009   46.743295  1.149509
   primary  3  0  4946.311     0.000  4945.301  0.003  100.000000  1.915939
```

In [6]:
```
# Plot gamma-ray intensities from DataFrame
plot_df_data(df['E'], df['RI'], "{0}".format(compound_nucleus))
```

pyEGAF also displays associated level information.

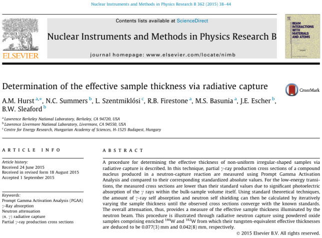
Attenuation in Prompt Gamma Activation Analysis

https://github.com/AaronMHurst/attenuation_integration

- `C++` implementation for calculating attenuation integrated over sample thickness (t):

$$\frac{I_\gamma}{I_0}\int_{x=0}^{x=t} dx = \int_{x=0}^{x=t} \exp\left(\frac{-\rho\left(\frac{\mu_\gamma}{\rho}\right)_{E_\gamma} x}{\cos\theta}\right) dx.$$

- Build project out-of-source with `CMake`.
- Finds unique solution for effective t corresponding to observed attenuation.
- Project bundled with mass-attenuation coefficients for 100 elements (H ($Z = 1$) to Fm ($Z = 100$)) taken from XMuDat.
- Interpolated energies from 1 keV to 20 MeV.
- Program can also be used to calculate simple attenuation for elemental (e.g., Re, La...) or stoichiometric compound (e.g., $ReCl_3$, $LaCl_3 \cdot 7H_2O$...) samples.



Nuclear Instruments and Methods in Physics Research B 362 (2015) 38–44

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Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Determination of the effective sample thickness via radiative capture

A.M. Hurst [a,*], N.C. Summers [b], L. Szentmiklósi [c], R.B. Firestone [a], M.S. Basunia [a], J.E. Escher [b], B.W. Sleaford [b]

[a] Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
[b] Lawrence Livermore National Laboratory, Livermore, CA 94550, USA
[c] Centre for Energy Research, Hungarian Academy of Sciences, H-1525 Budapest, Hungary

ARTICLE INFO

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Keywords:
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Neutron attenuation
(n, γ) radiative capture
Partial γ-ray production cross sections

ABSTRACT

A procedure for determining the effective thickness of non-uniform irregular-shaped samples via radiative capture is described. In this technique, partial γ-ray production cross sections of a compound nucleus produced in a neutron-capture reaction are measured using Prompt Gamma Activation Analysis and compared to their corresponding standardized absolute values. For the low-energy transitions, the measured cross sections are lower than their standard values due to significant photoelectric absorption of the γ rays within the bulk-sample volume itself. Using standard theoretical techniques, the amount of γ-ray self absorption and neutron self shielding can then be calculated by iteratively varying the sample thickness until the observed cross sections converge with the known standards. The overall attenuation, thus, provides a measure of the effective sample thickness illuminated by the neutron beam. This procedure is illustrated through radiative neutron capture using powdered oxide samples comprising enriched ^{186}W and ^{182}W from which their tungsten-equivalent effective thicknesses are deduced to be 0.077(3) mm and 0.042(8) mm, respectively.

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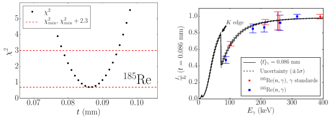
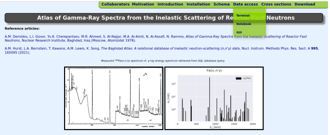


[D.A. Matters *el al.* PRC **93**, 054319 (2016)]

The *"Baghdad Atlas"*: Fast-reactor $(n, n'\gamma)$ database

https://nucleardata.berkeley.edu/atlas/

- Energy-integrated $(n, n'\gamma)$ data disseminated in book format.
- ~ 7000 γ rays $(E_\gamma, I_\gamma, E_L)$ from 105 samples: 76 natural and 29 enriched.
- Ge(Li) viewing filtered fast-neutron beam line at the IRT-M Reactor, NRI, Baghdad, Iraq.
- Unique ^{56}Fe 847-keV $2_1^+ \rightarrow 0_{gs}^+$ γ-ray normalization.
- Digitized database, open source dissemination.
- Downloadable `SQLite` platform built with `Makefile`.
- Enhanced mathematical functionality provided by shared-object library compiled from `C` module during build.
- Interact with data using `SQL` scripts or `Jupyter Notebook`.
- *Future: Deploy to GitHub and develop PyPI project.*



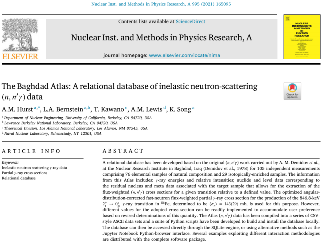
Atlas of Gamma-Ray Spectra from the Inelastic Scattering of Reactor Fast Neutrons

Reference articles:

A.M. Demidov, L.I. Govor, Yu.K. Cherepantsev, M.R. Ahmed, S. Al-Najjar, M.A. Al-Amili, N. Al-Assafi, N. Rammo, *Atlas of Gamma-Ray Spectra from the Inelastic Scattering of Reactor Fast Neutrons*, Nuclear Research Institute, Baghdad, Iraq (Moscow, Atomizdat 1978).

A.M. Hurst, L.A. Bernstein, T. Kawano, A.M. Lewis, K. Song, *The Baghdad Atlas: A relational database of inelastic neutron-scattering (n,n'γ) data*, Nucl. Instrum. Methods Phys. Res. Sect. A **995**, 165095 (2021).

Measured ^{nat}Fe(n,n'γ) spectrum cf. γ-ray energy spectrum retrieved from SQL database query



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The Baghdad Atlas: A relational database of inelastic neutron-scattering $(n, n'\gamma)$ data

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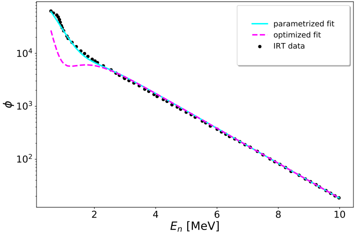
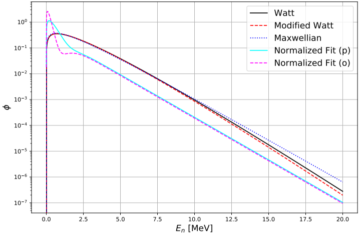
ABSTRACT

A relational database has been developed based on the original $(n, n'\gamma)$ work carried out by A. M. Demidov *et al.*, at the Nuclear Research Institute in Baghdad, Iraq (Demidov et al., 1978) for 105 independent measurements comprising 76 elemental samples of natural composition and 29 isotopically-enriched samples. The information from this Atlas includes: γ-ray energies and relative intensities; nuclide and level data corresponding to the residual nucleus and meta data associated with the target sample that allows for the extraction of the flux-weighted $(n, n'\gamma)$ cross sections for a given transition relative to a defined value. The optimized angular-distribution-corrected fast-neutron flux-weighted partial γ-ray cross section for the production of the 846.8-keV $2_1^+ \rightarrow 0_{gs}^+$ γ-ray transition in ^{56}Fe, determined to be $\langle\sigma_\gamma\rangle = 143(29)$ mb, is used for this purpose. However, different values for the adopted cross section can be readily implemented to accommodate user preference based on revised determinations of this quantity. The Atlas $(n, n'\gamma)$ data has been compiled into a series of CSV-style ASCII data sets and a suite of Python scripts have been developed to build and install the database locally. The database can then be accessed directly through the SQLite engine, or using alternative methods such as the Jupyter Notebook Python-browser interface. Several examples exploiting different interaction methodologies are distributed with the complete software package.

Flux at the Baghdad Research Reactor





Flux described by compound function:

$$\phi(E_n) = \text{Maxwellian}(E_n \ll 1.5) + \text{Exponential}(E_n \gg 1.5).$$

- Adjust kT in χ^2 minimization using ^{56}Fe data to optimize flux:

$$\chi^2 = (\boldsymbol{B_{Fe}} - \boldsymbol{B_{kT}})\boldsymbol{V}^{-1}(\widetilde{\boldsymbol{B_{Fe}}} - \widetilde{\boldsymbol{B_{kT}}}).$$

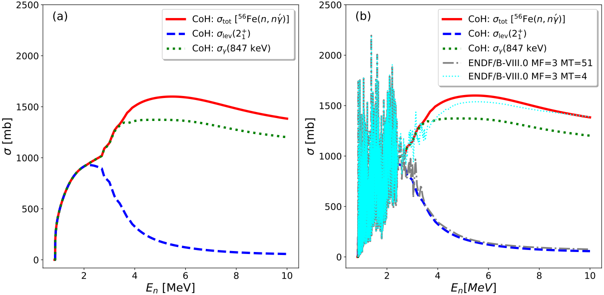
- ^{56}Fe data well reproduced for the three strongest transitions: $E_\gamma = 846.8, 1238.3, 1810.8$ keV.

Flux satisfies normalization condition:

$$\int_{-\infty}^{+\infty} \phi^*(E_n)\phi(E_n)dE_n = 1$$

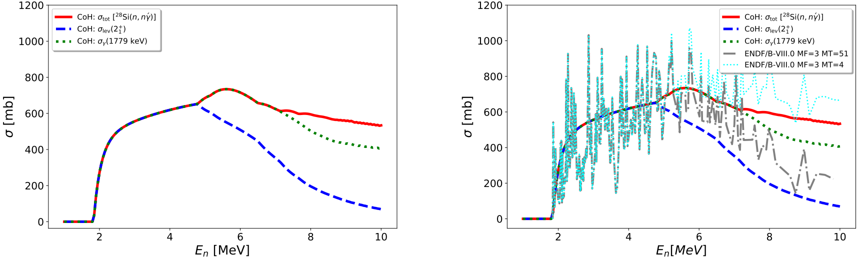
- Watt $\langle E_n \rangle = 2.00$ MeV.
- Modified Watt $\langle E_n \rangle = 1.98$ MeV.
- Maxwellian $\langle E_n \rangle = 1.94$ MeV.
- Parameterized IRT-M $\langle E_n \rangle = 0.88$ MeV.
- Optimized IRT-M $\langle E_n \rangle = 0.63$ MeV.

Convolution of flux with $^{56}\mathrm{Fe}(n, n'\gamma)$ reaction calculations and data libraries



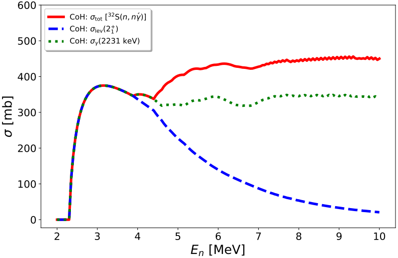
- Deduce flux-weighted averages for all graphed quantities for ^{56}Fe.
- Results indicate: $\frac{\langle\sigma_{\mathrm{lev}}^{\mathrm{CoH}}\rangle}{\langle\sigma_{\mathrm{tot}}^{\mathrm{CoH}}\rangle} \approx \frac{\langle\sigma_{\mathrm{lev}}^{\mathrm{ENDF}}\rangle}{\langle\sigma_{\mathrm{tot}}^{\mathrm{ENDF}}\rangle}$.
- Find $\langle\sigma_{\gamma}^{\mathrm{ENDF}}\rangle \approx \langle\sigma_{\mathrm{tot}}^{\mathrm{ENDF}}\rangle \frac{\langle\sigma_{\gamma}^{\mathrm{CoH}}\rangle}{\langle\sigma_{\mathrm{tot}}^{\mathrm{CoH}}\rangle}$.
- CoH calculation and ENDF are consistent for $^{56}\mathrm{Fe}(n, n'\gamma)$.

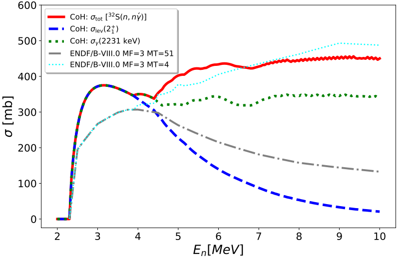
Validation using the flux: ^{28}Si$(n,n'\gamma)$; $E_\gamma = 1779$ keV



Source	$\langle\sigma_\gamma\rangle$ [mb]	$\langle\sigma_{\rm tot}\rangle$ [mb]	$\langle\sigma_{\rm lev}\rangle$ [mb]	$\frac{\langle\sigma_{\rm lev}\rangle}{\langle\sigma_{\rm tot}\rangle}$
CoH	55.69	55.84	53.45	0.957
ENDF	48.17	48.30	46.59	0.965
Baghdad Atlas	**47.1(94)**	—	—	—

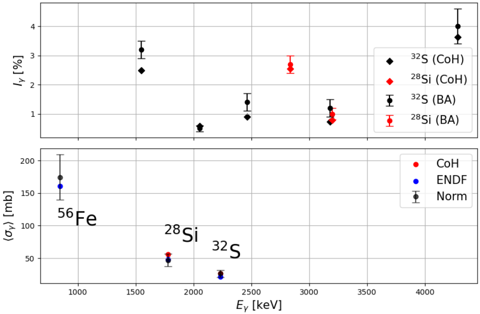
Validation using the flux: ^{32}S$(n, n'\gamma)$; $E_\gamma = 2231$ keV





Source	$\langle\sigma_\gamma\rangle$ [mb]	$\langle\sigma_{\mathrm{tot}}\rangle$ [mb]	$\langle\sigma_{\mathrm{lev}}\rangle$ [mb]	$\frac{\langle\sigma_{\mathrm{lev}}\rangle}{\langle\sigma_{\mathrm{tot}}\rangle}$
CoH	26.57	27.91	23.95	0.858
ENDF	21.67	22.76	19.98	0.878
Baghdad Atlas	**26.3(53)**	—	—	—

Reproduction of known data in ^{56}Fe, ^{32}S, and ^{28}Si using the flux



- Absolute flux-weighted quantities from CoH and ENDF reproduce known absolute I_γ data in the Baghdad Atlas.
- Explore additional isotopes covering broader energy range.

Neutron flux at the Baghdad Research IRT-M Reactor is *well characterized* in region $0.862 \leq E_n \leq 5.0$ MeV.

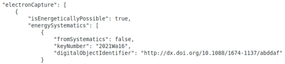
BEApR: BErkeley Alpha and proton Radioactivity

https://nucleardata.berkeley.edu/research/betap.html

BEApR: BErkeley Alpha and proton Radioactivity

The **"BEApR" database** is a global heavy charged-particle database arranged by algebraic isospin projection, as well as charge and mass, for proton-rich nuclides that undergo direct proton- or α-decay, in addition to β^+ delayed charged-particle emission. This is an ongoing activity with a dedicated website that gets regularly updated.

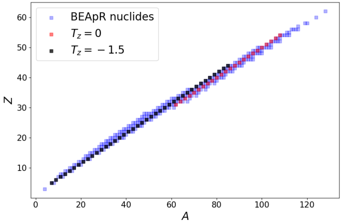
- Led by J.C. Batchelder.
- Work in progress: Downloadable PDFs $-4 \leq T_Z \leq +19$.
- Arranged by T_z and Z/A.
- JSON format developed.
- Python project development underway.
- Built up from *many* source datasets, e.g.,

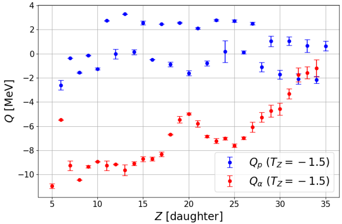


```
"electronCapture": [
    {
        "isEnergeticallyPossible": true,
        "energySystematics": [
            {
                "fromSystematics": false,
                "keyNumber": "2021Wa16",
                "digitalObjectIdentifier": "http://dx.doi.org/10.1088/1674-1137/abddaf"
            }
```

^{39}Ca ϵ decay

[2021Wa16]: M. Wang, W.J. Huang, F.G. Kondev, G. Audi, S. Naimi, *"The AME 2020 atomic mass evaluation"*, Chin. Phys. C 45, 030003 (2021).



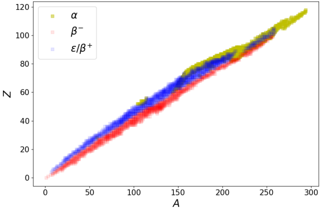


Open-source Python library paceENSDF on GitHub

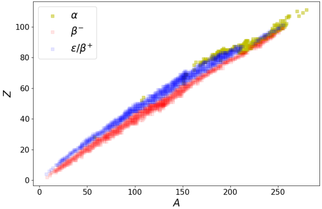
`https://github.com/AaronMHurst/pace_ensdf`

- *Python Archive of Coincident Emissions from ENSDF*.
- Translated 3254 ENSDF-decay datasets to `JSON` format.
- Converted each ENSDF-decay dataset into RIPL format.
- Generated 2394 `JSON`-formatted coincidence datasets, i.e., only those containing γ rays.
- Developed suite of Python modules enabling interaction, analysis, and visualization of the **ENSDF-decay** data and derived **coincidence** $\gamma - \gamma$ and $\gamma - X$-ray data.
- Docstrings provided for all methods.
- JSON schema keys documented extensively in `README`.
- 283 unit tests (multiple virtual `Python3` environments).
- Installation, testing scripts, and `Jupyter Notebooks`.
- `JSON` and `RIPL` files bundled with software.
- Over 2500 downloads.

ENSDF decay (all)



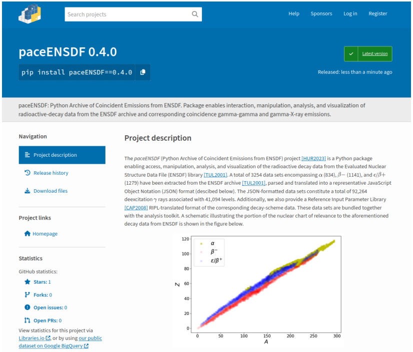
ENSDF decay (with γ data)



`git clone https://github.com/AaronMHurst/pace_ensdf.git`

paceENSDF on the Python Package Index (PyPI) repository

https://pypi.org/project/paceENSDF



paceENSDF 0.4.0

`pip install paceENSDF==0.4.0`

Released: less than a minute ago

paceENSDF: Python Archive of Coincident Emissions from ENSDF. Package enables interaction, manipulation, analysis, and visualization of radioactive-decay data from the ENSDF archive and corresponding coincidence gamma-gamma and gamma-X-ray emissions.

GitHub statistics:
Stars: 1
Forks: 0
Open issues: 0
Open PRs: 0

View statistics for this project via Libraries.io, or by using our public dataset on Google BigQuery

Project description

The *paceENSDF* (Python Archive of Coincident Emissions from ENSDF) project [HUR2023] is a Python package enabling access, manipulation, analysis, and visualization of the radioactive decay data from the Evaluated Nuclear Structure Data File (ENSDF) library [TUL2001]. A total of 3254 data sets encompassing α (834), $\beta-$ (1141), and $\epsilon/\beta+$ (1279) have been extracted from the ENSDF archive [TUL2001], parsed and translated into a representative JavaScript Object Notation (JSON) format (descibed below). The JSON-formatted data sets constitute a total of 92,264 deexcitation γ rays associated with 41,094 levels. Additionally, we also provide a Reference Input Parameter Library [CAP2008] RIPL-translated format of the corresponding decay-scheme data. These data sets are bundled together with the analysis toolkit. A schematic illustrating the portion of the nuclear chart of relevance to the aforementioned decay data from ENSDF is shown in the figure below.

- `pip install paceENSDF`
- FreeBSD License

EPJ Web of Conferences **284**, 18002 (2023) https://doi.org/10.1051/epjconf/202328418002
ND2022

A decay database of coincident $\gamma-\gamma$ and $\gamma-X$-ray branching ratios for in-field spectroscopy applications

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[2]Pacific Northwest National Laboratory, Richland, Washington, 99352, USA
[3]Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California, 94720, USA

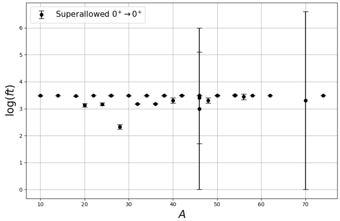
Abstract. Current fieldable spectroscopy techniques often use single detector systems heavily impacted by interferences from intense background radiation fields. These effects result in low-confidence measurements that can lead to misinterpretation of the collected spectrum. To help improve interpretation of the fission products and short-lived radionuclides produced in a composite sample, a coincidence-γ database is being developed in support of a robust portable γ and X-ray coincidence detector system concurrently under development at the Pacific Northwest National Laboratory for in-field deployment. Hitherto, no database exists containing coincident $\gamma-\gamma$ and $\gamma-X$-ray branching-ratio intensities on an absolute scale that will greatly enhance isotopic identification for in-field applications. As part of this project, software has been developed to parse all radioactive-decay data sets from the Evaluated Nuclear Structure Data File (ENSDF) archive to enable translation into a more useful JavaScript Object Notation (JSON) formats that more readily supports query-based data manipulation. The coincident database described in this work is the first of its kind and contains coincidence $\gamma-\gamma$ and $\gamma-X$-ray intensities and their corresponding uncertainties, together with auxiliary metadata associated with each decay data set. The new JSON format provides a convenient and portable means of data storage that can be imported into analysis frameworks with relatively low overhead allowing for meaningful comparison with measured data.

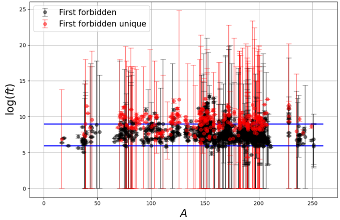
Querying the ENSDF data

Superallowed transitions in ϵ/β^+ and first-forbidden transitions in β^- decay

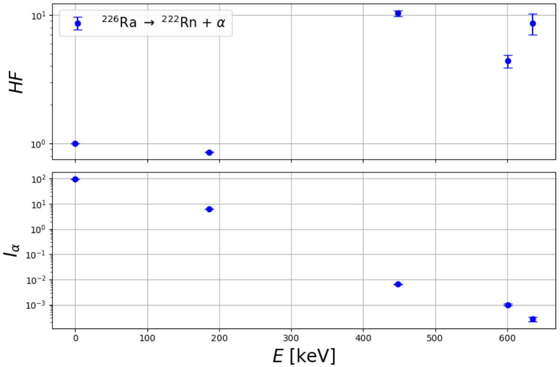
Transition	$\log(ft)$	l
SA	3.5	0
A	4 – 7.5	0
1^{st} F	6 – 9	1
2^{nd} F	10 – 13	2
3^{rd} F	14 – 20	3
4^{th} F	≈ 23	4

- Angular momentum selection rules for **firm** J^π assignments.
- Examine trends and anomalies.





Hindrance factors in α decay



- Low-lying levels populated in α decay of ^{226}Ra $\rightarrow$ ^{222}Rn.
- Variance and correlation between I_α and hindrance factors.
- Negative correlation.

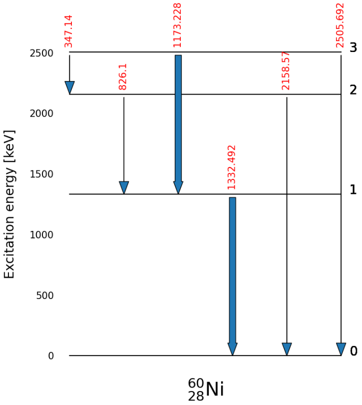
$$V = \begin{pmatrix} 14.91 & -80.80 \\ -80.80 & 1368.72 \end{pmatrix}$$

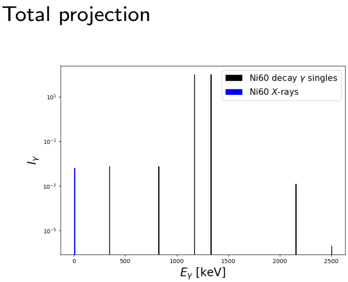
$$C = \begin{pmatrix} 1 & -0.57 \\ -0.57 & 1 \end{pmatrix}$$

Delayed γ-ray emission from radioactive compounds

Example: $^{59}\mathrm{Co}(n,\gamma)^{60}\mathrm{Co} \rightarrow {}^{60}\mathrm{Ni} + \beta^{-}$ [$T_{1/2} = 1925.28(14)$ d]

Delayed γ rays observed in ^{60}Ni some time after n-interrogation of ^{59}Co: Activation signatures from paceENSDF (*Python Archive of Coincident Emissions from ENSDF*).





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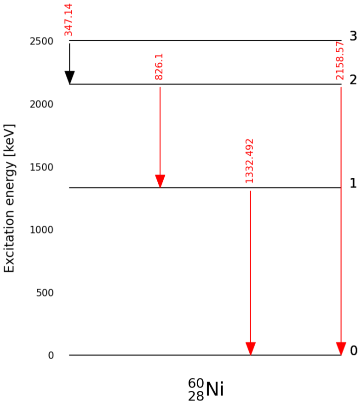
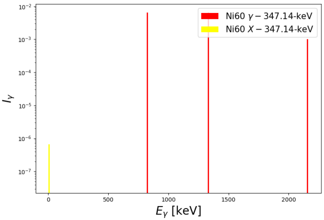


Gate on 3 → 2 transition (347 keV)



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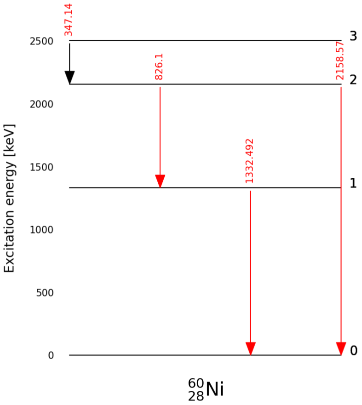
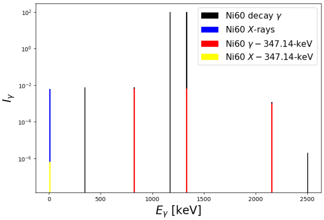
Example: $^{59}\text{Co}(n,\gamma)^{60}\text{Co} \rightarrow {}^{60}\text{Ni} + \beta^-$ $[T_{1/2} = 1925.28(14)$ d$]$

Delayed γ rays observed in ^{60}Ni some time after *n*-interrogation of ^{59}Co: Activation signatures from paceENSDF (*Python Archive of Coincident Emissions from ENSDF*).

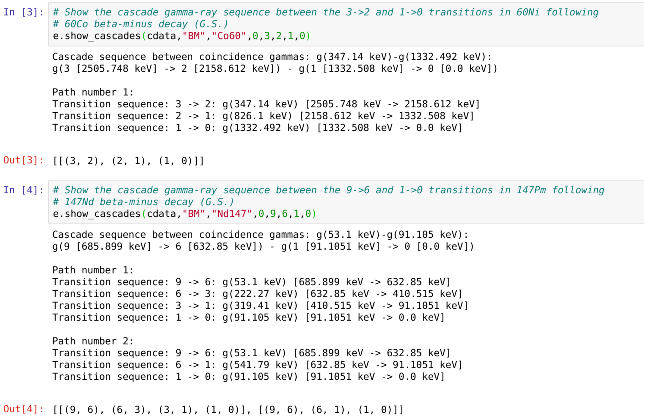


"Before" and *"after"*



Parallel paths in γ-ray cascades

```
>>> help(e.show_cascades)
```

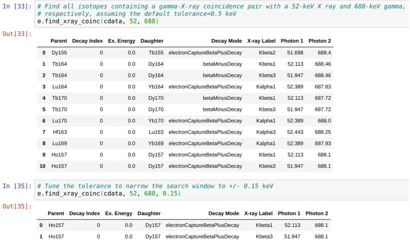


```
In [3]: # Show the cascade gamma-ray sequence between the 3->2 and 1->0 transitions in 60Ni following
        # 60Co beta-minus decay (G.S.)
        e.show_cascades(cdata,"BM","Co60",0,3,2,1,0)

        Cascade sequence between coincidence gammas: g(347.14 keV)-g(1332.492 keV):
        g(3 [2505.748 keV] -> 2 [2158.612 keV]) - g(1 [1332.508 keV] -> 0 [0.0 keV])

        Path number 1:
        Transition sequence: 3 -> 2: g(347.14 keV) [2505.748 keV -> 2158.612 keV]
        Transition sequence: 2 -> 1: g(826.1 keV) [2158.612 keV -> 1332.508 keV]
        Transition sequence: 1 -> 0: g(1332.492 keV) [1332.508 keV -> 0.0 keV]

Out[3]: [[(3, 2), (2, 1), (1, 0)]]

In [4]: # Show the cascade gamma-ray sequence between the 9->6 and 1->0 transitions in 147Pm following
        # 147Nd beta-minus decay (G.S.)
        e.show_cascades(cdata,"BM","Nd147",0,9,6,1,0)

        Cascade sequence between coincidence gammas: g(53.1 keV)-g(91.105 keV):
        g(9 [685.899 keV] -> 6 [632.85 keV]) - g(1 [91.1051 keV] -> 0 [0.0 keV])

        Path number 1:
        Transition sequence: 9 -> 6: g(53.1 keV) [685.899 keV -> 632.85 keV]
        Transition sequence: 6 -> 3: g(222.27 keV) [632.85 keV -> 410.515 keV]
        Transition sequence: 3 -> 1: g(319.41 keV) [410.515 keV -> 91.1051 keV]
        Transition sequence: 1 -> 0: g(91.105 keV) [91.1051 keV -> 0.0 keV]

        Path number 2:
        Transition sequence: 9 -> 6: g(53.1 keV) [685.899 keV -> 632.85 keV]
        Transition sequence: 6 -> 1: g(541.79 keV) [632.85 keV -> 91.1051 keV]
        Transition sequence: 1 -> 0: g(91.105 keV) [91.1051 keV -> 0.0 keV]

Out[4]: [[(9, 6), (6, 3), (3, 1), (1, 0)], [(9, 6), (6, 1), (1, 0)]]
```

Allows for γ-ray cascade reconstruction and re-calculation of coincidence intensities if required.

Forensics applications: Search for $\gamma-\gamma$ and $\gamma-X$-ray pairs

$\gamma-X$-ray search



In [33]:
```
# Find all isotopes containing a gamma-X-ray coincidence pair with a 52-keV X ray and 688-keV gamma,
# respectively, assuming the default tolerance=0.5 keV
e.find_xray_coinc(cdata, 52, 688)
```

Out[33]:

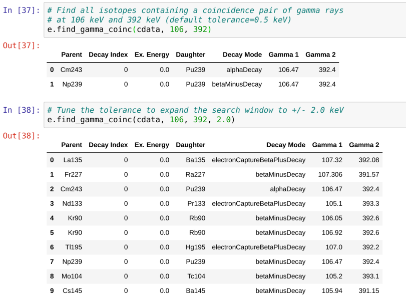
	Parent	Decay Index	Ex. Energy	Daughter	Decay Mode	X-ray Label	Photon 1	Photon 2
0	Dy155	0	0.0	Tb155	electronCaptureBetaPlusDecay	Kbeta2	51.698	688.4
1	Tb164	0	0.0	Dy164	betaMinusDecay	Kbeta1	52.113	688.46
2	Tb164	0	0.0	Dy164	betaMinusDecay	Kbeta3	51.947	688.46
3	Lu164	0	0.0	Yb164	electronCaptureBetaPlusDecay	Kalpha1	52.389	687.83
4	Tb170	0	0.0	Dy170	betaMinusDecay	Kbeta1	52.113	687.72
5	Tb170	0	0.0	Dy170	betaMinusDecay	Kbeta3	51.947	687.72
6	Lu170	0	0.0	Yb170	electronCaptureBetaPlusDecay	Kalpha1	52.389	688.0
7	Hf163	0	0.0	Lu163	electronCaptureBetaPlusDecay	Kalpha3	52.443	688.25
8	Lu169	0	0.0	Yb169	electronCaptureBetaPlusDecay	Kalpha1	52.389	687.93
9	Ho157	0	0.0	Dy157	electronCaptureBetaPlusDecay	Kbeta1	52.113	688.1
10	Ho157	0	0.0	Dy157	electronCaptureBetaPlusDecay	Kbeta3	51.947	688.1

In [35]:
```
# Tune the tolerance to narrow the search window to +/- 0.15 keV
e.find_xray_coinc(cdata, 52, 688, 0.15)
```

Out[35]:

	Parent	Decay Index	Ex. Energy	Daughter	Decay Mode	X-ray Label	Photon 1	Photon 2
0	Ho157	0	0.0	Dy157	electronCaptureBetaPlusDecay	Kbeta1	52.113	688.1
1	Ho157	0	0.0	Dy157	electronCaptureBetaPlusDecay	Kbeta3	51.947	688.1

$\gamma-\gamma$ search



In [37]:
```
# Find all isotopes containing a coincidence pair of gamma rays
# at 106 keV and 392 keV (default tolerance=0.5 keV)
e.find_gamma_coinc(cdata, 106, 392)
```

Out[37]:

	Parent	Decay Index	Ex. Energy	Daughter	Decay Mode	Gamma 1	Gamma 2
0	Cm243	0	0.0	Pu239	alphaDecay	106.47	392.4
1	Np239	0	0.0	Pu239	betaMinusDecay	106.47	392.4

In [38]:
```
# Tune the tolerance to expand the search window to +/- 2.0 keV
e.find_gamma_coinc(cdata, 106, 392, 2.0)
```

Out[38]:

	Parent	Decay Index	Ex. Energy	Daughter	Decay Mode	Gamma 1	Gamma 2
0	La135	0	0.0	Ba135	electronCaptureBetaPlusDecay	107.32	392.08
1	Fr227	0	0.0	Ra227	betaMinusDecay	107.306	391.57
2	Cm243	0	0.0	Pu239	alphaDecay	106.47	392.4
3	Nd133	0	0.0	Pr133	electronCaptureBetaPlusDecay	105.1	393.3
4	Kr90	0	0.0	Rb90	betaMinusDecay	106.05	392.6
5	Kr90	0	0.0	Rb90	betaMinusDecay	106.92	392.6
6	Tl195	0	0.0	Hg195	electronCaptureBetaPlusDecay	107.0	392.2
7	Np239	0	0.0	Pu239	betaMinusDecay	106.47	392.4
8	Mo104	0	0.0	Tc104	betaMinusDecay	105.2	393.1
9	Cs145	0	0.0	Ba145	betaMinusDecay	105.94	391.15

Search methods for single γ rays and X rays also implemented in addition to $\gamma-\gamma$ and $\gamma-X$-ray pairs.

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