Photon Strength Function and Nuclear Level Density Databases

Work done under the Quasi-continuum Nuclear Data Evaluator Traineeship

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US Nuclear Data Program Annual Meeting, Oct 28 – 31, 2025

Experience in experimental Nuclear Physics

Nuclear data measurements for basic sciences: nucleosynthesis and nuclear structure [1,2]

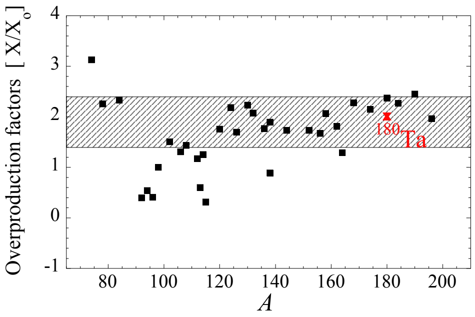
Development of nuclear physics facilities: Low-energy nuclear physics beam-line

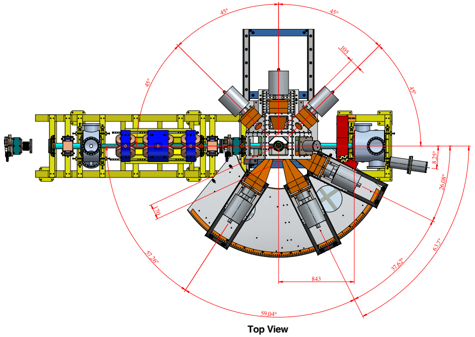
- ✓ Radiative (p,γ) and (α,γ) capture for PSF measurements
- ✓ Angular distribution

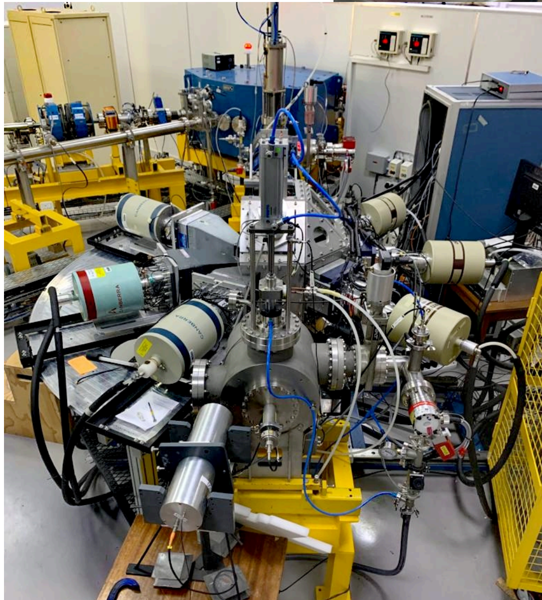
Maintenance of Compton suppressed HPGe CLOVER detectors

and associated electronics.

Interests: Nuclear data and Experimental Nuclear Physics







[1] Brits, *et al.*, Phys. Rev. **C** 99, 054330 (2019)
[2] Malatji, *et al.*, Phys. Lett. **B** 791, 403-408 (2019), Phys. Rev. **C** 103, 014309 (2021)

Photon Strength Function Database

2013: Consultancy ’s meeting at IAEA with recommendation on PSF database
2016-2019: IAEA Coordinated Research Project
Photonuclear Data and Photon Strength Functions F41032

https://www-nds.iaea.org/PSFdatabase/

Eur. Phys. J. A (2019) **55**: 172
DOI 10.1140/epja/i2019-12840-1

THE EUROPEAN PHYSICAL JOURNAL A

Review

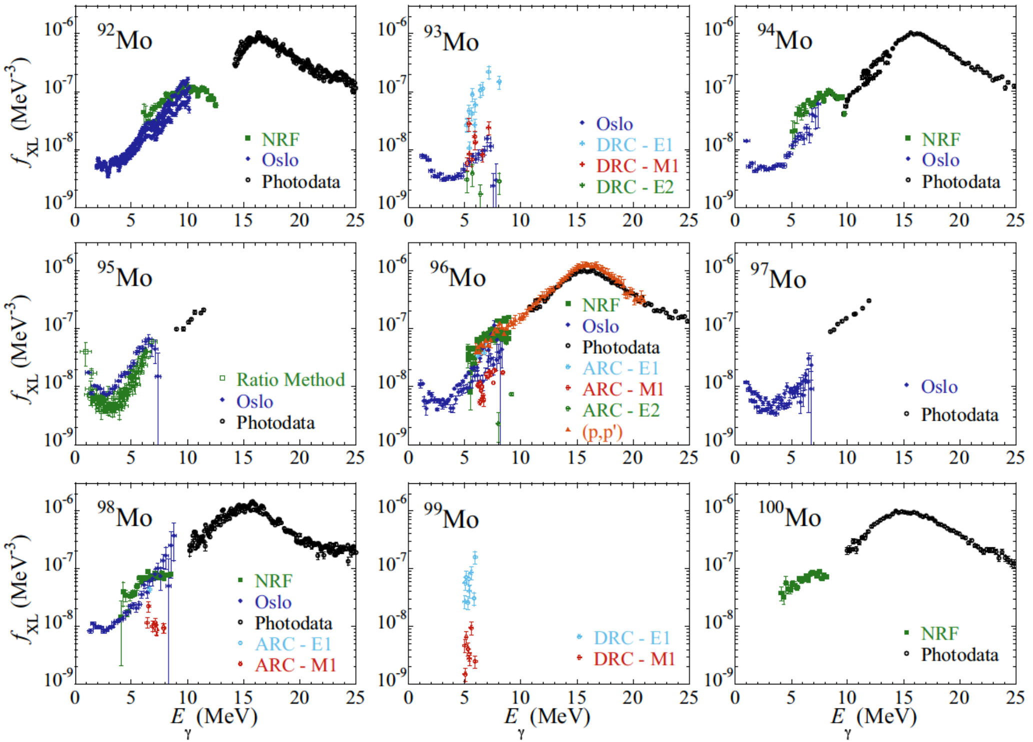
Reference database for photon strength functions

S. Goriely[1], P. Dimitriou[2,a], M. Wiedeking[3], T. Belgya[4], R. Firestone[5], J. Kopecky[6], M. Krtička[7], V. Plujko[8], R. Schwengner[9], S. Siem[10], H. Utsunomiya[11], S. Hilaire[12], S. Péru[12], Y.S. Cho[13], D.M. Filipescu[14], N. Iwamoto[15], T. Kawano[16], V. Varlamov[17], and R. Xu[18]

IAEA Coordinated Research Project on Updating Nuclear Level Densities for Applications F41034, **2024-2028**

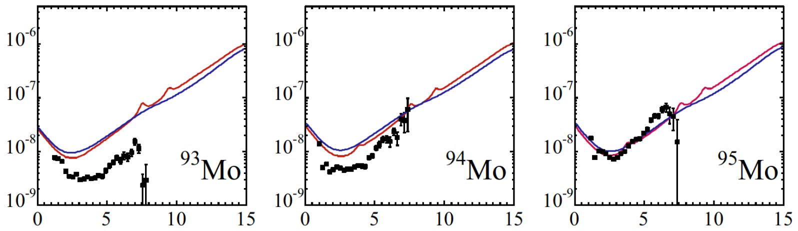
Data updated annually as of 2024

NLD & PSF: Why should we care?



Goriely, Dimitriou, Wiedeking et al., Eur. Phys. J A 55, 172 (2019)

- Data is important for applications and basic sciences.
- No single Exp. technique can accurately measure NLD and/or PSF across the entire range of energies.
- Some inconsistencies (Experiments, Theory)
- Data needs to compiled, accessed and recommended where possible.
- Validation of the theoretical PSF.



Models: Semi-microscopic **D1M-QRPA** and phenomenological **E1 & M1 SMLO**

NLD & PSF: How are these data measured?

Techniques for NLD

Primary γ spectra with the Oslo methods (Ex < Sn)

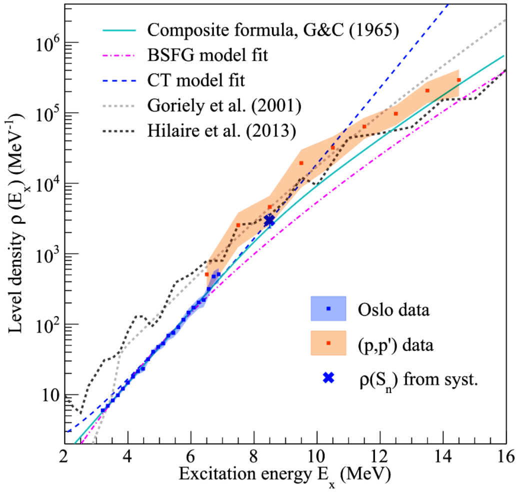
Spin/parity resolved level densities from (p,p´) or (e,e´)

Discrete levels (Ex < 2 - 3 MeV or < 50 - 100 levels/MeV)

Neutron/proton resonances (Ex = Sn or Sp)

Particle evaporation spectra (Ex = 4 - 15 MeV)

Ericson fluctuations (Ex ~ 15 MeV)



Markova, Larsen, von Neumann-Cosel, et al., Phys. Rev. C 106, 034322 (2022)

Techniques for PSF

Oslo, beta-Oslo, inverse Oslo Methods ($<S_n$)

Ratio/Shape Methods ($<S_n$)

Nuclear Resonance Fluorescence ($<S_n$)

Inelastic p scattering with polarized beam ($<S_n$ and $>S_n$)

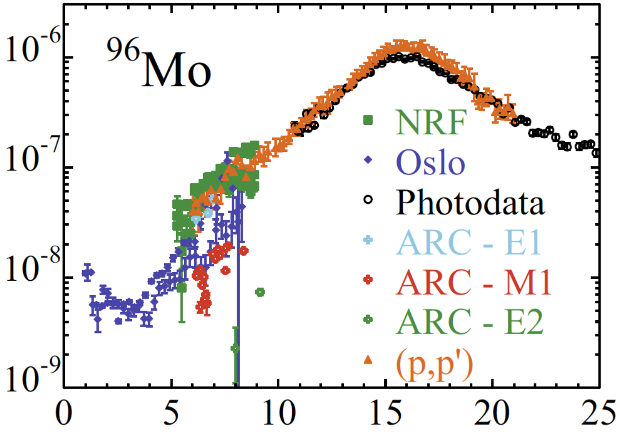
Primaries from p-capture ($>S_p$ and $<S_n$)

Primaries from charged particle reactions ($<S_n$)

Two-step cascade, n/p capture ($<S_n$)

Photonuclear Reactions ($>S_n$)

Primaries from n-capture ($>S_n$)



Goriely, Dimitriou, Wiedeking et al., Eur. Phys. J A 55, 172 (2019)

Data in the PSF database 2024

Experimental data:
324 unique nuclides (1071 datafiles) for all experimental methods

154 nuclides	Z = 2-94	(337 files)	Photonuclear
103 nuclides	Z = 21-94	(133 files)	**Oslo Methods**
58 nuclides	Z = 9-90	(137 files)	Thermal neutron capture
63 nuclides	Z = 9-94	(115 files)	Absolute Photonuclear
54 nuclides	Z = 33-94	(123 files)	Average Resonance Capture
52 nuclides	Z = 9-94	(99 files)	Discrete Resonance Capture
27 nuclides	Z = 26-82	(34 files)	**Nuclear Resonance Fluorescence**
22 nuclides	Z = 22-40	(37 files)	**Proton capture**
11 nuclides	Z = 26-66	(31 files)	**Ratio and Shape Method**
8 nuclides	Z = 42-82	(25 files)	**Proton scattering**

Theoretical
Two models validated and recommended to perform global calculations of
E1 and M1 PSFs for all nuclides across the nuclear chart: D1M-QRPA and SMLO.

PSF database 2025 Update

Added assessed data for 34 nuclei:

^{51}Ti: 2 files, bOM, OM
^{56,57,58,60}Fe: 22 files, bOM, OM, SM
^{59}Co: 1 file, NRF
^{67}Ni: 1 files, iOM
^{66}Zn: 1 file, NRF
^{76}Ge: 1 file, SM
^{88}Kr: 2 files, bOM, SM
^{111,112,113,114,116,117,118,119,120,122,124}Sn: 7 files, OM
^{128,130}Te: 5 files, OM, NRF
^{140}Ba: 1 file, bOM
^{147,149}Sm: 2 files, OM
^{161,162,163,164}Dy: 4 files, OM
^{186}W: 1 file, OM
^{195}Pt: 1 file, OM
^{198}Au: 2 files, OM
^{239}U: 1 file, OM

Additional new isotopes to each method

5 nuclides	OM
4 nuclides	bOM
3 nuclides	SM
1 nuclides	iOM
1 nuclides	NRF

53 new data files and
53 new readme files

Corrected previously published files: 20
Change file labels: 528

Sent to IAEA for dissemination (Dec 2025)

PSF database format

Data File

```
# f1_exp_026_056_OM_1.dat
#
# Z = 26, A = 56
# No. of entries: 74
# Col 1: photon energy E in MeV
# Col 2: bin width dE in MeV
# Col 3: dipole strength f1 in MeV^-3
# Col 4: uncertainty df1 in MeV^-3
# Format: 2f10.3, 2e12.3
# Author: A. C. Larsen et al., J. Phys. G: Nucl. Part. Phys. 44, 064005
(2017)
# Compiler: K.L Malatji, T.A. Laplace, M. Wiedeking and V.W. Ingeberg
#     E         dE        f1          df1
    2.119     0.124     2.910e-08   1.345e-09
    2.244     0.124     2.291e-08   1.256e-09
    2.368     0.124     1.894e-08   1.125e-09
    2.491     0.124     1.127e-08   8.272e-10
    2.615     0.124     2.245e-08   9.846e-10
    2.740     0.124     1.802e-08   9.124e-10
    2.864     0.124     1.497e-08   7.458e-10
    2.987     0.124     1.400e-08   6.710e-10
    3.111     0.124     1.286e-08   6.331e-10
    3.236     0.124     1.751e-08   6.753e-10
    3.360     0.124     1.277e-08   6.481e-10
    3.483     0.124     1.524e-08   7.051e-10
    3.607     0.124     1.227e-08   6.104e-10
    3.732     0.124     8.691e-09   5.142e-10
    3.856     0.124     1.168e-08   4.962e-10
    3.979     0.124     8.796e-09   5.114e-10
    4.104     0.124     9.851e-09   4.653e-10
    4.228     0.124     1.048e-08   5.700e-10
    4.351     0.124     1.130e-08   5.168e-10
```

Investigate ways to make data machine readable

Readme File

```
# f1_NLD_exp_026_056_OM_1.readme
#
# Data were published by A. C. Larsen et al., J. Phys. G: Nucl. Part. Phys. 44, 064005 (2017)
#
# Reaction 56Fe(p,p)56Fe with beam energy 16.0 MeV
# at Oslo Cyclotron Laboratory (OCL).
#
# Particle - gamma coincidences were measured in CACTUS/SiRi and the
# resulting coincidence spectra was unfolded [M. Guttormsen et al. NIM Phys. Res. A 374, 371 (1996)]
# with the response of CACTUS.
# The first generation matrix is then found using an iterative
# method [M. Guttormsen et al., NIM Phys. Res. A 255, 518 (1987)]
#
# The functional shape of the level density and the gamma-ray transition coefficient
# is extracted from the first generation matrix using a chi-square
# minimalization method [A. Schiller et al., NIM Phys. Res. A 447, 498 (2000)].
#
# Data taken with LaBr3:Ce (From HECTOR, Uni. Milano)
#
# Absolute value of the level density and transmission coefficient is
# found by normalization to known values.
#
# The level density is normalized to:
#       (i) The level density at the neutron separation energy.
#       (ii) Known discrete levels at low energy.
#
# The transmission coefficients are normalized with the process
# described in [A. Voinov et al., Phys. Rev. C 63, 044313 (2001)]
#
#
# Inputs used for the normalization:
#       (i) Spin cutoff model of [T. von Egidy and D. Bucurescu, Phys. Rev. C 80, 054310 (2009)]
#       (ii) Level density at the neutron separation energy
#               rho(Sn) = 2.180e+03 ± 5.900e+02 1/MeV is found using
#               the neutron resonance spacing D0 = 3.36 ± 1.24 keV
#               estimated from systematics (see publication for more details).
#       (iii) Average radiative width <Gg0> = 1900.0 ± 600.0 meV
#               estimated from systematics (see publication for more details).
#
# The reaction will populate primarily the quasi-continuum
# such that most transitions are assumed to be dipole, such
# that the dipole strength is found by f1(Eg) = T(Eg)/(2*pi*Eg**3).
#
#
#
# The uncertainties of the resulting level density
# and photon strength function are statistical errors only.
```

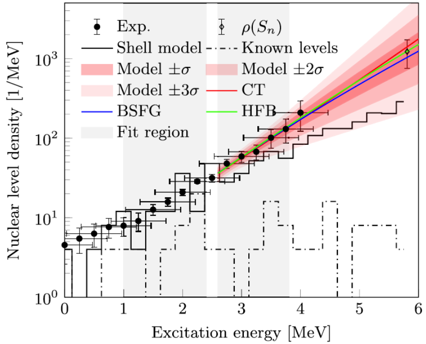
Challenges in Data Compilation, Assessment, and Outlier Analysis

OM: Assign quality indicator as a measure of reliability since the method is changing over time

- Criteria for assigning Quality Indicators

A	Z	Residual	Target	projectile	ejectile	Ebeam	PSF_ref	Full experimental uncertainties	Full model uncertainties	D02	Gg	Shape Method	After March 2014	Quality indicator 1 to 5
44	21	Sc	Sc	3he	a	38.0	A. C. Larsen et al	no	No	Yes	No	No	no	1
45	21	Sc	Sc	3he	3he	38.0	A. C. Larsen et al	no	No	Yes	No	No	no	1
43	21	Sc	46Ti	a	p	32.0	A. Bürger et al., P	no	No	Yes	No	No	no	1
46	22	Ti	Ti	p	p	15.0	M. Guttormsen e	yes	no	no	no	No	no	1
46	22	Ti	Ti	p	p	15.0	M. Guttormsen e	yes	no	no	no	No	no	1
46	22	Ti	Ti	p	p	15.0	M. Guttormsen e	yes	no	no	no	No	no	1
44	22	Ti	Ti	p	t	32.0	A. C. Larsen et al	no	Yes	no	no	No	no	2
44	22	Ti	Ti	p	t	32.0	A. C. Larsen et al	no	Yes	no	no	No	no	2
51	22	Ti	Ti	p	d	12.5	Liddick et al, Phy	Yes	No	yes	yes	no	yes	4
51	22	Ti				0	Liddick et al, Phy	no	no	yes	yes	no	yes	3
50	23	V	V	3he	a	30.0	A. C. Larsen et al	no	no	no	no	no	no	1
51	23	V	V	3he	3he	30.0	A. C. Larsen et al	no	no	Yes	Yes	no	no	1
56	26	Fe	Fe	3he	a	45.0	A. Voinov et al.,	no	No	No	No	no	no	1
57	26	Fe	Fe	3he	3he	45.0	A. Voinov et al.,	no	No	Yes	Yes	no	no	1
56	26	Fe	Fe	3he	a	45.0	E. Algin et al., Ph	no	No	No	No	no	no	1
57	26	Fe	Fe	3he	3he	45.0	E. Algin et al., Ph	no	No	Yes	Yes	no	no	1
56	26	Fe	Fe	p	p	16.0	A. C. Larsen et al	no	No	No	No	no	yes	2
56	26	Fe	Fe	p	p	16.0	A. C. Larsen et al	no	No	Yes	Yes	no	yes	2
56	26	Fe	Fe	p	p	16.0	A. C. Larsen et al	yes	Yes	No	No	no	yes	3
57	26	Fe	Fe	p	p	16.0	A. C. Larsen et al	yes	Yes	Yes	Yes	no	yes	4
58	26	Fe	d	Fe	Fe	7.5/u	A. D. Abbott et a	yes	No	yes	yes	yes	yes	5
60	26	Fe					A. Spyrou et al., l	yes	No	No	No	No	Yes	2
64	28	Ni	Ni	p	p	16.0	L. Crespo Campo	yes	Yes	No	no	no	yes	3

Bayesian analysis (unavailability of exp. D_0 & Γ_γ)



V. W. Ingeberg et al., Phys. Rev. C 111, 015803 (2025)

Induced Uncertainties from Digitized Data:

- Small error bars
- Overlapping points
- Line tracing errors

Systematics for normalization? In some cases missing from publication

Outlier Analysis (See next talk: **T. Laplace**)

PSF

Home Search Data Atlas

Photon Strength Function Database

Experimental data

The Photon Strength Function (PSF) Database contains all the experimental PSF data that were compiled by the IAEA Coordinated Research Project (CRP) on Generating a Reference Database for Photon Strength Functions. The methods that have been used to extract experimental PSF data are extensively described and assessed in the CRP technical report that is published in [1], and in the recent IAEA reports [2], [3], and [4]. The data files naming convention is self-explanatory and includes: the type and multipolarity of the PSF **XL={E1|E2|M1|1}** (1 stands for E1+M1), if it is **experimental or theoretical** data, **nuclide (Z,A)**, method used: **NRF, OM, ARC/DRC, PG, PP, RM, PHOTONUCLEAR**, and the NSR keynumber is added for photonuclear data. For detailed definitions, please refer to our Glossary page.

Each data file is accompanied by a **README file** with the same naming convention but with the extension `readme`. The README file contains all the information about the measurement, the experimental method, the model dependent analysis and parameters, as well as the reference.

Query the database

You can easily search the database using any combination of the available options: **Z, A, XL, Method, Energy**. A plot will be produced automatically based on your query. To retrieve the entire database, simply click the search button without applying any filters.

Search database

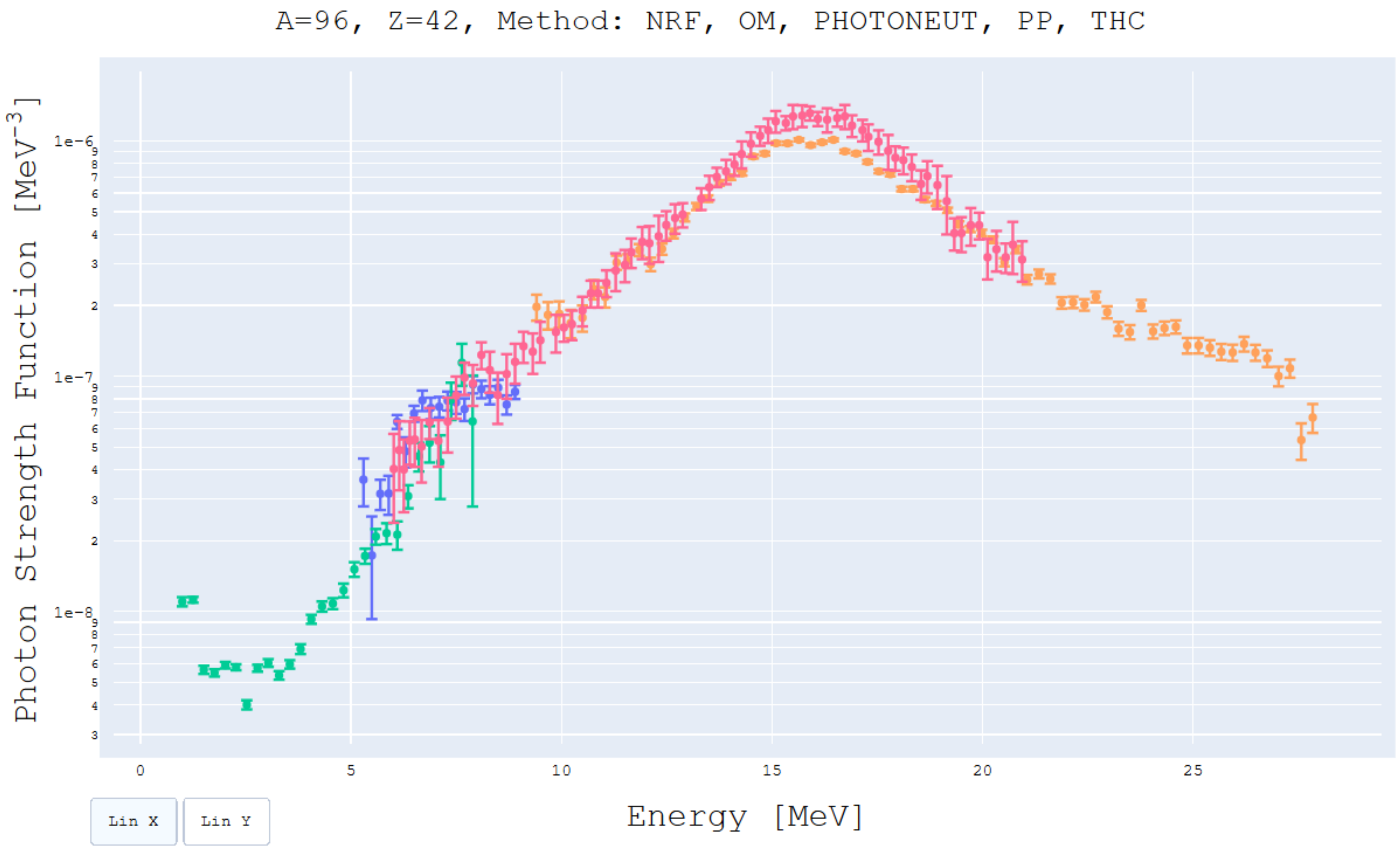
Download the database

You can download the latest version of the PSF Database in compressed format:

Download database

Version v2024.1 - released on the 1st of November, 2024

1,130 Data Files | 47,683 Data Points



A=96, Z=42, Method: NRF, OM, PHOTONEUT, PP, THC
Photon Strength Function [MeV^-3]
1e-6
1e-7
1e-8
0
5
10
15
20
25
Energy [MeV]
Lin X
Lin Y

Theoretical data

Theoretical PSF data recommended by the IAEA CRP on Reference Database for Photon Strength Functions are also available for downloading. These theoretical PSFs were validated according to the CRP prescription [1].

Two global models have been used to perform global calculations of E1 and M1 PSFs for all nuclides across the nuclear chart: the **D1M-QRPA** and **SMLO**. Details about the models and calculations are available in [1], [2], and [3].

The files contain PSFs in units of [MeV-3] at various excitation energies U (QRPA files) or temperature T (SMLO files) so that they can be used for de-excitation processes. Note that for photoabsorption, U=0 or T=0, while for de-excitation the user needs to use the relation: $U=aT^2$ with a=A/10.

Download D1M-QRPA
61Mb

Download SMLO E1
65Mb

Download SMLO M1
15Mb

Other models

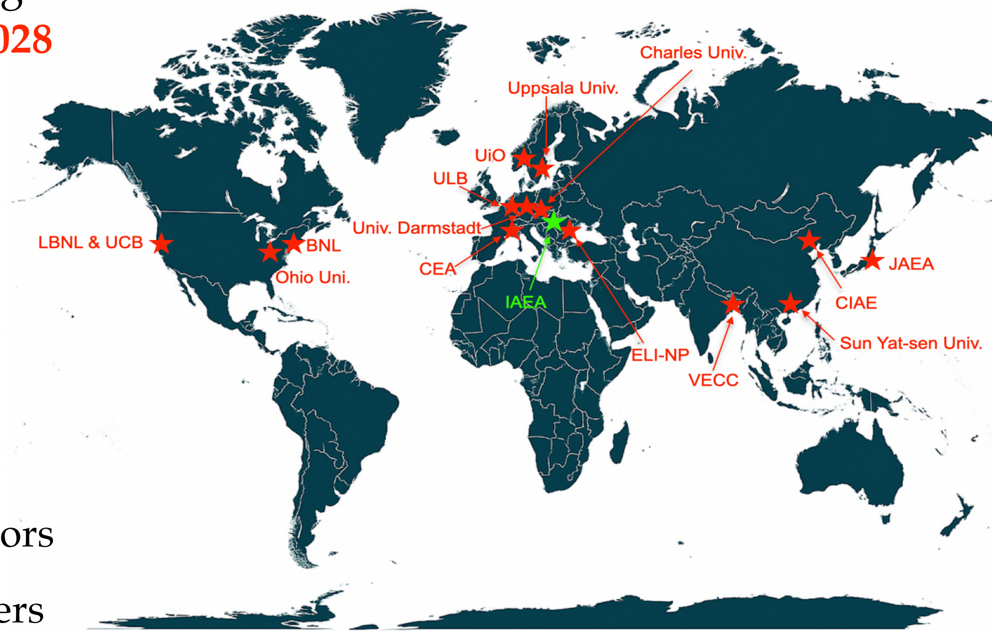
Theoretical PSF data generated by the triple Lorentzian model (TLO) [4] are now also available for dowloading. The folder contains the source files for generating the PSF data as well as the data files themselves. These PSFs have not been validated according to the CRP prescription [1].

Download TLO
13Mb

Nuclear Level Density database 2024-2028

IAEA Coordinated Research Project on Updating Nuclear Level Densities for Applications F41034, **2024-2028**

List of participants



Kick-off meeting: 24-28 March 2025, IAEA

LBNL/UCB action items (6/45):

- Compile of Oslo-type experimental NLD
- Compile all the shape-method NLD
- Assess of experimental data and quality indicators
- Comparison of assessed data and identify outliers
- Compile list of anticipated nuclei (data available for **153** nuclei, with Z =15 - 94)
- Develop publication guidelines for NLD/PSF data to be incorporated in database

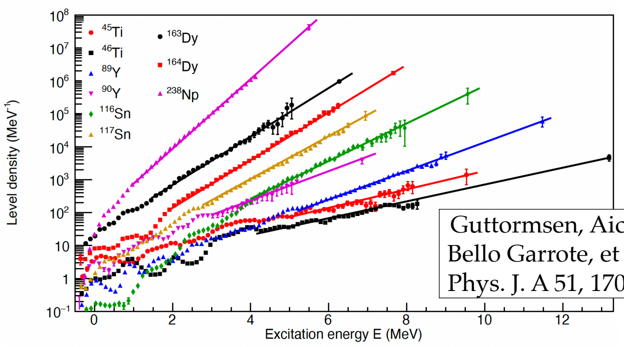
Summary

Photon Strength Function database: https://www-nds.iaea.org/PSFdatabase/

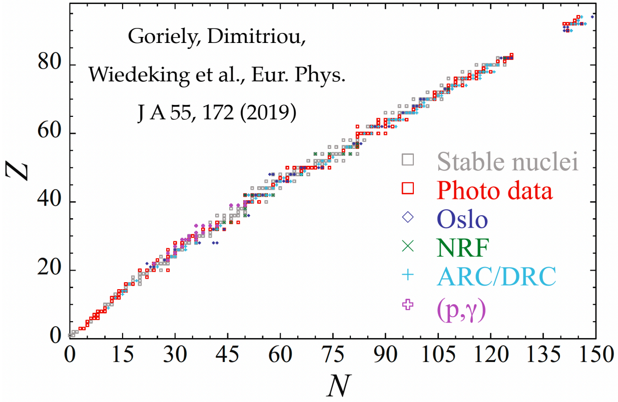
- since 2019
- last update 2024 (1071 datafiles)
- next update 2025 (+53 datafiles & +34 new nuclides)

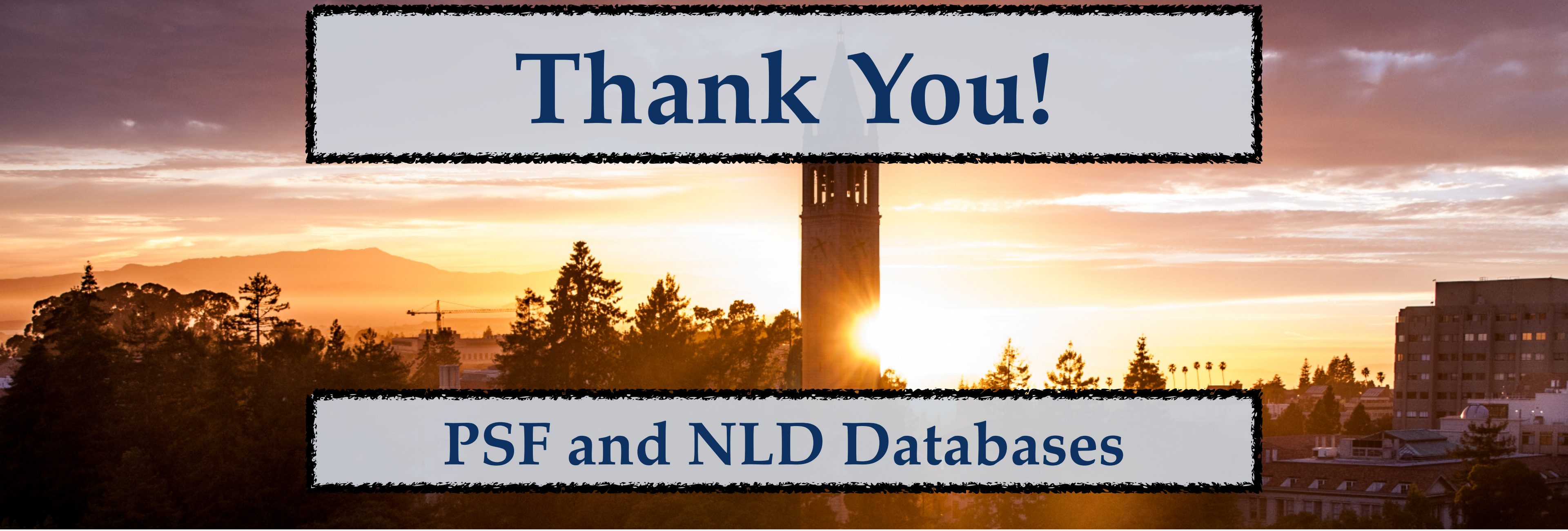
Nuclear Level Density database 2024-2028

- data available for **153** nuclei, with Z =15 - 94



Guttormsen, Aiche, Bello Garrote, et al., Eur. Phys. J. A 51, 170 (2015)





Thank You!

PSF and NLD Databases

Work done under the Quasi-continuum Nuclear Data Evaluator Traineeship

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