BERKELEY LAB

LAWRENCE BERKELEY NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

ENSDF: Structure via particle spectroscopy and a few tips for evaluation

M. Shamsuzzoha Basunia, LBNL

Joint ICTP-IAEA Workshop on Nuclear Structure and Decay Data:

Experiment, Theory and Evaluation

Trieste, Italy, Oct 15 – 26, 2018

Outline:

- Objectives
- Datasets in ENSDF
- Reaction datasets (particle)
- General comments
  - ➢ Examples
- A few tips for evaluation
  - ➢ Workflow: Mass chain evaluation
- Uncertainty
  - ➢ Examples
- List of some useful references

Objectives:

Evaluation of experimental nuclear structure data:

- *Completeness*
- *Quality and correctness*
- *Up-to-date*

Resources:

- ➢ *Guidelines, Manual, mentoring*
- ➢ *NSR (major), Web of Science, Google, etc.*
- ➢ *XUNDL*
- ➢ *Existing ENSDF files*
- ➢ *General policies - in year's first NDS issue*
- ➢ *Other evaluations/compilations*
- ➢ *Codes*

ENSDF Datasets

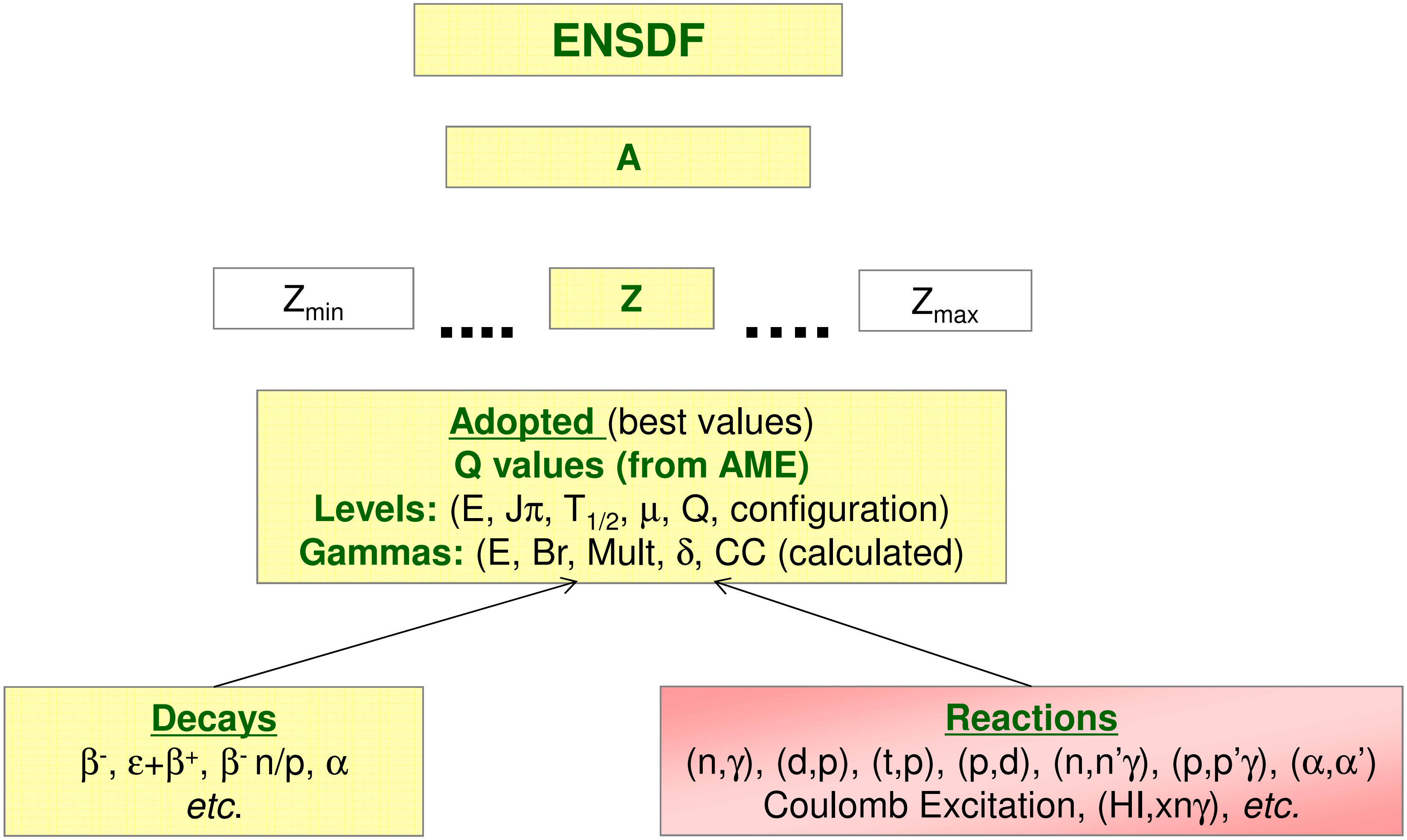
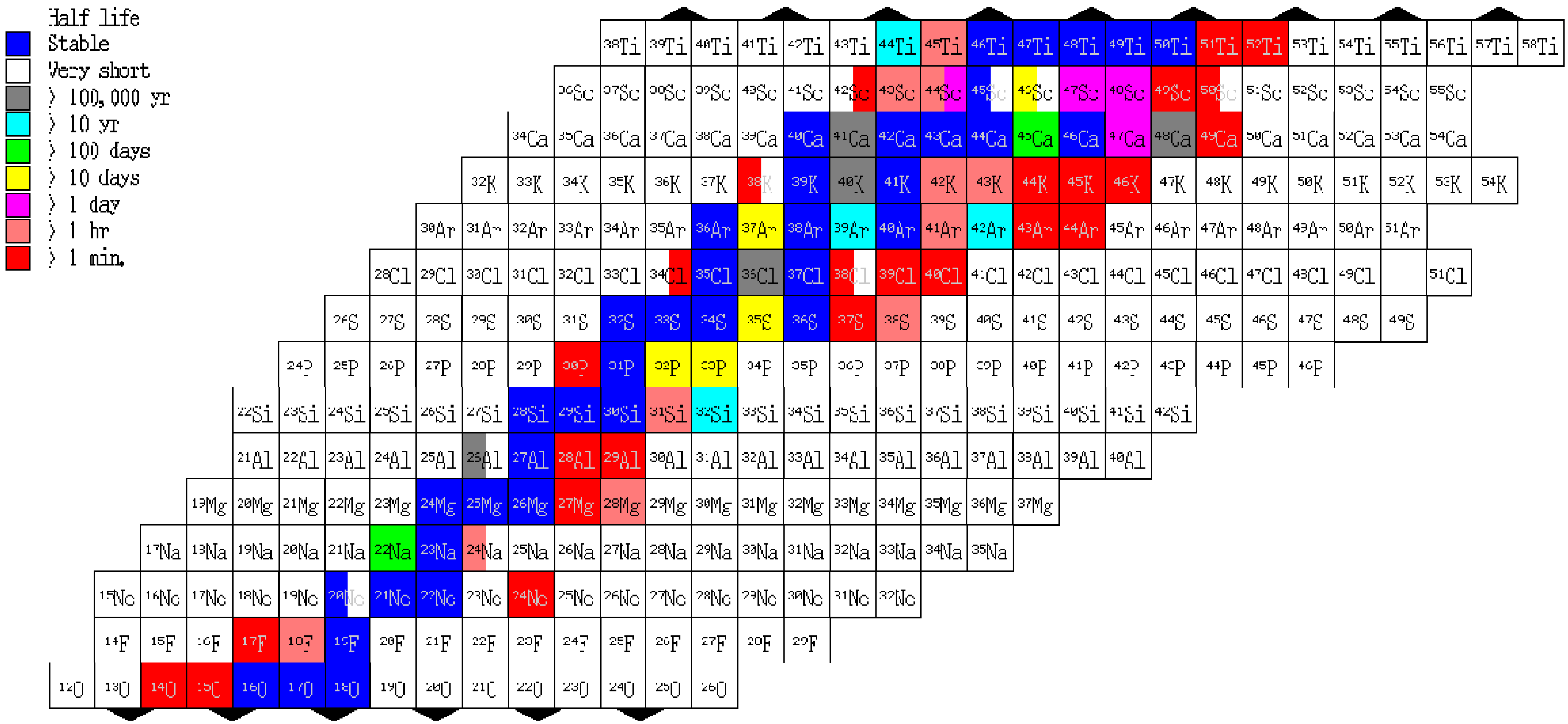


Chart of Nuclides (partial):



Types of Reactions:

Reactions – particle transfer/scattering:

- Stripping and Pickup Reactions
- Multi-particle Transfer Reactions
- Charge-Exchange Reactions
- Inelastic Scattering
- Resonance Reactions …

Reactions with inverse kinematics:

- Knock-out, breakup reaction using radioactive ion beam (RIB)

Provides information of nuclear shell structure

Quantities of Interest :

Particle energy spectrum – no γ rays:

- E(level) from particle energy spectrum or excitation function.
- L – angular momentum transfer
- S, C^2S - spectroscopic factors
  - Different definition exists in the literature
  - 'Fingerprints' for deformed nuclei
- β_2, β_4 - deformation parameters (if model independent)
- Γ, Γ_i – total or partial widths for level
- B(Eλ), B(Mλ) – transition probabilities
- Jπ, T – spin, parity, isospin

Stripping and Pickup:

Examples:

Stripping: (d,p), (pol d,p), (^{3}He,d), (α,^{3}He), *etc.*

Pickup: (p,d), (t,α), (^{3}He,α), *etc.*

Provides:

1) Q-values and excitation energies – from measured spectrum

2) L-transfer – from angular distribution of cross sections and DWBA

2013Sc06 - Phys. Rev. C87, 034306

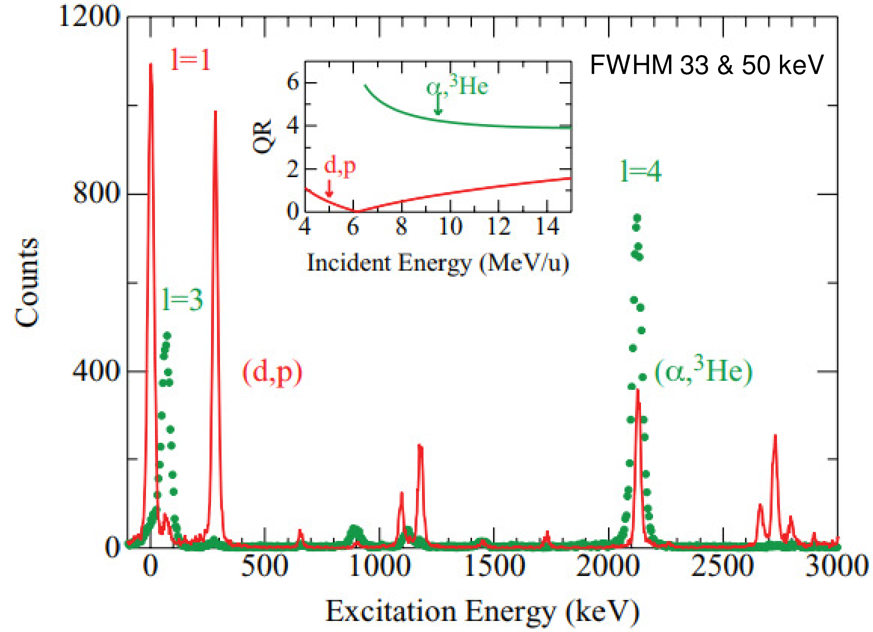


FIG. 2. (Color online) Spectra for the ^{60}Ni(d,p) and (α,^{3}He) reactions at 15° and 7°, respectively, indicating the strong enhancement of the lower ℓ values in the former reaction and the higher ones in the latter. The inset shows the reason for this: the momentum matching for the two reactions as a function of bombarding energy (deduced from a crude semiclassical picture), where the arrows show the bombarding energies used in this work, and Q is the momentum transfer and R the radius.

Stripping and Pickup:

Provides:

3) J-transfer – from analyzing power using polarized beams

4) Hole or particle character (from relative pickup and stripping strengths)

5) Configuration identification and purity (from absolute cross sections)

Quantities of interest:

- E (level)
- L (angular momentum transfer)
- S, C^2S - spectroscopic factors
- Configuration
- Items to note in dataset:
  - Target $J\pi$ (unless 0^+), spectrum resolution (FWHM), range of angles measured, in *lab* or *c.m. system*

Multi-particle Transfer:

Examples:

(p,t), (pol d, α), (t,p), (α,p), (α,d), (^{6}Li,d), ….

Quantities of interest:

- E(level)
- L – if angular distribution can be fitted by a unique value

Two-nucleon transfer (p,t), (t,p), (^{3}He,n):

- Observation of strong group (Identical nucleons transferred in a relative s state).

Charge Exchange Reactions:

Examples:

(*p*,*n*), (^{3}He,t), (d,^{2}He), (^{6}Li,^{6}He)
…

- Widely used for GT strength – to study the problem of GT strength quenching in beta decay
- GT$^+$ and GT$^-$ giant resonances – using (n,p) and (p,n)

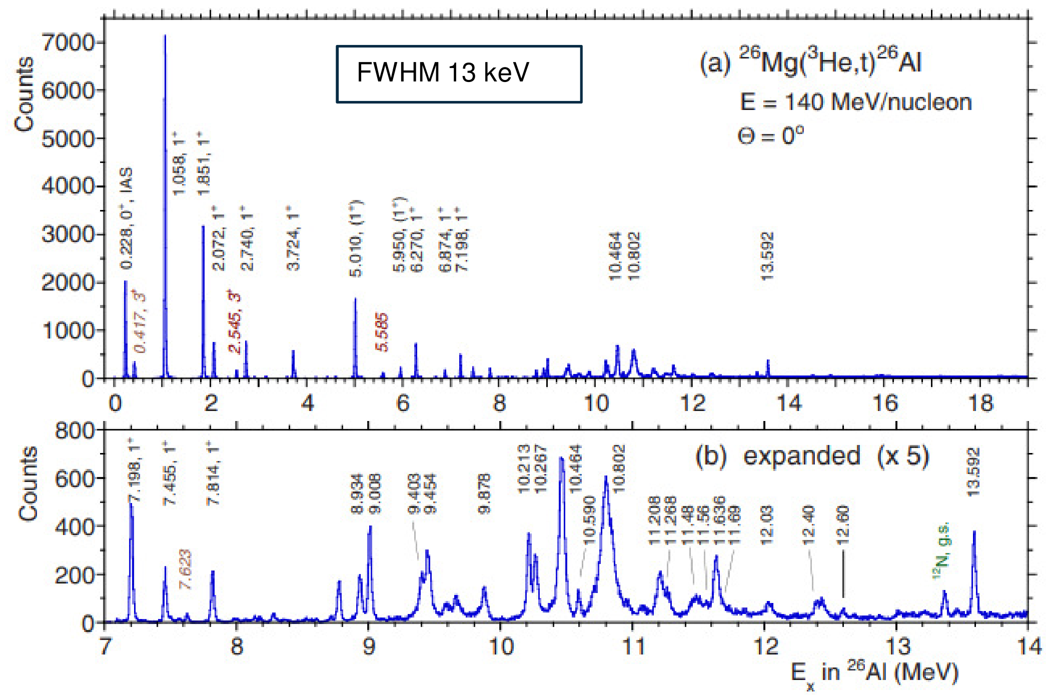
Quantities of interest:

- E(level)
- Isobaric analogue state

2017Wi16 - Phys. Rev. C 96, 064309

High-resolution study of $T_z = +1 \rightarrow 0$ Gamow-Teller transitions in the ^{26}Mg(^{3}He,*t*)^{26}Al reaction

Kalayar Win,[1,*] Y. Fujita,[2,3,†] Yee Yee Oo,[1,‡] H. Fujita,[2] Y. F. Niu,[4,5] T. Adachi,[2] G. P. A. Berg,[6] G. Colò,[4,7] H. Dohmann,[8]



Inelastic Scattering:

Examples:

(e,e'), (p,p'), (d,d'), (α,α') (projectile energy **above** the Coulomb barrier)

Quantities of interest:

- E(level)
- L – if angular distribution is fitted by unique L value
- Natural, unnatural parity – (usually from (α,α'))
- B(Eλ), B(Mλ) – transition probabilities (typically from (e,e')).
- Isospin – (p,p') vs. (d,d'), (α,α')

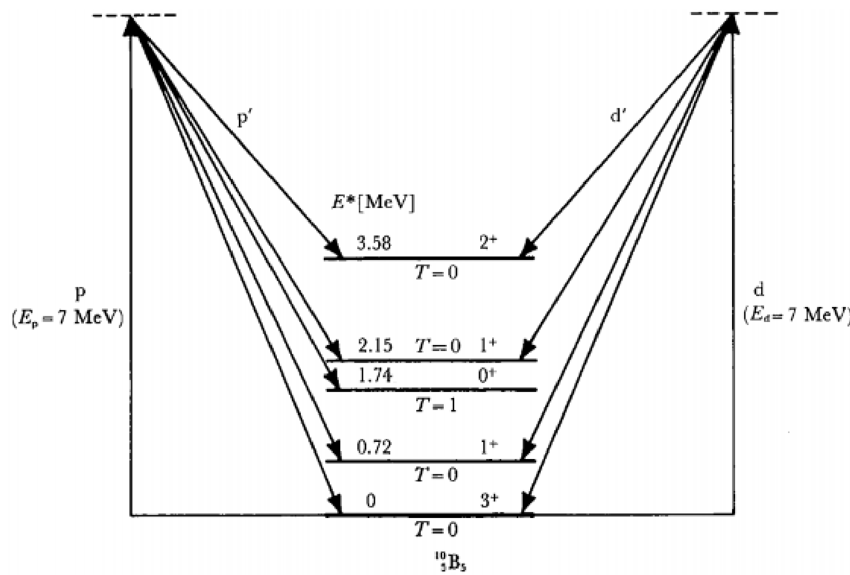


Fig. 5-6. Elastic and inelastic proton and deuteron scattering at 7 MeV to various levels in ^{10}B. The absence of (d, d') scattering to the second excited level is significant in that it illustrates the operation of an isospin selection rule forbidding d' transitions to $T=1$ states while permitting them to $T=0$ states.

BERKELEY LAB

Resonance Reactions:

Charged-particle Resonances:

Examples:

(p,p), (p,X), (p,p'γ) …

Quantities of interest:

- Level excitation energy - deduced from center-of-mass resonances energy and S_n, S_p
- Isobaric analogue states
- Giant resonances
- Level spins and parities, and L-values (when available).
- Total level widths or partial widths

Resonance Reactions: Cont.

Quantities of interest: Cont.

- Resonance strength
- Cross sections and reaction Q values
- Gamma-ray energies (often measured but not given by authors)
- Gamma-ray intensities - generally branching ratios (often missing branches)
- Gamma-ray multipolarities and mixing ratios.

Recommendation:

Adopt charged-particle resonance data

Reactions with Inverse Kinematics

Using Radioactive ion beam (RIB)

- Knock-out, breakup reactions

Example:

$^{2}H(^{25}Al,n)$, $(^{96}Sr,p)$, $^{1}H(^{21}Na,p)$, $^{12}C(^{23}O,^{22}Ox)$, $C(^{36}S,X)$, etc.

Quantities of interest:

- E (level)
- L transfer – from width of longitudinal momentum distribution and model analysis
- Particle removal cross section
- Absolute transition intensities give reliable spectroscopic factors

2004Co11 - PRL 93, 062501

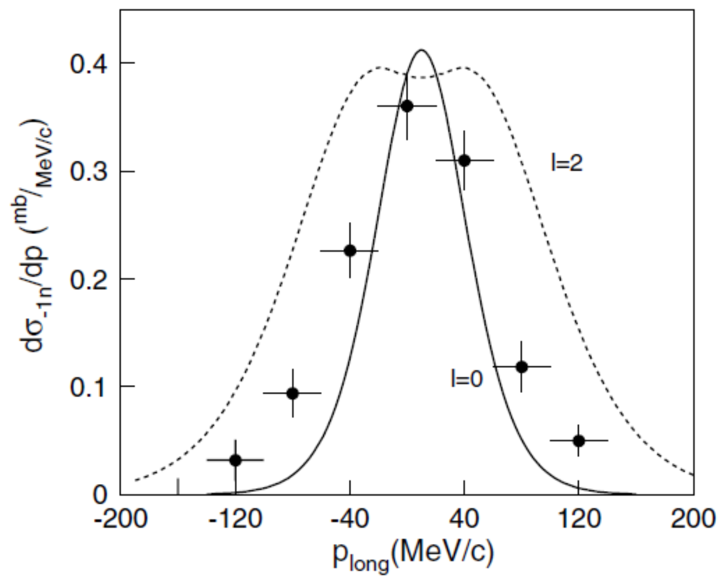


FIG. 3. Ground-state exclusive momentum distribution for ^{22}O fragments after one-neutron knockout reaction from ^{23}O compared with calculations assuming $l = 0$ and $l = 2$ (see text).

With future FRIB – more data expected from these reactions

General Comments:

Particle transfer datasets:

- Often - level energy with higher uncertainty
- Challenge – overlapping levels with different centroid values
- Jπ is helpful to distinguish if available
- For Jπ argument – L value, natural or unnatural parity, vector analyzing power, etc.
  - ✓For L value - list how it was obtained, i.e. $\sigma(\theta)_{exp}$ compared with DWBA calculations or with shape of level with known Jπ
  - ✓Caution for higher L values!
- Options in Adopted Levels
  - ✓ Lowercase letters in 'XREF'
  - ✓'XREF' energy as comments

Communicate what is measured/listed by authors

Example: Overlapping levels

^{26}Mg(t,^{3}He) 1974Fl01,1987Pe06,2006Ze01

1974Fl01: Triton beam E=23.5 MeV provided by Los Alamos Van de Graff facility impinged upon ^{26}Mg target. Reaction products measured from 15 to 30° at 5° intervals using E–ΔE silicon surface–barrier–detector telescope with a 50 μm ΔE detector. Excited states in ^{26}Na were populated using charge–exchange (t,^{3}He) reaction and relative dσ/dΩ measured.

1987Pe06: ^{3}H$^-$ ions accelerated to 36 MeV by tandem Van de Graff accelerator with average beam intensity of 200 nA and incident upon self–supporting foils of ^{26}Mg with thicknesses of 0.20 mg/cm^2 and 1.50 mg/cm^2. Recoiling particles measured using Daresbury 1 m scattering chamber in conjunction with five ΔE–E semiconductor telescopes. ΔE detectors were between 118 and 155 μm thick and E detectors 5 mm thick. Particle–energy spectra and differential cross sections obtained over angular range 15 to 50°. Results compared to DWBA calculations.

2006Ze01,2007Ze04: E=115 MeV/nucleon. Triton beam produced from 140 MeV/nucleon α beam impinging on a Be target. Measured ^{3}He spectrum, σ(θ) using the s800 spectrometer of two two–dimensional cathode–readout drift detectors (CRDCs). FWHM=300 keV, DWBA analysis. Deduced Gamow–Teller transition strengths.

^{26}Na Levels

E(level)†	Jπ§	L$^\#$	B(GT)$^\#$	Comments
0.0	3+			
88 *15*	1+	0	0.41 *5*	
241 *15*	2+			
420 *15*	2+			
1.4×10$^{3\#}$ *2*	1+$^\#$	0	0.09 *2*	E(level): A group of unresolved levels between 1450 and 1650 keV is also reported in 1987Pe06.

1400 ± 200

Example: Overlapping levels

Adopted Levels, Gammas

$Q(\beta^-)$=9354 *4*; S(n)=5574 *4*; S(p)=12090 *50*; $Q(\alpha)$=−12079 *13* 2012Wa38.

^{26}Na Levels

Cross Reference (XREF) Flags

A ^{26}Ne β^- Decay
B ^{14}C(^{14}C,dγ)
C ^{25}Na(d,pγ)
D ^{26}Ne(d,2nγ)
E Coulomb Excitation
F ^{26}Mg(n,p)
G ^{26}Mg(t,^{3}He)
H ^{26}Mg(^{7}Li,^{7}Be)
I ^{26}Mg(^{11}B,^{11}C)

E(level)†	Jπ	XREF	$T_{1/2}$	Comments
0.0	3+	ABCDE GHI	1.07128 s *25*	%β^-=100; μ=+2.851 *2*; Q=−0.0053 *2*.
1408.0 *10*		B g		
1509.0 *11*	(1+)‡	ABCD g		XREF: B(1514).
1660.2 *12*		B		
1808.0 *6*	(3+)#	C G		XREF: G(1860).

BERKELEY LAB

Example: Spin-parity arguments

^{26}Mg Levels

Cross Reference (XREF) Flags

A ^{26}Na β^- Decay
B ^{26}Al ε Decay (7.17×10^5 y)
C ^{26}Al ε Decay (6.3460 s)
D ^{27}Na β^-n Decay
E ^{18}O(^{13}C,αnγ)
F ^{22}Ne(^{6}Li,d)
G ^{23}Na(α,pγ)
H ^{24}Mg(t,p)
I ^{25}Mg(n,γ) E=thermal
J ^{25}Mg(n,γ),(n,n): Res
K ^{25}Mg(d,p)
L ^{25}Mg(α,^{3}He)
M ^{26}Mg(pol γ,γ'),(γ,γ')
N ^{26}Mg(γ,n): Res
O Others:
^{26}Mg(e,e')
^{26}Mg(p,p'),(p,p'γ)
^{26}Mg(α,$\alpha'\gamma$),^{22}Ne(α,n)
^{27}Al(μ^-,νnγ)
^{27}Al(d,^{3}He)
^{27}Al(t,α)
^{28}Si(μ^-,νpnγ)

E(level)†	Jπ	XREF	$T_{1/2}$ c	Comments
4835.13 *5*	2+	A E GHI KL O	28 fs *6*	Jπ: L=2 in (t,p).
5711.2 *8*	1+,2+	E H K O		Jπ: L=2 in (d,p), γ to 0+.

Particle transfer (j=l+s) and target Jπ(^{25}Mg)=5/2+ yield spin 0 to 5; Parity from $(-1)^L$

BERKELEY LAB

Example: Centroid, uncertainty

Adopted Levels, Gammas

Q(β^-)=−18110 *SY*; S(n)=19040 *10*; S(p)=5513.8 *5*; Q(α)=−9166.0 *3*   2012Wa38.
ΔQ(β^-)=200 (syst) (2012Wa38).

5th resonance above Sp in ^{26}Si

^{26}Si Levels

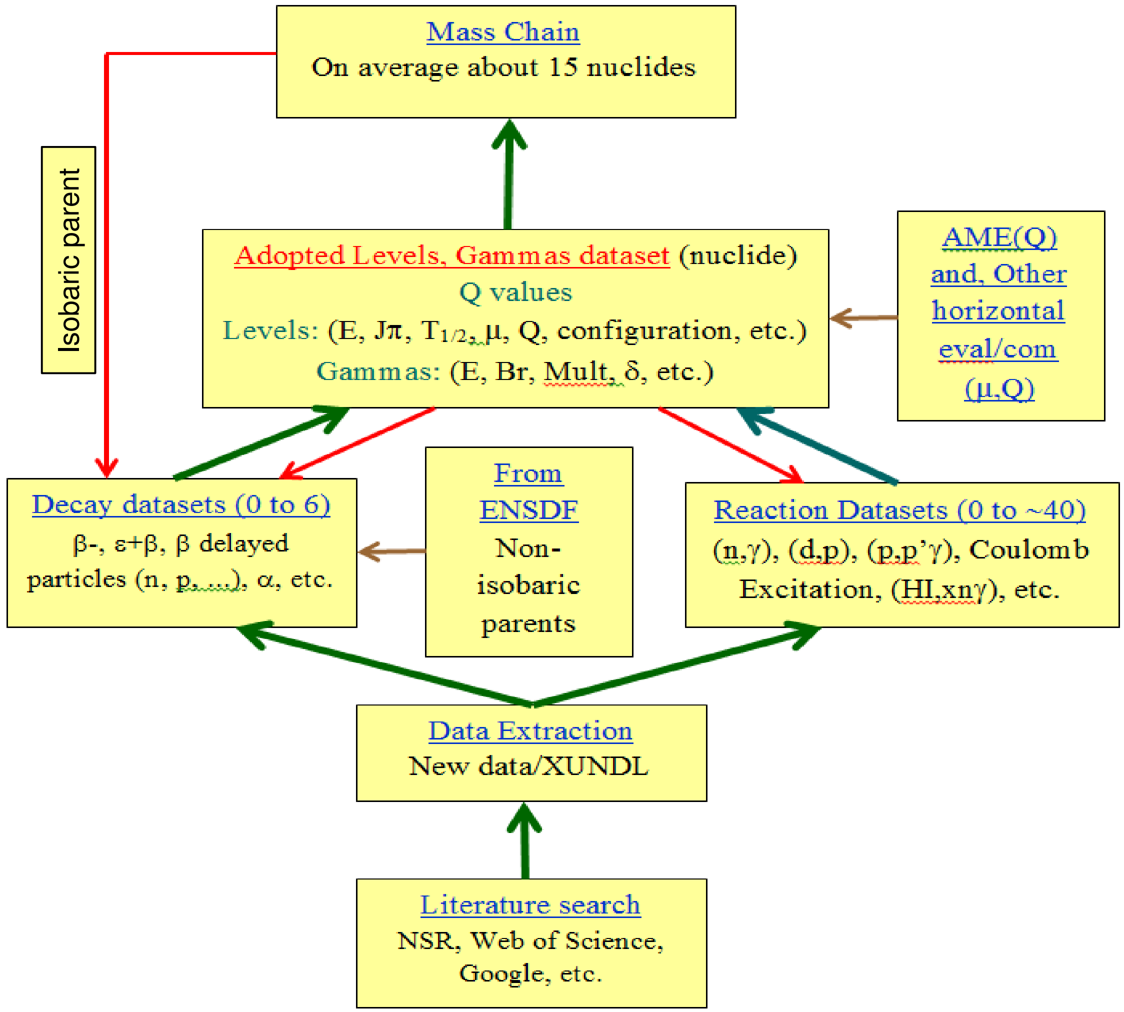
Cross Reference (XREF) Flags

A ^{26}P ε Decay	E ^{12}C(^{16}O,2nγ)	I ^{28}Si(p,p2nγ)
B ^{27}S β^+p Decay	F ^{24}Mg(^{3}He,n)	J ^{28}Si(p,t)
C ^{1}H(^{25}Al,p)	G ^{24}Mg(^{3}He,nγ)	K ^{28}Si(α,^{6}He)
D ^{1}H(^{27}Si,^{26}Siγ)	H Coulomb Excitation	L ^{29}Si(^{3}He,^{6}He)

E(level)†	Jπ#	XREF	$T_{1/2}$ e	Comments
5676.2 *3*	1+	DEFG J L		Γ_γ=1.2×10^{-4} keV (2009Pe04); other value; Γ_p=1.3×10^{-12} keV; Γ_γ=1.1×10^{-4} keV (2006Ba65).
5890.1 *3*	0+	G K		Jπ: Proposed in 2015Do07 (^{3}He,nγ), based on isotropic distribution of γ rays and absence of 0− analogue states in ^{26}Al and ^{26}Mg. Also in 2014Ko41.
5929.4§ *8*	3+ c	A F JK		XREF: F(5912)K(5918).
5945.9‡ *40*	(0+) cd	F J L		E(level): Weighted average of 5946 keV *4* (2004Pa42), 5946 keV *4* (2006Ba65), 5945 keV *8* (2002Ca24), and 5946 keV *4* (2009Pe04).

‡ The existence of this level as a separate resonance is called into question in 2015Do07 due to lack of evidence in their (^{3}He,nγ) measurement and also argue that 5946 keV level might the same level as that at 5929.4 keV. This inference is refuted in 2016Ch09 on the basis of (^{3}He,nγ) (2004Pa42) and (p,t) (2010Ma43) measurements that have populated both this resonance and the 5929.4–keV resonance simultaneously.

Tips for evaluation: Workflow - mass chain evaluation



Challenges:

Knowledge:

- Often a beginner has experience with a particular field
- However – needs to deal with data sources from many different experiments.
- Conflicting or discrepant data (Physics, experiment type, facility, statistics, etc.)
- Dealing with uncertainties
- Develops slowly with reading and evaluation work

Data management skill:

- Many components – data, source ref., data sets, use of codes, organization, txt to pdf, ENSDF policies, etc.
- Efficiency
  - Keep the latest mass chain txt and pdf files
  - Codes - know which one and when to use for a data set
  - Work on a dataset at a time within a nuclide – name to differentiate from one to another (may be as Nucl_datatype/projectile.txt)
  - Avoid repetitive work on the same dataset
  - Find mistakes/typos

Workflow: Tips for evaluation

Literature search (completeness): For current and missing references

Nuclear Science References (NSR)

Quick Search | Text Search | **Indexed Search** | Keynumber Search | Combine View | Recent References

Initialization Parameters

Publication year range: 2005 to 2018

Primary only: ☐ View All: ☐ Require measured quantity: ☑

Output year order: ○ Ascending ◉ Descending

Output format: ◉ HTML ○ BibTex ○ Text ○ Keynum ○ Exchange

○ Search all entries ◉ Search entries added since 1 / 1 / 2005 (month/day/year)

Search Parameters

Nuclide ▼ 218Ac browse...

AND

(none) ▼ browse...

AND

(none) ▼ browse...

Search Reset

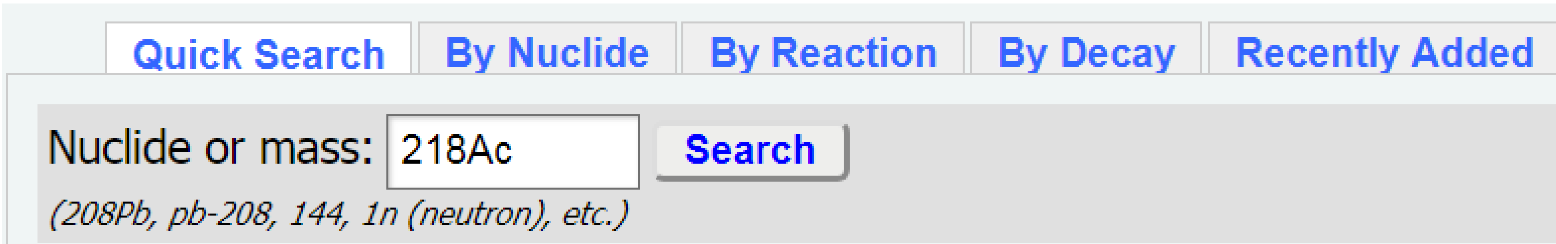
Documentation:
Save the output in a file, print and work on it.

Good practice: Search Web of Science (if available) and Google

BERKELEY LAB

Workflow: Tips for evaluation

XUNDL search



- ✓ Save in a file
- ✓ Check all retrieved literature (New or already in XUNDL)
- ✓ Check with exiting nuclide XREF, if new data or to be combined

Note:

1. XUNDL datasets are in ENSDF **format** (mainly reflects the paper) – not necessarily following the ENSDF **policies**.
2. For ENSDF – check the paper and XUNDL dataset for mistake, omission, or extra data

Important: XUNDL dataset will need slight modification to include in the ENSDF evaluation.

Workflow: Tips for evaluation

Decay and reaction datasets

Cross Reference (XREF) Flags

A	^{59}Cr β^- decay	D	^{64}Ni(^{3}He,^{8}B)
B	^{13}C(^{48}Ca,pnγ)	E	^{238}U(^{70}Zn,Xγ)
C	^{59}Co(π^-,π^+)		

- ✓ After sorting new datasets from literature - create new or combine with existing dataset
- ✓ Remember to check if anything taken/needed from Adopted Levels, Gammas dataset

Decay data sets:

Very important one and perhaps the most interesting one too

Presentations: by Kondev (1st week) later this week by McCutchan

Workflow: Adopted levels, Gammas

Helpful for nuclides, lets say ≥ 10 source datasets

1. Adopt γ-ray energy from measurement - (helpful GAMUT outputs and "pandora.gle")
2. Level energy from γ-ray least squares fit (use GTOL features ('unc' or '?' for a proper fit).
3. Level energy for others (no γ-ray connection) (helpful "pandora.lev" output file)
4. Calculated γ-ray energies, if needed (recoil correction?)
5. Adopt γ-ray **branching** - (helpful GAMUT outputs and "pandora.gle")
6. Adopt γ-ray multipolarity and mixing ratios (helpful 'pandora.gle')
7. Adopt level $T_{1/2}$
8. Adopt Jπ for adopted levels

Workflow: Adopted levels, Gammas (con't)

9. Run Bricc
10. Run RULER (check for unexpected outputs (bug in the code))
11. Physics checks using pandora.err output
12. Check for format (fmtchk)
13. Produce pdf file (JAVA-NDS)
14. Check for BANDs, if present (looking through pdf figures)
15. Check data back flow from Adopted Levels to source datasets for consistency.

Some variation in the order is ok – but adopt relevant qualities before running a code

Uncertainty: Example

Uncertainty: An important issue

PHYSICAL REVIEW C VOLUME 58, NUMBER 2 AUGUST 1998

1998To14

Identification of ^{180}Tl α decay

K. S. Toth,[1] X.-J. Xu,[2,3,4] C. R. Bingham,[1,4] J. C. Batchelder,[5,6] L. F. Conticchio,[7,8] W. B. Walters,[8] L. T. Brown,[7,9] C. N. Davids,[7] R. J. Irvine,[10] D. Seweryniak,[7,8] J. Wauters,[4] and E. F. Zganjar[5]
[1]*Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831*

TABLE I. Summary of results from the present work compared with literature values where available.

	E_α (keV)		$T_{1/2}$ (ms)		I_α (relative)	
Isotope	This work	Previous	This work	Previous	This work	Previous
^{181}Tl	6186(10)	6180 [12]	3200(300)	3400(600) [12]	100	100 [12]
^{181}Tl^m	6578(10)	6566(20) [5]	1.4(5)	2.7(10) [5]	100	100 [5]
^{180}Tl	6208(10)				18(5)[a]	
	6281(10)		1600(400)		30(6)[a]	
	6362(10)		1500(300)		30(6)[a]	
	6470(20)				7(3)[a]	
	6560(10)		1400(300)		15(3)[a]	
^{179}Tl	6569(10)	6568(18) [9]	230(40)	430(350) [9]	100	100 [9]
		6560(20) [10]		160^{+90}_{-40} [10]		100 [10]
^{179}Tl^m	7213(10)	7201(20) [9]	1.8(4)	$0.7^{+0.6}_{-0.4}$ [9]	80(20)	100 [9]
		7200(10) [10]		1.4(5) [10]		100 [10]
	7096(10)		1.6(8)		20(9)	

[a]Intensities deduced from the parent spectrum [Fig. 1(c)] correlated with ^{176}Au α decay.

Uncertainty (Con't): Example

20(9)/[20(9)+80(20)]=1/[1+80(20)/20(9)]=1/[1+4(2)]*100=20(8)

80(20)/[80(20)+20(9)]=1/[1+20(9)/80(20)]=1/[1+0.25(13)]*100=80(8)

^{179}Tl α Decay (1.5 ms) 2002Ro17,1998To14,1996Pa01

^{175}Au

2004Ba89

Parent ^{179}Tl: E=0.0+x; Jπ=(11/2−); $T_{1/2}$=1.5 ms *3*; Q(g.s.)=6718 *8*; %α decay≈100.
Other: 1983Sc24.
2002Ro17: Target: 90.4% enriched 202Pb; Projectile: ^{78}Kr, E=355 MeV (340 MeV at midtarget); gas-filled separator, parallel-plate avalanche counters, Si strip detector, HPGe detector; deduced $T_{1/2}$, corrected for random correlation rates.
1998To14: Target: ^{90}Zr; Projectile: ^{92}Mo, E=420 MeV (404 MeV at mid-target); fragmented mass analyzer, gas-filled parallel grid avalanche counter, double-sided Si strip detector with 40 horizontal and 40 vertical strips; measured: Eα, t, Iα.

α radiations

Eα	E(level)	Iα‡§	HF	Comments
7096 *10*		20 *8*		Eα: Observed only in 1998To14. An expected level of 116 keV above the (11/2−) state at (0.0+x) keV level, calculated from the 7209α and 7096α energy difference, has not been observed in ^{175}Au level scheme (2001Ko44).
7209 *8*	0.0+x	80 *8*	≈1.1†	Eα: Weighted average of 7213 *10* (1998To14), 7201 *20* (1996Pa01), and 7200 *20* (1983Sc24).

† Using r_0=1.537; average of r_0(^{174}Pt)=1.545 *10*, and r_0(^{176}Hg)=1.53 *4* (1998Ak04).
‡ For α intensity per 100 decays, multiply by ≈1.00.
§ Normalized from 1998To14 values.

Code: PABS

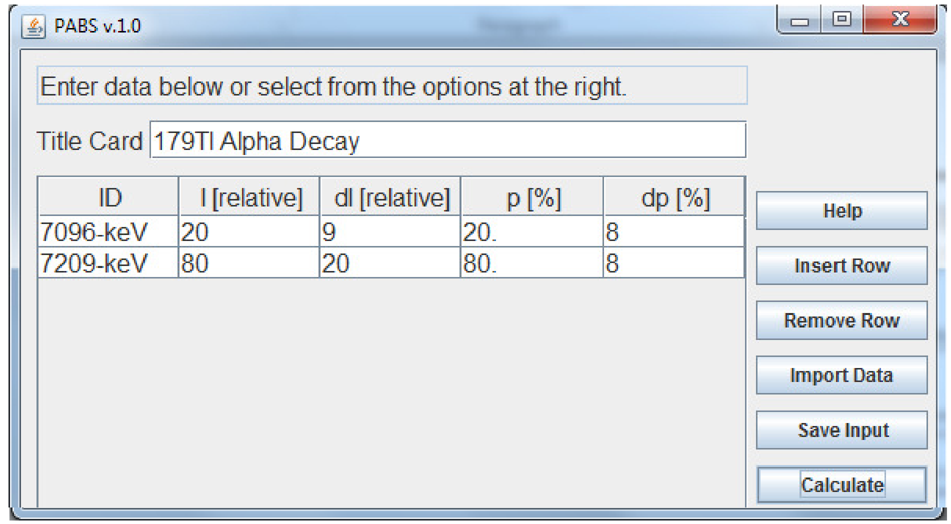
PABS: A Computer Program to Normalize Emission Probabilities and Calculate Realistic Uncertainties

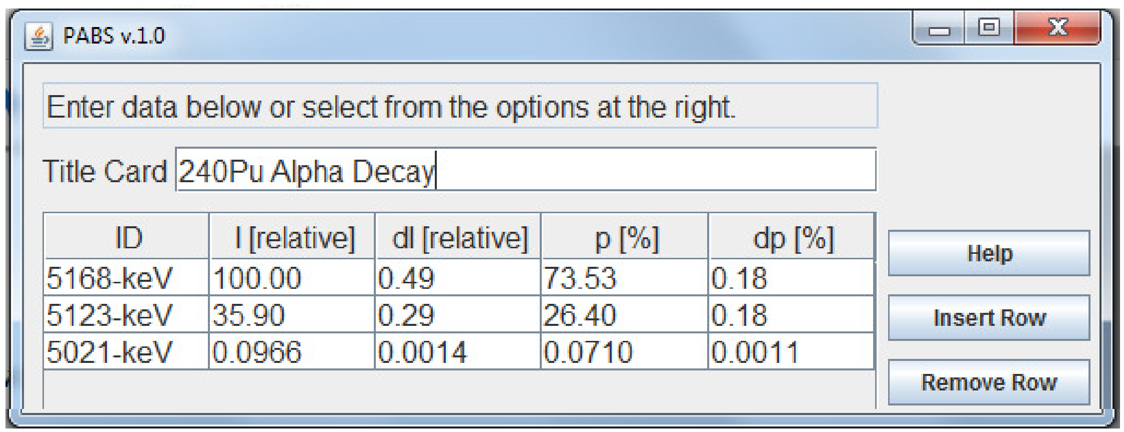
D. S. Caron[*], E. Browne[#], and E. B. Norman[*]

[*] *Nuclear Engineering Department, University of California, Berkeley, California 94720*

[#]Nuclear Science Division

August, 2009





E. Browne, Nuclear Instruments and Methods in Physics Research **A265**, 541 (1988)

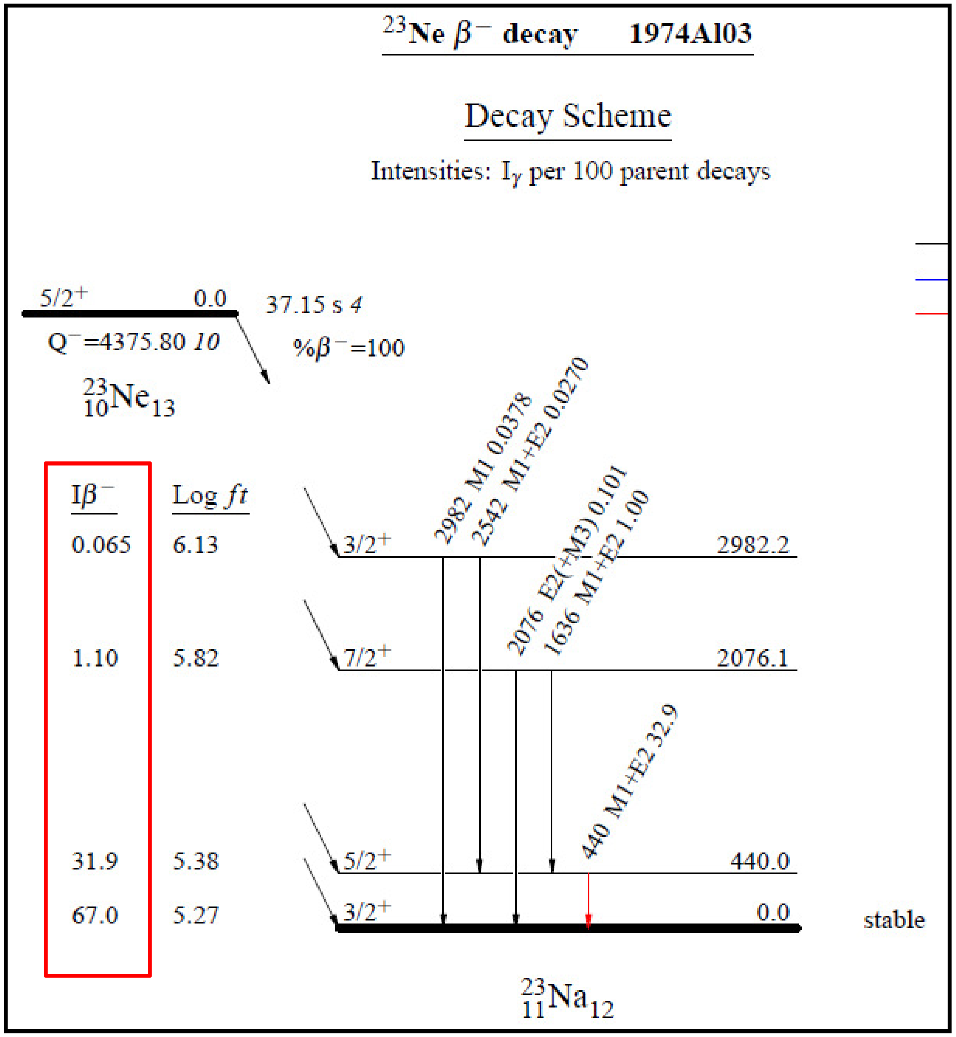
Uncertainty: Excited state β feeding in ^{23}Ne β- decay (example)

1957Pe12 - β measurements

g.s. feeding: 67 ± 3
1st excit. state: 32 ± 3
2nd excit. state: 1.00 ± 0.15

1974Al04 - γ measurements

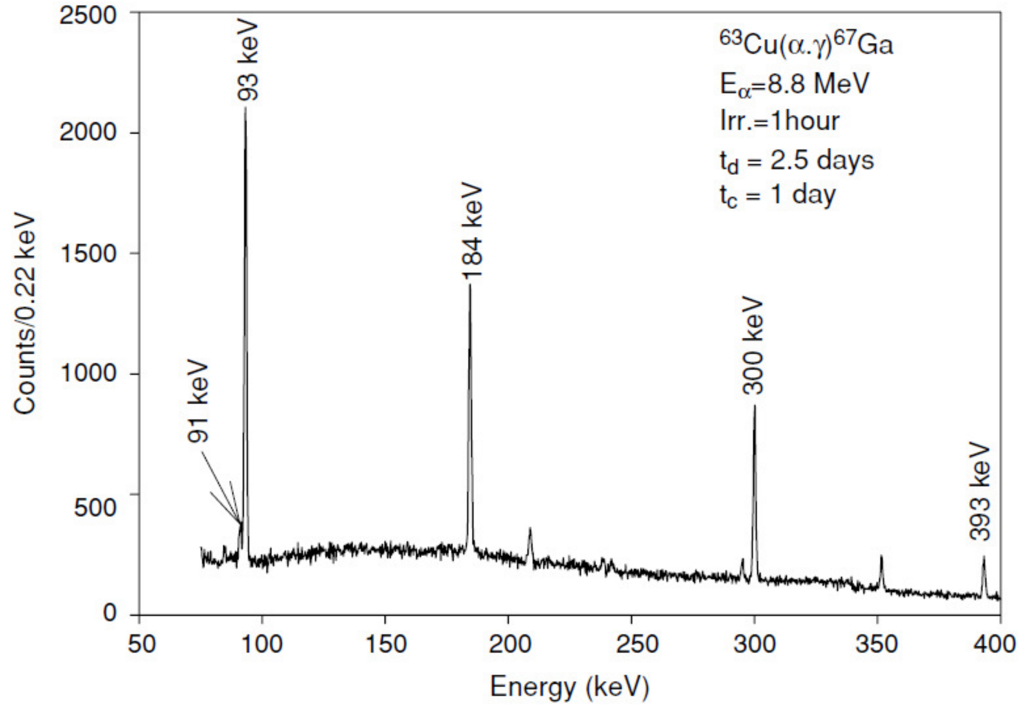
E_γ (keV)	Iγ (relative) Present
440	33.0
1636	1.00 ± 0.04
2076	0.101 ± 0.006
2542	0.027 ± 0.002
2982	0.038 ± 0.002



Uncertainty (con't): 440-keV γ ray absolute intensity (^{23}Ne β- decay)

Often – in γ measurements

Iγ (relative): strongest 100 (no uncertainty) and if not stated, we can assume propagated to other reported Iγ values.



Imposing γ measurements uncertainty in normalization:

We can report 440-keV absolute intensity as **32.9 ± 1.3** instead of 32.9 ± 30 (if beta feeding unc.)

E_γ ‡	I_γ &@	E_i(level)	J^π_i	E_f	J^π_f	Mult.§	δ †§	α #	Comments
440	100	440.0	5/2$^+$	0.0	3/2$^+$	M1+E2	+0.065 *5*		%Iγ=32.9 *13* I_γ: 33.0 (1974Al03).

BERKELEY LAB

Uncertainty:

In weighted average, if yields more precise value than the input uncertainties, consider the lowest input in final result

GTOL: Default ΔE=1-keV for $E\gamma$ without uncertainty. For other values see "Read Me" file to apply.

GABS: Recently modified to yield %$I\gamma$ (if normalized from decay scheme) - to avoid double consideration of $\Delta I\gamma$.

LOGFT: Sometime yields uncertainty up to three decimal places – may be reduced to one or two

RULER: Check outputs – for overlapping zero values (bug in the code) – need fixing manually

In brief:

- Inter connected data
  - Any changes in one dataset may prompt changes in other datasets
- Many different experiments, experimental setup, analytical approaches
  - Sometimes documentation is poor
- Identify mistakes or inconsistent data
- Many special cases: In decay datasets, mass region related issues
- Remember to use latest version of the analysis programs
- Keep notes of important observations to list those in the abstract

List of some useful references:

- 2017Wa10 – Atomic mass evaluation
- 2017Au03 – The NUBASE evaluation of nuclear properties
- 2013Ma15 – Ground state spin (compilation)
- 2014StZZ, 2016St16 – Nuclear and quadrupole moments (compilation)
- 1998Ak04 – r_0 radius parameter – for alpha hindrance factor calculation (revision ongoing)
- 2015Bi05 – β-delayed neutron emission prob. and half-life (Z=2 to 28) (evaluation)
- 2016Ba?? - β-delayed proton and alpha emission – In press
- 2016Pr01 – B(E2) values from 1st 2+ states (compilation and evaluation)
- 2006MuZX – Atlas of neutron resonances
- 2015Ja04 – Atlas of Nuclear Isomers
- 1997Mo25 – Nuclear properties (calculation)
- Also many reports, documents, presentations, etc.

Nuclear Data Sheets: (User's info)

NUCLEAR DATA SHEETS

GENERAL POLICIES - Presentation of Data

The Nuclear Data Sheets are prepared from the Evaluated Nuclear Structure Data File (ENSDF), a computer file maintained by the National Nuclear Data Center on behalf of the International Network for Nuclear Structure and Decay Data Evaluations. See page iii for a list of the members of this network and their evaluation responsibilities. The presentation of material in the Nuclear Data Sheets reflects the organization of ENSDF, which is a collection of "data sets". For each nuclear species, these data sets present the following types of information:

- The adopted properties of the nucleus.
- The evaluated results of a single type of experiment, such as a

For the nuclide:

1. **Q(β⁻)**: β⁻ decay energy [always presented as Q(β⁻)=M(A,Z)–M(A,Z+1)] and α decay energy [Q(α)] for the ground state.
2. **S(n) and S(p)**: Neutron and proton separation energies.
3. **XREF**: Cross-reference symbol assignments for the various experimental data sets.

For each level:

1. **E(lev)**: Excitation energy (relative to the ground state).
2. **J^{π}**: Spin and parity with arguments supporting the assignment.

Nuclear Data Sheets Symbols and Abbreviations

A	mass number*, A = Z + N
A_2, A_4	coefficients of Legendre polynomials in angular-correlation or angular-distribution measurement
av	average
B(EL), B(ML)	reduced EL, ML transition probability in $e^2 \times (\text{barn})^L$, $\mu_N^2 \times (\text{barn})^{L-1}$
calc, CA	calculated, calculation
CCBA	coupled-channel Born approximation
ce	conversion electron
chem	chemical separation
circ	circular
c.m.	center of mass
coef	coefficient

pol	polarized, polarization
priv comm	private communication
PWBA	plane-wave Born approximation
Q	(1) reaction energy*, (2) disintegration energy*, (3) quadrupole moment*, in units of barns, (4) quadrupole
Q(ε)	total disintegration energy in ε decay
Q(β−)	total disintegration energy in β− decay
Q(α)	total disintegration energy in α decay, E(α) + E(recoil)
R	$r_o A^{1/3}$, nuclear radius*
RDM	recoil distance measurement
RUL	recommended upper limit for γ-ray strength
rel	relative
res	resonance

Useful to have handy (available at Nuclear Data Sheet publication web site – https://www.sciencedirect.com/journal/nuclear-data-sheets/issues)

Thank you

Questions/Comments