ENSDF – Reaction Data

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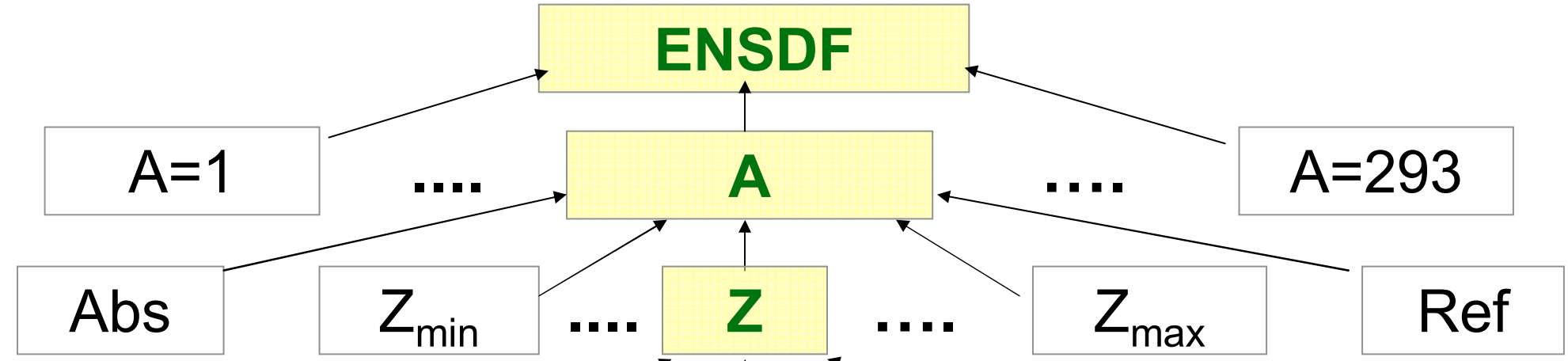
ENSDF Database Structure



Adopted

(best values)

Q values

Levels:

(E, Jπ, T1/2, μ, Q, config, excitn.)

Gammas:

(E, Br, Mult, δ)

1 dataset

Decays

β^-

$\varepsilon+\beta^+$

α

β^-n

etc.

0 to ~6 datasets

Reactions

(HI,xnγ)

(p,p' γ)

(n, γ)

Coul. Exc.

(α,α')

(d,p)

etc.

0 to ~40 datasets

Summary

Principal Categories of Reactions.

- Reactions in which gammas are not detected:
  - Stripping and Pickup Reactions
  - Multi-particle Transfer Reactions
  - Charge-Exchange Reactions
  - Inelastic Scattering
  - Coulomb Excitation (particles detected)
  - Resonance Reactions …
- Reactions in which gammas are detected:
  - Summary of information available from γ-ray measurements
  - Inelastic Scattering
  - Nuclear Resonance Fluorescence
  - (light ion,xnypγ)
  - (heavy ion,xnypγ)
  - Particle Capture
  - Coulomb Excitation (γ's detected)

Gammas <u>not</u> detected

Measured Quantities of Interest:

- E(level) from particle spectrum or excitation function.
- L – angular momentum transfer
- S, C^2S - spectroscopic factors
- β_2, β_4 - deformation parameters (if model independent)
- Γ, Γ_i – total or partial widths for level
- B(Eλ), B(M λ) – transition probabilities

Stripping and Pickup

Examples:

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

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

Quantities to Record:

- **E(level),** deduced by authors from charged particle spectrum.
- **L** and **S** or **C²S** from authors' DWBA analysis:

$(d\sigma/d\omega(\theta))_{exp} = (d\sigma/d\omega(\theta))_{DWBA}$.x N x C^2S'

where $S'=S$ (pickup) or

$S'=S \times (2J_f+1)/(2J_i+1)$ (stripping)

(**$d\sigma/d\omega$** for one angle should be given in suitably relabeled S field when spectroscopic-factor information is not provided by authors.)

- **J** from L±1/2 for polarised beam if vector analysing power shows clear preference between L+1/2 and L-1/2.

Relevant Documentation:

Target Jπ (unless 0^+)

Spectrum resolution (FWHM, keV)

Normalisation factor for DWBA analysis

Range of angles measured, lab or c.m. (but specify which).

Stripping and Pickup, ctd.

Deformed Nuclides; α and lighter beams:

$(d\sigma/d\omega(\theta))_{exp}$ / $[(d\sigma/d\omega(\theta))_{DWBA}.x\ 2N] = c^2(jl)\,V^2$,

where c is amplitude of Nilsson state wavefunction for transferred nucleon, V is fullness factor describing partial filling of target nucleus orbitals.

• The pattern of cross sections among rotational-band members may provide a characteristic **fingerprint** for a specific Nilsson configuration, enabling a set of levels to be assigned as specific J members of a band with that configuration if:

(i) the experimental fingerprint agrees well with that predicted by Nilsson-model wavefunctions, and

(ii) the fingerprint differs distinctly from those for other plausible configurations.

Example: $(d\sigma/d\omega(60°))$ calculated (1997Bu03) for $^{226}Ra(t,\alpha)^{225}Fr$:

Orbital:	1/2[400]	1/2[530]	**1/2[541]**	3/2[402]	3/2[651]	**3/2[532]**	Expt.	Mixed
J=3/2	23	14	1.5	103	0.0	0.7	~1.5	0.9
J=5/2	7.6	0.2	13	4.6	0.03	6.2	14	10
J=7/2	0.4	39	2.0	1.2	0.0	3.3	20	4.1
J=9/2	0.05	0.4	33	0.05	2.0	26	~45	49

Reality (not so simple!): 3/2[532] Coriolis mixed with 1/2[541] fits σ, energy.

Multi-particle Transfer

Examples:

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

Quantities to Record:

• E(level)

• L – if angular distribution can be fitted by a unique value

Deduced Quantities:

Jπ- from J(target)+L (vector sum) and $\pi_i\pi_f=(-1)^{Jf}$, for <u>strong</u> groups only in two-neutron, two-proton or α–particle transfer.

(*i.e.,* pairs of identical particles can be assumed to be transferred in relative s state for **strong** groups).

Charge-Exchange Reactions

Examples:

(p,n), (^{3}He,t)

Quantities of interest:

- E(level)
- Isobaric analog state information.

Inelastic Scattering

Examples:

(e,e'), (p,p'), (d,d'), (α,α') (at projectile energies **above** the Coulomb barrier).

Quantities to Record:

- E(level)
- L – if angular distribution is fitted by unique L value
- β2, β4 … - deformation parameters (if model independent); specify whether 'charge' or 'nuclear', if relevant (typically from (α,α') or (e,e')).
- B(Eλ), B(M λ) – transition probabilities (typically from (e,e')).

Coulomb Excitation
(particles detected)

Examples:
(p,p'), (d,d'), (α,α') with projectile energy **below** Coulomb barrier.
Quantities to Record:

- E(level)
- Jπ:
    - determined if the excitation probability agrees with that calculated by Alder (1960Al23).
    - low energy Coulomb excitation is predominantly E2
- B(Eλ) – for excitation

Resonance Reactions

Examples:

(p,p), (p,X), (γ,n) … (excitation function data, σ(E), dσ/dω(θ,E))

Quantities of interest:

• E(level) – can be given as 'S(p)+976.3', *etc*., where 976.3 is E(p) for resonance (c.m. or lab. energy, but must specify which), if desired.

• Ep, Eγ at resonance - can be given in relabeled 'S' or 'L' field.

• Is this an isobaric analog state? (If so, specify state of which it is the analog).

• Partial widths – can be given in comments or relabeled 'S' field.

• Is this a giant resonance? (If so, which one?)

Note:

ENSDF is primarily concerned with bound levels, but includes all isobaric analog states, giant resonances, and unbound levels which overlap or give information on bound levels.

Reactions with Gammas Detected

Measured Quantities of Interest:

- E_γ - photon energy
- $I\gamma$ - relative intensity (or photon branching)
- α, α_K, … - electron conversion coefficients, usually from $I(ce)/I\gamma$, sometimes from intensity balance (note: this gives α_{exp}).
- K/L, L1/ L3 … - ce subshell ratios
- A_2, A_4 … - Legendre polynomial coefficients characterizing angular distribution ($\gamma(\theta)$) or angular correlation ($\gamma\gamma(\theta)$).
- DCO ratio – directional correlation of gammas from oriented nuclei.
- Asymmetry ratio - *e.g.*, $I\gamma(\theta_1)/I\gamma(\theta_2)$
- Linear polarization
- Level $T_{1/2}$ – from γ(t), DSAM, RDM, centroid-shift, delayed coincidence, *etc*., if measured in that reaction (state method used).
- g-factor – include if measured in that reaction

Reactions with Gammas Detected – ctd.

Deduced Quantities of Interest:

• E(level) – from least-squares adjustment of Eγ (GTOL), avoiding Eγ for lines that have uncertain or multiple placements whenever possible. Note serious misfits.

• Band structure – indicate via band flags for levels. (Note: life will be easier if a given band has the same band-flag character in each dataset in the nuclide!)

• Jπ - default is adopted value; however, it may be much more useful to indicate authors' values in reaction dataset and add parentheses in *Adopted Levels* if insufficient (or no!) supporting arguments are available.

• M - transition multipolarity

• δ – mixing ratio (√((L+1)-pole/(L-pole)), Krane-Steffen sign convention.

Gamma-ray Energies

• Give measured energy and uncertainty (*i.e.*, do not correct for recoil energy loss).

• State source of data (unless obvious, *e.g.*, if only one keynumber)

• Uncertainties: if authors give uncertainty as:

(i) “0.3 keV for strong lines, 1 keV for weak or poorly resolved lines”; assign 0.3 to those which could be reasonably considered ‘strong’ and 1 to all others, but give authors’ statement in general comment on $E\gamma$ and define the $I\gamma$ that you consider ‘strong’ (or assign 1 keV to all).

(ii) “do not exceed 0.5 keV”; 0.5 could be assigned for all lines.

(iii) If no uncertainty is stated, point that out in general comment (for the purpose of deducing E(level) using GTOL, a default of 1 keV (adjustable by user via control record at head of dataset) will be used and this should be noted in a comment on level energy)

• If measured $E\gamma$ not available but G record is needed in order to give other information, deduce it from level energy difference and remove recoil energy loss; give no $\Delta E\gamma$ and say where $E\gamma$ came from.

Gamma-ray Intensities

- Give relative intensities, if available (don't renormalise so strongest is 100).
- Don't mix data from different reactions, or data from same reaction at different energies, when entering RI on G records (use different datasets instead, or include in comments or tabulation).
- If branching ratios are measured independently (*e.g.*, from $\gamma\gamma$ coincidences), quote these also (*e.g.*, in a comment); one set of data may be more precise than the other.
- Give uncertainties whenever authors state them; if authors give both statistical and systematic uncertainties, show statistical on G record but state systematic in comment (so uncertainty in Iγ ratios is not distorted).
- If both prompt and delayed Iγ are given, use separate datasets for them or give one set under comments.
- For multiply-placed lines, specify whether quoted Iγ has been suitably divided between placements (& or @ in column 77).

Conversion Coefficients

• Give measured α_K, α_L, *etc*., and subshell ratios (in comments or on continuation of G record); state how photon and ce intensity scales were normalised.

• Quote experimental coefficients (usually α) obtained using intensity balance arguments (these are frequently buried in the text of a paper); specify as “from intensity balance at xxxx level” where relevant.

• Include α(theory) on G record (from HSICC) when needed for calculation or argument.

γ Linear Polarisation

γ linear polarisation data may be available from Compton polarimeter measurements of relative Iγ in planes perpendicular and parallel to reaction plane.
Such data may distinguish between <u>electric</u> and <u>magnetic</u> radiations.

Angular Distributions

I_γ as a function of angle θ with respect to beam direction:

$$\mathbf{W(\theta)=1+A_2P_2(\cos\theta)+A_4P_4(\cos\theta)+\ldots}$$

- Include A_2, A_4 … ; these data are very important to evaluators and readers alike, as they provide information vital to transition multipolarity assignments.
- Remember that these are signed quantities.
- A_2, A_4 … depend on ΔJ, mixing ratio and degree of alignment σ/J, where σ is half-width of Gaussian describing the magnetic substate population.
- σ/J is usually determined from measurements of $W(\theta)$ for known $\Delta J=2$ transitions. However, many authors assume $\sigma/J=0.3$, for practical purposes.
- σ/J affects only the magnitudes of A_2, A_4.
- For high-spin states, $W(\theta)$ is largely independent of J.
- Alignment is reduced if level lifetime is not small.
- **$W(\theta)$ can determine ΔJ but <u>not</u> $\Delta\pi$.**

Angular Distributions – ctd.

Typical values of A_2, A_4 for θ relative to beam direction if $\sigma/J=0.3$
(B. Singh, McMaster University)

ΔJ	Multipolarity	Sign of A_2	Sign of A_4	Typical A_2	Typical A_4
2	Q	+	-	+0.3	-0.1
1	D	-		-0.2	0.0
1	Q	-	+	-0.1	+0.2
1	D+Q	+ or -	+	+0.5 to -0.8	0.0 to +0.2
0	D	+		+0.35	0.0
0	Q	-	-	-0.25	-0.25
0	D+Q	+ or -	-	+0.35 to -0.25	0.0 to -0.25

DCO Ratios

Directional **C**orrelations of γ-rays from **O**riented states of Nuclei

- If γ_K (known multipolarity) and γ_U (unknown multipolarity) are measured in coincidence using detectors at angles θ_1 and θ_2 to the beam:
- DCO=I(γ_U(at θ_1) gated by γ_K(at θ_2))/I(γ_U(at θ_2) gated by γ_K(at θ_1)) .
- Sensitive to ΔJ, multipolarity and mixing ratio; **independent of $\Delta\pi$.**
- Gating transitions are frequently stretched Q, but stretched D may also be used, so specify which was used.
- Authors frequently indicate expected DCO values for stretched Q and stretched D transitions for the geometry used. It is helpful to state these.
- Remember that identical values are expected for stretched Q and for D, $\Delta J=0$ transitions (although the latter are less common).

DCO Ratios – ctd.

Typical DCO values for θ_1=37°, θ_2=79°, σ/J=0.3 (B. Singh, McMaster U.)

ΔJ_γ gate, Mult	ΔJ_γ	Mult	Typical DCO
2, Q	2	Q	1.0
2, Q	1	D	0.56
2, Q	1	D+Q	0.2 to 1.3
2, Q	0	D	1.0
2, Q	0	D+Q	0.6 to 1.0
1, D	2	Q	1/0.56
1, D	1	D	1.0
1, D	0	D	1/0.56

Multipolarity

• L and $\Delta\pi$ may be determined from measured subshell ratios or conversion coefficients.

• L alone can be determined by angular distributions or DCO ratios or γ asymmetry ratios.

• $\Delta\pi$ may be determined by γ linear polarisation measurements.

• When transition strengths are calculable ($T_{1/2}$ and branching known), **R**ecommended **U**pper **L**imits (RUL) can be used to rule out some multipolarities (*e.g.*, a stretched Q transition for which $B(M2)_W$ exceeds 1 can be assigned as E2). Similarly, for a D+Q transition with large mixing, RUL may enable the rejection of E1+M2.

• Assign Mult only when measured information indicates clear preference for that assignment; otherwise, let $\gamma(\theta)$ or DCO data speak for themselves. (Exception: if no measurement exists but mult. is needed for some reason, use [M1+E2], *etc*., type of entry.)

• Mult determined for a doublet will be not reliable; it can be given in comment (with disclaimer), but not on G record.

Mixing Ratios

- Include on G record whenever available.
- Calculate from conversion electron data or $\gamma\gamma(\theta)$ using DELTA, or from subshell ratios.
- Rely on authors' deductions from $\gamma(\theta)$, DCO or nuclear orientation data.
- Note: In (HI,xnγ) studies, model-dependent values of δ are sometimes deduced from in-band cascade to crossover transition intensity ratios; these could be given in comments (stating relevant K) if considered really important, but should not be entered on G record.
- Check that correct sign convention was used by authors. Convert to Krane-Steffen if not, and take special care if uncertainties are asymmetric (-2.3 +4-2 becomes +2.3 +2-4 upon sign reversal).

Inelastic Scattering

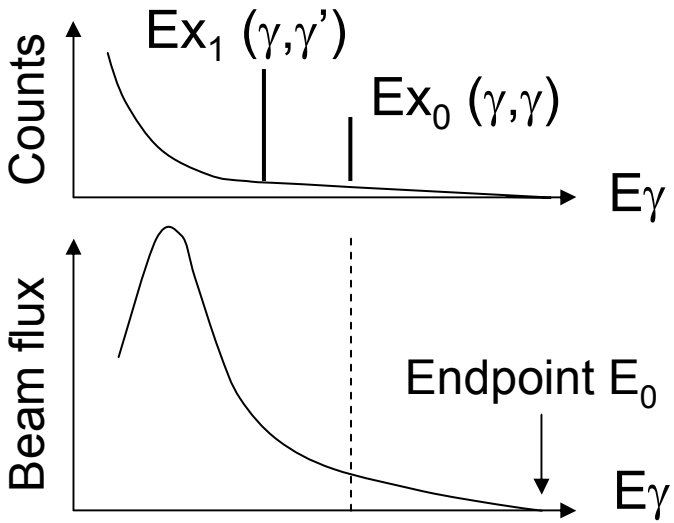
(p,p'γ), (n,n'γ), *etc*.; beam energies > Coulomb barrier.

Separate these datasets from those for (p,p'), (n,n') … and from that for Coulomb excitation.

Information of interest: typically Eγ, Iγ, $\gamma(\theta)$; maybe γ linear polarisation.

Nuclear Resonance Fluorescence

(γ,γ) and (γ,γ') measurements with Bremsstrahlung spectrum; low momentum transfer so excite low-spin states (mainly E1 and M1, but some E2 excitation).



- γ spectrum measured; areas of γ peaks at Ex_0 and Ex_1, combined with knowledge of $N\gamma(Ex_0)$, yields scattering cross sections from which width and branching information may be obtained.
- γ asymmetry differentiates D and Q excitation
- γ linear polarization differentiates M and E

Nuclear Resonance Fluorescence – ctd.

(Integrated) scattering crossection I_s (eV b) is often given:

$$I_s = ((2J+1)/(2J_0+1))\ (\Gamma\gamma_0\Gamma\gamma_f/\Gamma\gamma)\ (\pi\hbar c/E\gamma)^2\ W(\theta)/4\pi$$

where J is g.s. spin, J_0 is spin of excited level, $\Gamma\gamma \cong \Gamma$ is its total width and $\Gamma\gamma_0$, $\Gamma\gamma_f$ its decay widths for γ decay to the g.s. and the final state f (for elastic scattering, $\Gamma\gamma_0=\Gamma\gamma_f$); $W(\theta)$ represents the normalised angular distribution. Data are often taken at 127° where W=1 for D transitions.

- Give $\Gamma\gamma_0^2/\Gamma$ values (extract if necessary) on L record (col. 65 (value), 75 (unc.)); relabel field.
- If $\Gamma\gamma_f/\Gamma\gamma_0$ is measured, include relative branching on G records.

Γ is calculable from:

$$(\Gamma\gamma_0^2/\Gamma)\ /\ (\Gamma\gamma_0/\Gamma)^2$$

using known branching, or under the assumption $\Gamma=\Gamma\gamma_0+\Gamma\gamma_f$ (which needs to be stated).

- Then: $T_{1/2}$ (fs)= 0.456 /Γ (meV); include on L record.

Propagate uncertainties with care!

(Light Ion,xnypg)

(p,xnγ), (^{3}He, xnγ), (α,pγ), *etc*.

• Separate from (HI,xnγ) studies.

• Separate from datasets in which gammas are not measured (*e.g*., do not combine (d,pγ) and (d,p)).

(Heavy Ion,xnypγ)

• Relative intensities will be different for different reactions and also for a given reaction measured at different beam energies; in general, it will be simplest to use separate datasets for each study that provides significant Iγ or branching data.

• (HI,xnγ) reactions tend to populate yrast (lowest energy for given J) levels or near-yrast levels; populated states tend to have spins that increase as the excitation energy increases.

• Use band flags to delineate deduced band structure. If authors give configuration for band, include this in band description.

(Heavy Ion,xnypγ) – ctd.

• Note inconsistencies in γ order, postulated Jπ, configuration, *etc*., compared with other studies and especially with that in *Adopted Levels, Gammas.*

• Beware of multipolarity and Jπ assignments for which no supporting measurements exist. Sometimes, values inserted in order to generate a RADWARE band drawing live on in the published table of data; these do not qualify as 'data'!

• Multipolarities determined as D, Q, D+Q, *etc*, by γ(θ) or DCO are best left this way in the reaction dataset unless definite arguments exist to establish Δπ (otherwise 'D' (strong Jπ argument) and '(D)' (weak Jπ argument) become indistinguishable when written as, say, (M1)).

• Watch for and report statements of coincidence resolving time (or equivalent) since this might place a limit on level lifetime, thereby enabling RUL to be used to reject Δπ=yes for a transition multipolarity.

• For K=1/2 rotational bands, the decoupling parameter may give a clear indication of the Nilsson orbital involved in the band configuration.

(Heavy Ion,xnypγ) – ctd.

- For near-spherical nuclei, if a cascade of ΔJ=1 transitions is observed at high spin with regular energy progression, those transitions may be assigned as (M1) transitions within a common band. Exception: in rare cases, nuclei can have alternating parity bands (reflection asymmetry); for these, ΔJ=1, Δπ=yes cascades occur.
- For a well-deformed nucleus, if a cascade of ΔJ=2 transitions is observed at high spin with regular energy progression, those transitions may be assigned as E2 transitions within a common band.
- Note, however, that octupole-deformed nuclei may exhibit an apparent band which is really two ΔJ=2 rotational sequences of opposite parity, connected by cascading E1 transitions.

Special Case:

Superdeformed band data are updated continuously in ENSDF by Balraj Singh (McMaster University). One should check ENSDF as one finishes one's mass chain evaluation to be sure no SD-band data have been added since the chain was downloaded for revision.

Capture Reactions

(p,γ), (n,γ) E=thermal, (n,γ) E=res, *etc*.

• Use separate datasets for thermal and resonance n-capture data.

• Primary and secondary transitions usually appear in the same dataset even if their intensities require different normalisations.

• The Jπ of the thermal neutron capture state(s) is Jπ(target)±1/2 (*i.e*., s-wave capture is assumed).

• In thermal neutron capture, the multipolarity of a primary γ is E1, M1, E2 or M1+E2.

• For resonance n capture, ENSDF does <u>not</u> include the resonances and their properties; it is adequate to just list the bound states fed, their interconnecting gammas and any conclusions concerning level Jπ.

• In average resonance n capture, inclusion of primary gammas and their reduced intensities (which carry information on final state Jπ) is optional; a list of final level E and deduced Jπ would suffice.

Coulomb Excitation

- If authors give matrix element values, convert to B(Eλ) using

  $B(E\lambda) = |\langle M(E\lambda)\rangle|^2 / (2J_0+1)$ where J_0 is g.s. spin.

- If authors give B(Eλ)↓, convert it to B(Eλ)↑ and include it with level information.
- In the strongly deformed region, a cascade of E2 transitions with enhanced transition probabilities ($B(E2)_W > 10$) provides definitive evidence for a rotational band and for the sequence of Jπ values, provided the Jπ of one level is known independently.
- Calculate level $T_{1/2}$ from B(Eλ) and adopted γ-ray properties when possible.

ENSDF – Adopted Levels and Gammas

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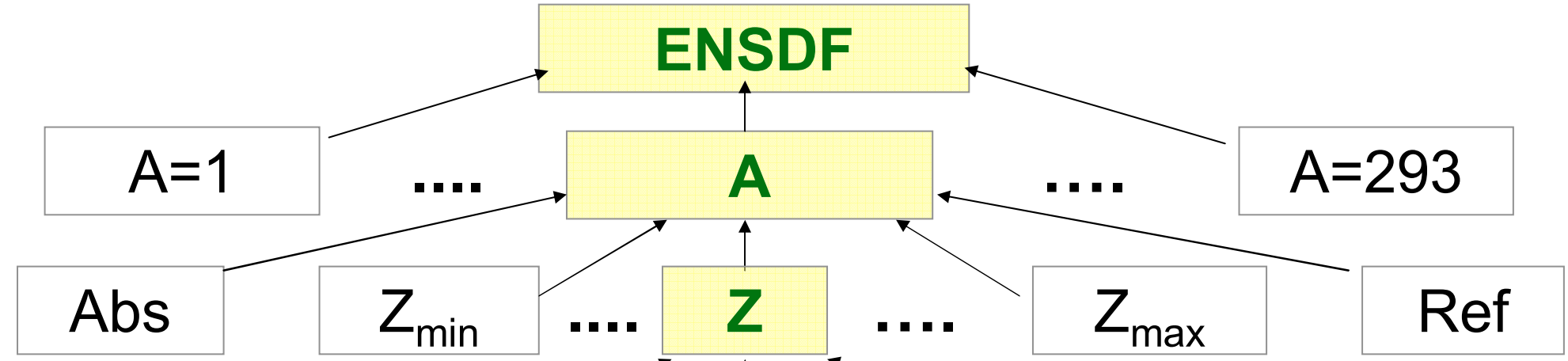
Workshop on Nuclear Structure and Decay Data: Theory and Evaluation, ICTP, Trieste, Apr. 4-15, 2005

ENSDF Database Structure



Adopted

(best values)

Q values

Levels:

(E, Jπ, T1/2, μ, Q, config, excitn.)

Gammas:

(E, Br, Mult, δ)

1 dataset

Decays

β^-

$\varepsilon+\beta^+$

α

β^-n

etc.

0 to ~6 datasets

Reactions

(HI,xnγ)

(p,p' γ)

(n, γ)

Coul. Exc.

(α,α')

(d,p)

etc.

0 to ~40 datasets

Adopted Levels, Gammas

This dataset is the heart of any nuclide evaluation !

- It is the condensation of all the information in all the other datasets and provides the **best values** known at the time of the evaluation.
- It provides the information that goes into the summary database NUDAT.
- It may be the **only** dataset that some readers will ever look at.
- The source of all data appearing here must be made transparent to the reader.

General Information

Q values:

• Usually rounded values from latest mass table (presently 2003Au03).

• Add new S(p), Q(α) (with keynumber) if available; compare with 2003Au03 value.

• Optional: Comment on uncertainties in 'SY' values; note newly-measured masses if very different from Audi's prediction.

General Comments:

e.g., Production/Identification, keynumber lists for major shell model calculations or isotope shift/hfs references (all optional).

Other Reactions:

Give reaction and keynumber if wanted for completeness, even though no data have been used and no reaction dataset has been created; *e.g.*, a continuum gamma study (optional).

Define XREF Symbols:

Every DSID in nuclide must be listed here, even if it won't be associated with any specific level.

Example 1 →

```
167IR    ADOPTED LEVELS
167IR C  Production: 92MO(78KR,p2n) E=357, 384 MEV (1997DA07).
167IR C  Identification: 1981HO10 unambiguously assign a new |a group to 167IR
167IR2C  by relating it to known transitions through a multi-dimensional
167IR3C  analysis correlating parent energies, daughter energies, and the
167IR4C  timing of events. The production reactions involved 58NI on
167IR5C  molybdenum-tin targets and 107AG on vanadium-nickel targets
167IR C  For calculation of proton decay widths for 167IR GS and isomer see
167IR2C  2000DA11.
167IR  Q            11760   SY-1070   6 6507     5    1995AU04,1997DA07
167IR CQ           |DS(n)=300 (1995AU04).
167IR CQ QA$from measured EA=6351 5 (1997DA07) for GS to GS transition; 1995AU04
167IR2CQ give QA=6495 50, reflecting lack of information concerning daughter
167IR3CQ state at that time.
167IR CQ SP        From measured EP=1064 6 (1997DA07) for GS to GS transition;
167IR2CQ SP=-1110 10 in 1995AU04.
167IR  XA171AU A DECAY (1.02 MS)
167IR  XB78KR(92MO,2NPG)
167IR  L 0           (1/2+)          35.2 MS   20
167IR2 L %A=48 6 (1997DA07)$%P=32 4 (1997DA07)$%EC+%B+=?
167IRX L XREF=B
167IR CL J         comparison of calculated and measured partial lifetimes for
167IR2CL p decay rule out d{-3/2} and h{-11/2} transitions, so 1997DA07 conclude
167IR3CL that an L=0 p is emitted to the 0+ GS of 166OS.
167IR CL %A,%P     From relative intensities of |a and p decay from level,
```

Level & Gamma Properties - General

- Every nuclide must have at least 1 level.
- Document sources of all data (dataset name, not just keynumber).
- Comment on serious discrepancies.
- Specify whether 'average' is weighted or unweighted (use larger of internal & external uncertainties in weighted averages).
- Remember to round off so uncertainty <26.
- Remember that 'level' and 'gamma' data appear in different tables in NDS; unhelpful to say "Jpi for levels with γ to 8+ isomer based on …" (in level table) or "mult for γ's observed in low spin reactions is from …" (in γ table).
- Do not include:
  - continuation G records giving CC, KC, *etc*.;
  - primary γ rays from n capture;
  - neutron capture state(s);
  - coincidence 'C' from col. 78 of G records.
  - unplaced γ rays listed in source datasets.

Level Properties

Level Energy:

• Use GTOL to calculate from adopted $E\gamma$ in most cases.

• Include all discrete levels and giant resonances; identify analog resonances.

• Adopt <u>minimum</u> number of levels consistent with source datasets.

T1/2 (or Γ):

• Specify source, *e.g.*, "from B(E2)↑ in Coulomb excitation", *etc*.

• Give bare-atom half-lives in comment (*e.g.*, "$T_{1/2}$(52Fe26+)= …").

• Remember $\Gamma=\Gamma\gamma+\Gamma p+\ldots$ for resonance, so note any assumptions such as '$\Gamma=\Gamma\gamma_0+\Gamma\gamma_1$' or '$\Gamma=\Gamma p$'.

Band Flag: (if relevant)

Give rotational band parameters in comment (if meaningful) from:

$E_K(J)=E_0+A(J(J+1)-K^2)+B(J(J+1)-K^2)^2+(-)^{(J+K)}(J+K)!/(J-K)!(A_{2K}+B_{2K}(J(J+1)-K^2)$.

Isospin: very important for low A !

Level Decay Branches: for g.s. and $T_{1/2} \geq 0.1$ s levels, include all modes that might reasonably be expected, even if not yet observed.

```
 92RB  Q 8100      7  5099   10 10750  60              1995AU04
 92RB  L 0.0          0-               4.492 S   20
 92RB2 L %B-=100 $ $B-N=0.0107 5 $
 92RBX L XREF=AB
--------------
192PO  Q             11.0E3 SY 2.2E3  SY 7320    7    1995AU04
192PO CQ            |DS(n)=360, |DS(p)=450 (1995AU04).
192PO  L 0.0          0+               33.2 MS   14
192POX L XREF=AB
192PO2 L %A AP 100$ %EC+%B+=?$
192PO CL            %A: only A DECAY observed. %(EC+B+) AP 0.4 can be
192PO2CL estimated from gross B decay theory (partial T AP 8 S)
192PO3CL (1973TA30), or AP 0.54 from partial BETA T of 6.1 S
192PO4CL calculated by 1997MO25.
-------------
168RE  Q -5800     SY8960    SY830     SY5063    13    1995AU04
168RE CQ           |DQ(|b)=400, |DS(n)=420, |DS(p)=510 (1995Au04).
168RE  L  0.0         (5+,6+,7+)       4.4 S     1
168RE2 L %EC+%B+=100$ %A AP 5E-3 $
168REX L XREF=AB
168RE CL            %A: deduced from IA/RI(199.3G in 168W) and EC decay
168RE2CL scheme for 168RE (1992Me10).
```

Example 2: decay branches

XREF Flags:

• Use ‘X(*)’ if level from dataset X cannot be uniquely identified with level in question.

• Use ‘X(energy)’ to resolve any ambiguity due to poor energy match between adopted level and dataset X level.

Example 3: XREF’s

```
59NI    L 5821      10
59NIX L XREF= BN(*5830)
59NI CL          JPI=3/2+ FROM (POL P,D) AND L(P,D)=2 FOR 5821 AND/OR
59NI2CL 5844 LEVEL(S).
59NI    L 5844      10 (3/2+,5/2+)
59NIX L XREF=BN(*5830)
59NI CL  J       L(D,P)=(2). JPI=3/2+ FROM (POL P,D) AND L(P,D)=2 FOR 5821
59NI2CL AND/OR 5844 LEVEL(S).
```

• Watch for systematic energy scale deviations between various reaction studies.

• Avoid associating a transfer reaction level with an adopted level whose configuration it would not excite.

Example 4

169Tm(d,p) Target: 1/2[411]p g.s.

n stripped from d

170Tm states populated must be 1/2[411]p⊗Ω[xxx]n

Populated:

1/2[411]p ± 1/2[521]n
1/2[411]p ± 5/2[512]n
1/2[411]p ± 7/2[633]n
1/2[411]p ± 3/2[521]n

Not populated:

7/2[404]p ± 7/2[633]n
1/2[541]p ± 5/2[512]n
1/2[541]p ± 7/2[633]n

B(Lλ)↑:

Give only when value measured, but branching or $T_{1/2}$ unknown (*e.g.*, E3 Coulomb excitation measured but no E3 transition observed).

Moments (μ, Q): static, model-independent values.

- Summarized in 1989Ra17 (evaluation) and 2001StZZ (listing); add new refs.
- Specify method used.
- Mention standards used, corrections applied (*e.g.*, Sternheimer).
- Signs matter.
- Convert g-factor data to μ.

Δ<r2> (DAVRSQ): include data in comment on g.s. (or isomer) if available.

Example 5: μ, Δ<r2>, *etc.*

```
167LU   L      0.0+X   1/2(+)          1 M       GE                    CM
167LUX L XREF=B
167LU2 L %EC+%B+=?$%IT=?
167LU3 L MOMM1=-0.0999 13 (1998GE13)$
167LU CL          DAVRSQ(170LU,167LU)=-0.291 (1998GE13); 10%
167LU2CL systematic uncertainty.
167LU CL          J,MOMM1: from collinear fast beam laser spectroscopy
167LU2CL (1998GE13). PI based on proximity of MOMM1 to value expected for
167LU3CL 1/2[411] orbital (-0.05) cf. that for the only other nearby J=1/2
167LU4CL orbital (viz. 1/2[541], |m AP +0.7).
167LU CL T        estimated by 1998GE13; based on known rare-earth diffusion …
```

.

Spin and Parity:

- An argument must be provided for every Jπ that is given.
- Use fewest and best arguments for definite Jπ; the more args. the better for uncertain J or π. Try to convince reader; enable a quick check on the impact of any new data that may become available later.
- Use flagged comments for long, repetitive arguments (*e.g.*, "Jpi based on presence of primary γ from ½+ capture state in (n, γ) E=thermal and log$f^{1u}t$<8.5 from 1/2- in … EC decay").
- If directly measured (*e.g.*, atomic beam), state the method.
- Note that μ no longer provides a strong Jπ argument (it used to).
- Avoid using multiply-placed γ's in "γ to Jπ" type arguments.
- Note that "γ's to 3/2+ and 5/2-" (2 levels) differs from "γ's to 3/2+, 5/2-" (1 level) – avoid ambiguities.
- "γ to Jπ" is a weak argument.
- In "γ to …" arguments, the level Jπ is what matters, not E(level).
- Use "logft=…from Jπ=1/2-" and L(d,p)=2 for 9/2+ target" type arguments; the parent/target Jπ is part of the argument.

Sample Jπ Arguments:

Argument(s)	**Jπ**
E2 737γ to 7/2+ g.s.; log*ft*<5.9 from 1/2+.	3/2+
Primary γ from 1/2+ in (n,γ) E=thermal; E1 438γ from 7/2- 832 level.	5/2+
From (pol d,p) and L(d,p)=3 for 0+ target.	5/2+
Log$f^{1u}t$<8.5 from 2-; M1 558γ from 4+ 1038 level.	3+
M1+E2 78γ to 1/2- 132 level.	3/2-
E1 122γ to 2- 244 level; 72γ to 4+ 50 level.	(2,3)+
Probable analog of 3/2- 358 level in ^{AA}ZZ.	(3/2-)
Unhindered α decay from (10-) parent.	(10-)
γ to 2- and γ to 4+.	(2+,3,4-)

Gamma-Ray Properties

Energy:

If E came from level energy difference, say so and recalculate after GTOL has been run (without that Eγ included, of course).

Rel. Branching:

• Scale Iγ so strongest branch is 100;

Exceptions:

Strongest line is multiply placed (& in col. 77) (give as <I+ΔI).

Strongest line is given as a limit.

Transition is within a superdeformed band.

• Omit uncertainty if only 1 branch.

• Give TI for E0 or fully converted transitions.

Multipolarity:

• [mult] means 'deduced solely from level scheme'; use [E2], *etc*., only if <u>needed</u> to calculate transition probability or CC for a transition with no measured multipolarity.

• Convert 'D' or 'Q' to '(E1)', '(E2)', *etc*., if preferred or if needed for calculation or Jπ argument; specify how Δπ was deduced.

• Remember that ‘M1,E2’ and ‘M1+E2’ are not equivalent.

Mixing Ratio:

• Include sign, if known. Absence of sign indicates modulus δ.

• If 2 solutions, give both in comment, none in MR field.

• Watch for cases where experiment gives higher limit than RUL allows.

Conv. Coeff. (CC):

Give when significant.

E0 Transitions:

Quote ρ^2(E0) from 2005Ki02 or 1999Wo07 (or from authors of later papers who provide it).

Reduced Transition Probs.:

• Give whenever calculable.

• If δ overlaps 0 or ∞, calculate for D or Q only.

• Calc. for [E1], [E2], [ΔJ>2].

• Watch out for data given as a limit.

← Example 6

Reduced Transition Probability Calculations (Special Cases)

I: Data given as limit:

δ(M1,E2)<0.3:

$B(E2)_W$: give as upper limit.

$B(M1)_W$: give av. of $B(M1)_W(\delta=0)$ and $B(M1)_W(\delta=0.3)$.

TI<i for non-dominant branch:

Assign 1/2i $\pm$ 1/2i to this transition to enable calculation of $B(L\lambda)_W$'s for other branches.

$T_{1/2}$<t:

Give resulting lower limits on B(Lλ)W's.

$T_{1/2}$>t:

Typically, forget it !

However, $B(E2)_W<0.005$ or $B(E1)_W< 2\times10^{-10}$ might, *e.g.*, be worth mentioning.

II: When $T_{1/2}$ was calculated directly from B(Lλ):

Calculate $B(L\lambda)_W\downarrow$ from measured $B(L\lambda)\uparrow$ and single-particle value (available from RULER).

Checking Your File

- Run FMTCHK and make the necessary corrections.
- Read through file (ENSDAT output may be helpful); it is amazing what the eye can catch this way.
- Check band drawings – a typographical error in Jπ or an incorrect band flag may be extremely easy to see there.
- Run PANDORA.
    - Use FILE.ERR output to identify physics errors.
    - Use FILE.GLE to check for:

(i) Inconsistencies in Jπ, MULT, δ between adopted and decay datasets.

(ii) Adopted photon branching that has not been renormalised so the strongest branch is 100.

(iii) Levels or transitions in decay or reaction datasets which were accidentally omitted from *Adopted Levels, Gammas* (or conversely).