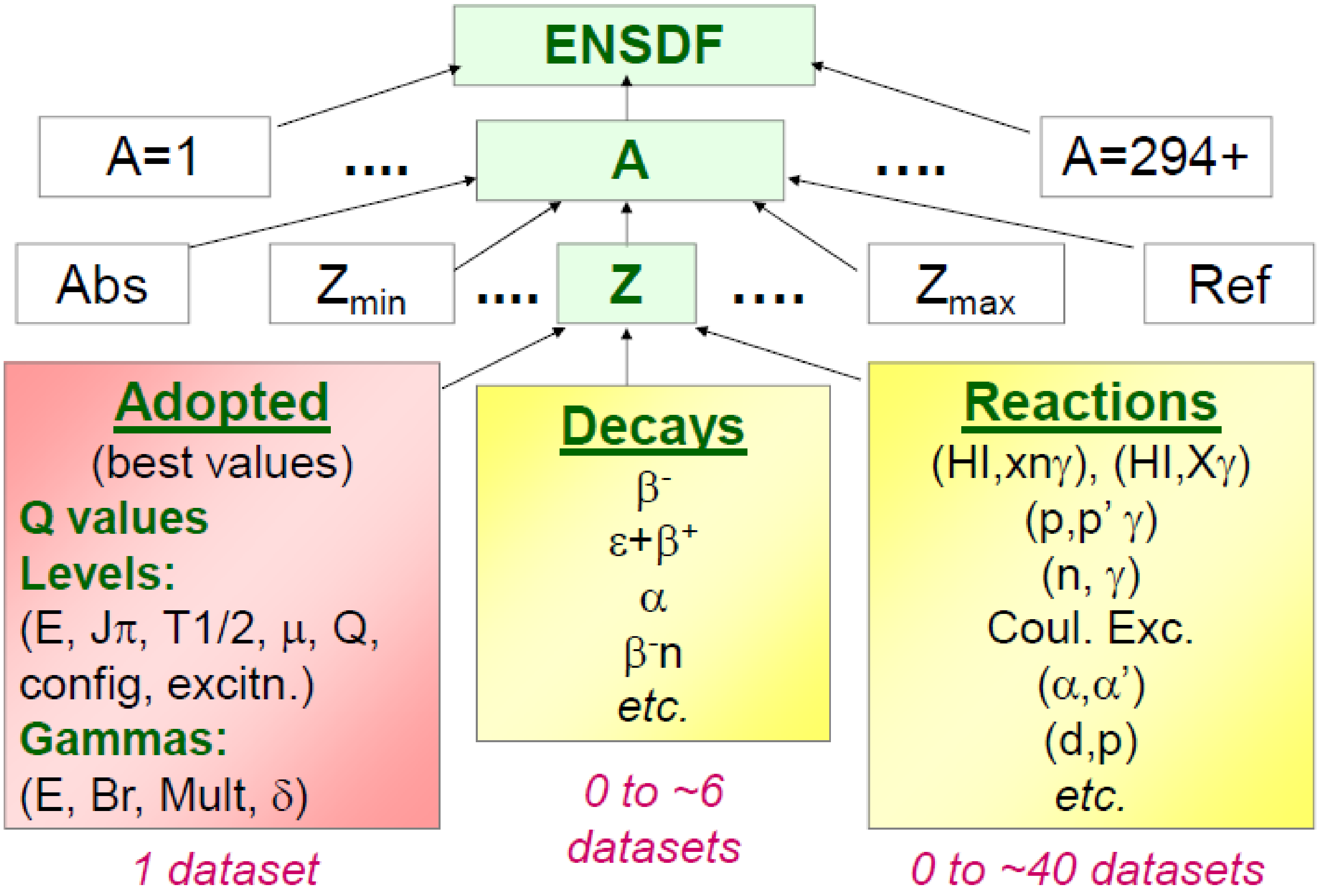
Adopted Levels and Gammas

Libby McCutchan
National Nuclear Data Center

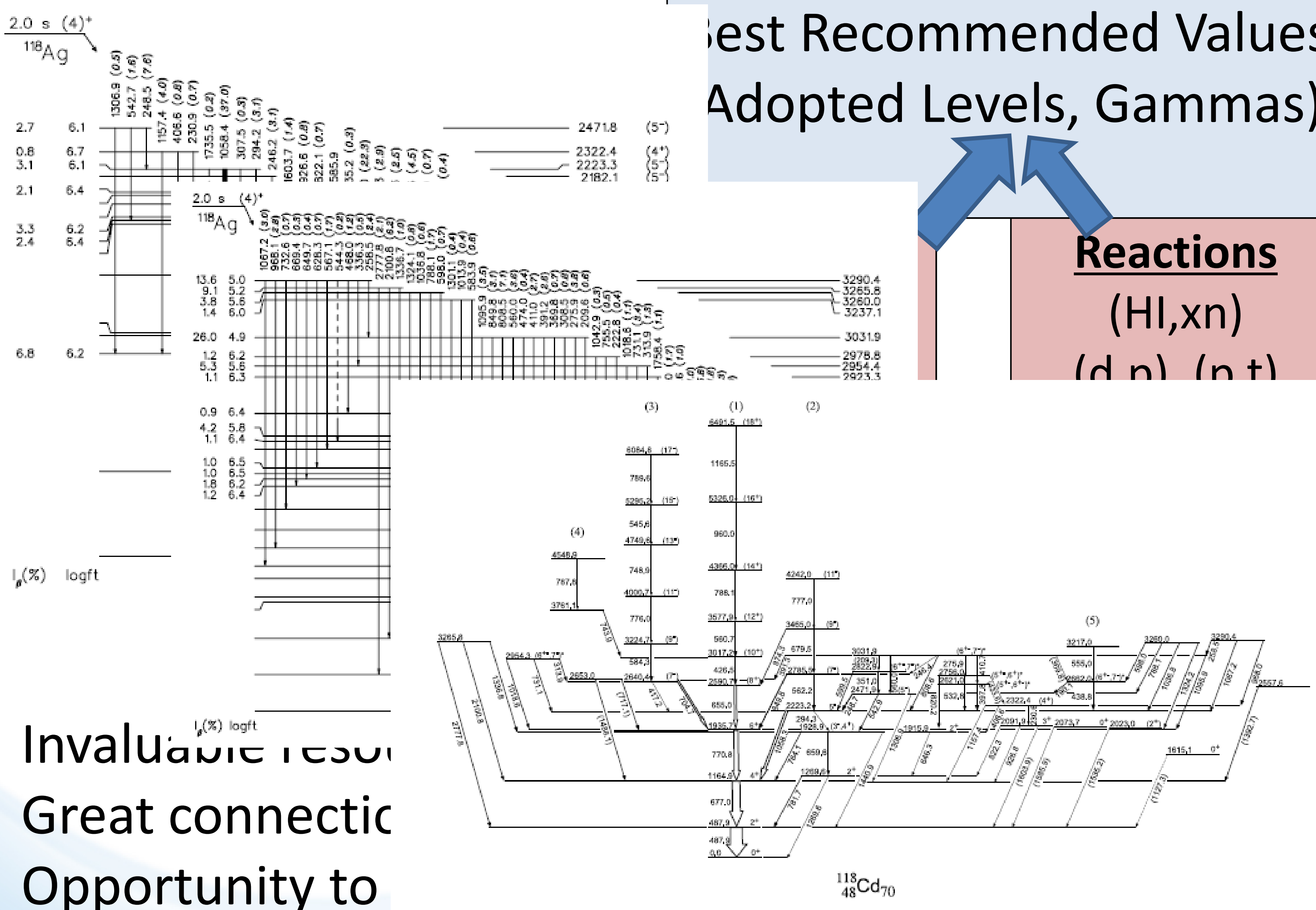
BROOKHAVEN NATIONAL LABORATORY
a passion for discovery
U.S. DEPARTMENT OF ENERGY | Office of Science

ENSDF Database Structure



Slide courtesy of Coral Baglin

What ENSDF evaluation is…



est Recommended Values
Adopted Levels, Gammas)

Reactions
(HI,xn)
(d,p), (p,t)

- Invaluable resou
- Great connectic
- Opportunity to … ns

The heart of the evaluation

- Solve the puzzle and provide your best set of recommended values for every property measured

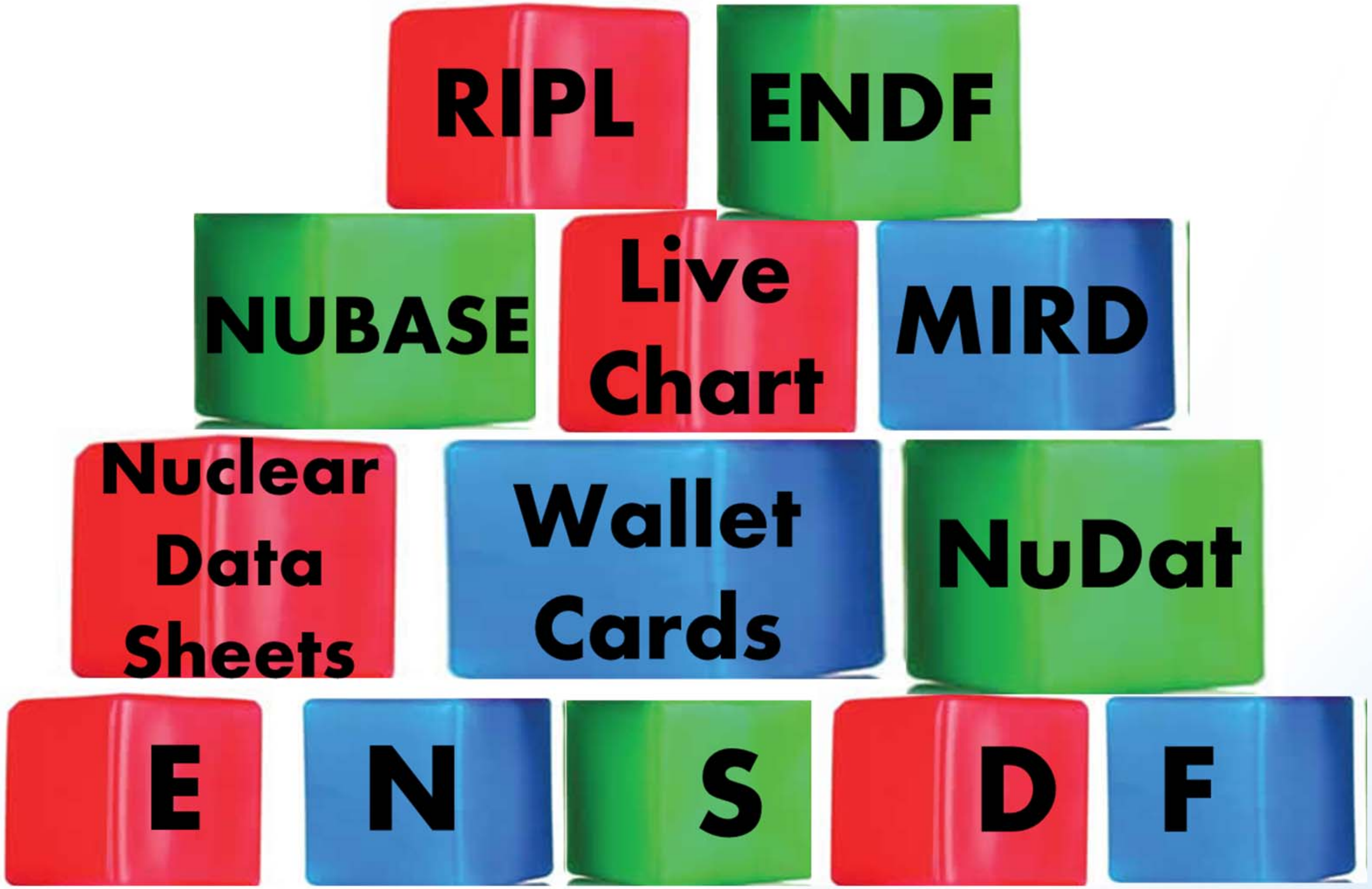
- Most derived libraries are based on the Adopted Levels/Gammas

- In many cases, the **ONLY** dataset readers consider

- Values provided here must be **transparent** and **traceable**

- Your place to provide input and point out discrepancies

ENSDF is the Foundation

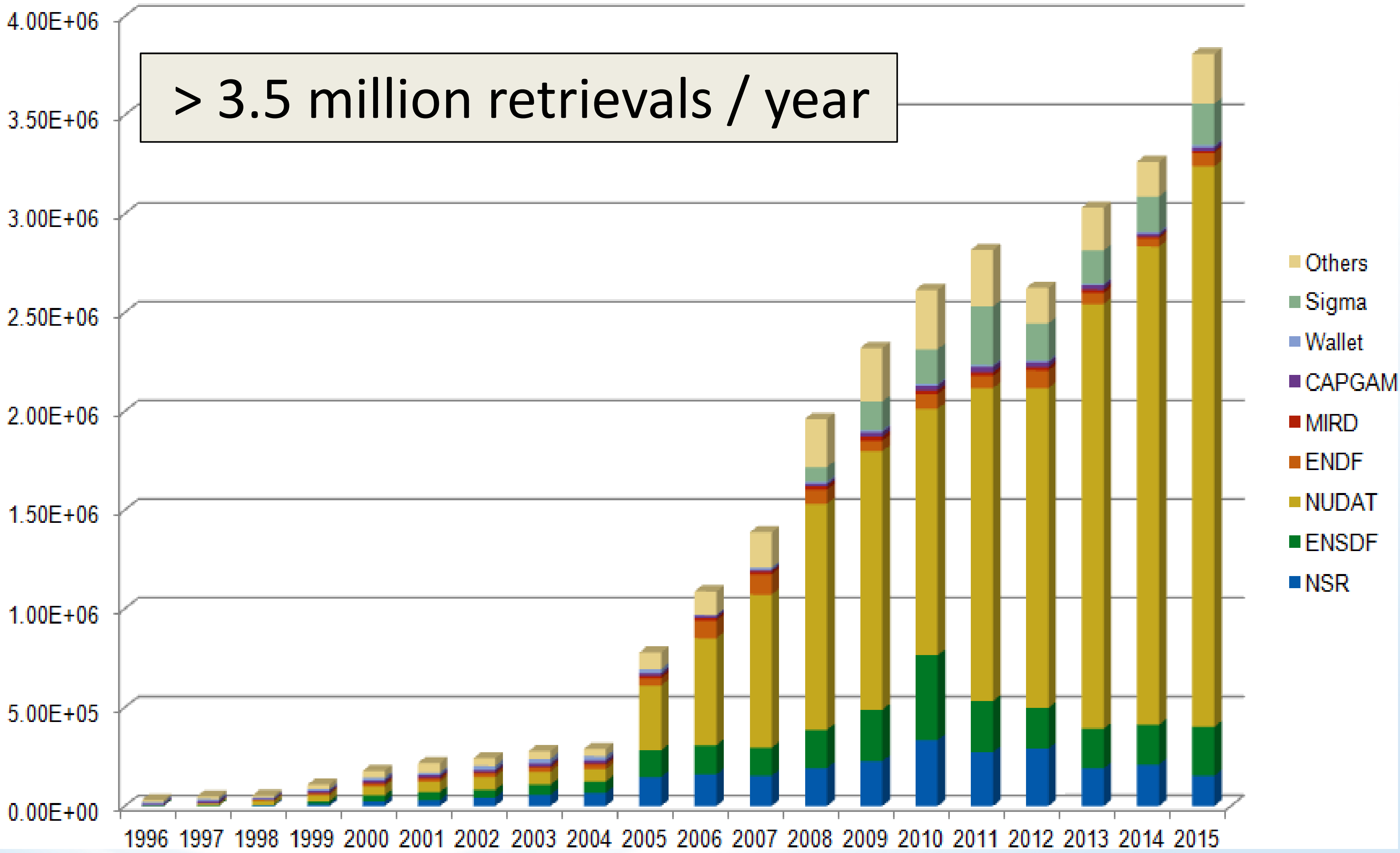


It is Unique: Only Nuclear Database continuously updated

It is Complete: **All** nuclei and **all** level and radiation properties

It is Versatile: Feeds back into both basic and applied sciences

Database Usage



NuDat is by far the most used means of accessing data

NuDat

Z \ N	83	84	85	86	87	88	89	90	N
Z	149Dy 4.20 M ε: 100.00%	150Dy 7.17 M ε: 64.00% α: 36.00%	151Dy 17.9 M ε: 94.40% α: 5.60%	152Dy 2.38 H ε: 99.90% α: 0.10%	153Dy 6.4 H ε: 99.99% α: 9.4E-3%	154Dy 3.0E+6 Y α: 100.00%	155Dy 9.9 H ε: 100.00%	156Dy STABLE 0.056%	157Dy 8.14 H ε: 100.00%
65	148Tb 60 M ε: 100.00%	149Tb 4.118 H ε: 83.30% α: 16.70%	150Tb 3.48 H ε: 100.00% α < 0.05%	151Tb 17.609 H ε: 99.99% α: 9.5E-3%	152Tb 17.5 H ε: 100.00% α < 7.0E-7%	153Tb 2.34 D ε: 100.00%	154Tb 21.5 H ε: 100.00% β- < 0.10%	155Tb 5.32 D ε: 100.00%	156Tb 5.35 D ε: 100.00%
64	147Gd 38.06 H ε: 100.00%	148Gd 70.9 Y α: 100.00%	149Gd 9.28 D ε: 100.00% α: 4.3E-4%	150Gd 1.79E+6 Y α: 100.00%	151Gd 123.9 D ε: 100.00% α≈8.0E-7%	152Gd 1.08E14 Y 0.20% α: 100.00%	153Gd 240.4 D ε: 100.00%	154Gd STABLE 2.18%	155Gd STABLE 14.80%
63	146Eu 4.61 D ε: 100.00%	147Eu 24.1 D ε: 100.00% α: 2.2E-3%	148Eu 54.5 D ε: 100.00% α: 9.4E-7%	149Eu 93.1 D ε: 100.00%	150Eu 36.9 Y ε: 100.00%	151Eu ≥1.7E+18 Y 47.81% α	152Eu 13.528 Y ε: 72.10% β-: 27.90%	153Eu STABLE 52.19%	154Eu 8.601 Y β-: 99.98% ε: 0.02%
62	145Sm 340 D ε: 100.00%	146Sm 10.3E+7 Y α: 100.00%	147Sm 1.060E11 Y 14.99% α: 100.00%	148Sm 7E+15 Y 11.24% α: 100.00%	149Sm STABLE 13.82%	150Sm STABLE 7.38%	151Sm 90 Y β-: 100.00%	152Sm STABLE 26.75%	153Sm 46.284 H β-: 100.00%

Ground and isomeric state information for $^{151}_{64}$**Gd**

E(level) (MeV)	Jπ	Δ(MeV)	$T_{1/2}$	Decay Modes
0.0	7/2-	-74.1877	123.9 d *10*	ε : 100.00 % α ≈ 8.0E-7 %

A list of levels, a level scheme and decay radiation information are available

NuDat Retrieval

ADOPTED LEVELS, GAMMAS for ^{151}Gd

Author: BALRAJ SINGH   Citation: Nuclear Data Sheets 110, 1 (2009)

Full ENSDF file

$Q(\beta-)$=-2565 keV *4* S_n= 6496 keV *7* S_p= 6685 keV *7* Q_α= 2653 keV *3*

References:
A: ^{151}Tb ε decay (17.609 h)
B: ^{151}Tb ε decay (25 s)
C: $^{130}Te(^{26}Mg,\gamma5n)$:sd
D: $^{149}Sm(\alpha,\gamma2n)$,$^{150}Sm(\alpha,\gamma3n)$
E: $^{152}Gd(d,t)$
F: $^{152}Gd(^3He,\alpha)$

E_{level} (keV)	XREF	Jπ	$T_{1/2}$	E_γ (keV)	I_γ	γ mult.	Final level	
0.0	EF	7/2-	123.9 d *10* % ε = 100 % α ≈ 0.8E-6					
108.094 *7*	A DEF	5/2-	2.80 ns *11*	108.088 *10*	100	M1+E2	0.0	7/2-
379.30 *3*	B DEF	9/2-		271.2 *3* 379.39 *4*	0.7 *1* 100.0 *4*	[E2] M1(+E2)	108.094 0.0	5/2- 7/2-
395.445 *7*	A DE	3/2-	0.29 ns *3*	287.357 *10* 395.444 *10*	100 *3* 38 *1*	M1+E2 E2	108.094 0.0	5/2- 7/2-
426.688 *7*	A DEF	5/2-		318.60 *3* 426.692 *10*	8.8 *3* 100 *3*	M1(+E2) M1	108.094 0.0	5/2- 7/2-
575.619 *8*	A	1/2-	0.23 ns *3*	148.918 *11* 180.186 *10*	3.1 *1* 100 *4*	[E2] M1+E2	426.688 395.445	5/2- 3/2-

References

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 radioactive decay, a single nuclear reaction, or the combined results of a number of similar types of experiments, such as (HI,xnγ) reactions. The data given in ENSDF are primarily derived from experimental information.

The general policies these data sets and in th Sheets (NDS) are discussed

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$^\Pi$**: Spin and parity with arguments supporting the assignment.
3. **$T_{1/2}$ or Γ**: Half-life or total width in center of mass.
4. **Decay branching** for the ground state and isomers (an isomer is defined as a nuclear level with $T_{1/2}\geq0.1$ s or one for which a separate decay data set is given in ENSDF).
5. **Q**,μ: Static electric and magnetic moments.

Guidelines for Evaluators

M. J. Martin

Oak Ridge National Laboratory, Oak Ridge Tennessee

Adopted Dataset

Sometimes it's the only dataset

Data for 75Ni

Download: AR_105B53DE50C8F95C841A82CF301D0F80_1.ens

^{75}Ni **Adopted Levels** 20130

Published: 2013 Nuclear Data Sheets.

Q_β=10230 *SY* **S_n=3860 *SY*** **S_p=19070 *SY*** **Q_α=-15670 *SY*** **2012Wa38**

S(2n)=10280 300, S(2p)=36210 760, Q(β^-n)=3690 300 (syst,2012Wa38).

Estimated uncertainties (2012Wa38): 300 for Q(β^-), 500 for S(n), 670 for S(p) and Q(α).

History

Type	Author	Citation	Cutoff Date
Full evaluation	Alexandru Negret, Balraj Singh	Nuclear Data Sheets 114, 841 (2013)	30-Jun-2013

1998Am04 (also 1995AmZY,1992WeZX): ^{75}Ni identified after the ^{9}Be(^{86}Kr,X) reaction at E=500 MeV/nucleon with a 2 g/cm^2 target. Bρ-ΔE-tof technique used, β particles detected.

2010Ho12 (also 2005Ho08): ^{75}Ni identified in the ^{9}Be(^{86}Kr,X) reaction at E=140 MeV/nucleon with a 376 g/cm^2 target. Fully-ionized ^{86}Kr beam, A1900 fragment separator at NSCL facility using Bρ-ΔE-Bρ method. After separation, the mixed beam was implanted into the NSCL β-counting system (BCS) consisting of stacks of Si PIN detectors, a double-sided Si strip detector (DSSD) for implantation of ions, and six single-sided Si strip detectors (SSSD) followed by two Si PIN diodes. The identification of each implanted event was made from energy loss, time-of-flight information and magnetic rigidity. The implantation detector measured time and position of ion implantations and β decays. Neutrons were detected with NERO detector. Measured β- and βn-correlated events with ion implants, half-life of ^{75}Ni and delayed-neutron emission probability. A total of 1905 implants were detected, and 43 correlated βn coincidences were observed.

Theoretical calculations (half-life,%β^-n): 1989Kr02, 2002Gr16, 2005Gr29, 2005Bo19, 2008Ma17.

^{75}Ni levels

E_{level}	$T_{1/2}$	Comments
0.0	344 ms *25*	%β^-=100; %β^-n=10.0 *28* (2010Ho12) **$T_{1/2}$:** from measurement of time sequence of decay type events correlated with the implanted nuclei (of ^{75}Ni) in Si detectors (2010Ho12). The authors used method of maximum likelihood analysis which required, as input parameters, values of β-detection efficiency, background, half-lives of daughter and granddaughter nuclei and experimental or theoretical values of %β^-n of all nuclei involved. Others: 344 ms *+20-24* (2005Ho08, previous result from 2010Ho12), 0.6 s 2 (1998Am04). **J^π:** 7/2+ proposed from systematics (2012Au07) and theory (1997Mo25). Shell-model calculations quoted in 2005Gr29 (also 2010RaZY) support 9/2+ for ^{69,71,73,75}Ni isotopes.

- When only ground state properties have been measured
- When only studied through a single reaction

Adopted Dataset

Other times its one of many

Data for 152Sm

Download: AR_105B53DE50C8F95C841A82CF301D0F80_2.ens **View:** Levels: PostScript level schemes in the Nuclear Data Sheets style
Bands: PostScript band drawings in the Nuclear Data Sheets style

^{152}Sm

Adopted Levels, Gammas

Published: 2013 Nuclear Data Sheets.

Q_{β}=-1874.6 *7* S_n=8257.7 *6* S_p=8666 *5* Q_{α}=220.9 *20* 2012Wa38

History

Type	Author	Citation	Cutoff Date
Full evaluation	M. J. Martin	Nuclear Data Sheets 114, 1497 (2013)	31-Aug-2013

^{152}Sm levels

Charge distribution: 2004An14 and references therein.

Isomer shift: 1979Po04, 1978Ya11, 1974Ba77, 1968Ga26, 1968Be24, 1967St12, 1967Ye01.

Isotope shift: 1979Po04, 1978Ya11, 1970Hi03.

The band assignments are from Coulomb excitation except for the Kπ=7- band which is from (α,2nγ).

Cross References (XREF) Flags

A ^{152}Pm β⁻ Decay (4.12 min)	N ^{154}Sm(p,t)
B ^{152}Pm β⁻ Decay (7.52 min)	O Muonic Atom
C ^{152}Pm β⁻ Decay (13.8 min)	P ^{252}Cf Spontaneous Fission Decay
D ^{152}Eu Electron Capture Decay (13.517 y)	Q ^{150}Sm(t,p)
E ^{152}Eu Electron Capture Decay (9.3116 h)	R ^{150}Sm(t,pγ)
F ^{150}Nd(α,2nγ)	S ^{155}Gd(n,α)
G ^{151}Sm(n,γ) E=Thermal	T ^{154}Sm(^{12}C,^{14}C)
H ^{151}Sm(d,p)	U ^{152}Sm(γ,γ'): Mossbauer
I ^{152}Sm(γ,γ')	V ^{154}Sm(α,^{6}He)
J ^{152}Sm(n,n'γ)	W ^{154}Sm(^{208}Pb,Xγ),(^{176}Yb,Xγ)
K Coulomb Excitation	X ^{152}Sm(α,α'): Giant Resonances
L ^{152}Sm(x,x')	Y ^{151}Sm(n,γ) E=Resonance
M ^{153}Eu(t,α)	

E_{level}[#]	Jπ	$T_{1/2}$[@]	XREF	Comments
0.0[&]	0+	stable	ABCDEFGHIJ KL NOPQR T VW	$\langle r^2 \rangle^{1/2}$=5.084 fm 6 (2004Zn14).
121.7818[&] *3*	2+	1.403 ns *11*	ABCDEFGHIJ KLMNOPQRST UVW	Additional documentation [0] μ=+0.82 *4* (1967At04,1992De29,2005St24) μ: from g=+0.411 19, a weighted average of 0.419 25 (muonic atom, 1967At04) and 0.40 3 (13-y Eu ε decay, 1992De29). Q=-1.683 *18* (1978Ya11,1979Po04,2005St24) Q: weighted average of -1.702 17 (1978Ya11) and -1.666 16 (1979Po04). Jπ: E2 γ to 0+. $T_{1/2}$: weighted average of $T_{1/2}$=1.396 ns 8 from 13-y ε decay and 1.420 ns 12 from B(E2)=3.451 8 with α=1.155 17. The B(E2) value is a weighted average of values from Coulomb excitation and muonic atom. Other: 1.47 ns 4 from 4.12-min Pm β⁻ decay. Isotope shift: 1995Be19, 1994Ji08.
366.4793[&] *9*	4+	57.7 ps *6*	ABCDEFGH J KLMN QRS	Additional documentation [1] μ=+1.68 *20* (1987By02,2005St24); Q=-2.6 *14*

Top of the file

Data for 151Gd

Download: AR_9B18DD8BB3CAB3D5DB3815B6182BBDD5_1.ens **View:** Levels: PostScript level schemes in the Nuclear Data Sheets style
Bands: PostScript band drawings in the Nuclear Data Sheets style

^{151}Gd

Adopted Levels, Gammas

Published: 2009 Nuclear Data Sheets.

Q_{β^-}=-2565 *4* S_n=6496 *7* S_p=6685 *7* Q_α=2653 *3* 2012Wa38

Q_{β^-}=-2565 *4* S_n=6497 *7* S_p=6687 *7* Q_α=2652.2 *29* 2003Au03

Note: Current evaluation has used the following Q record.

History

Type	Author	Citation	Cutoff Date
Full evaluation	Balraj Singh	Nuclear Data Sheets 110, 1 (2009)	20-Nov-2008

Additional documentation [0]

Mass excess measurement: 1975Ka25.

Isotope shift measurement: 1988Al40.

Additional documentation [1]

Theoretical work dealing with nuclear structure: 1979Sm01, 1977Bu28, 1977Kl04, 1977Sm01.

SD structure theory and analysis: 2002Pa25, 1999Kh05, 1998Ha53.

Additional documentation [2]

Adopted Levels

^{151}Gd levels

SD bands in ^{151}Gd are tentative.

Cross References (XREF) Flags

A ^{151}Tb Electron Capture Decay (17.609 h)	D ^{149}Sm(α,2nγ), ^{150}Sm(α,3nγ)
B ^{151}Tb Electron Capture Decay (25 s)	E ^{152}Gd(d,t)
C ^{130}Te(^{26}Mg,5nγ): SD	F ^{152}Gd(^{3}He,α)

E_{level}[@]	Jπ[#]	$T_{1/2}$	XREF	Comments
0.0[d]	7/2-	123.9 d *10*	EF	%ε=100; %α≈0.8×10^{-6} %α from Iα/I(K x ray)=0.8×10^{-8} *+8-4* (1965Si06). **Jπ:** atomic-beam method (1972Ek05) and L(d,t)=3. **$T_{1/2}$:** from 1984Gr15. Others: 1983Vo10, 1963Mi04, 1958An34, 1950He18. μ=0.77 *6* (1989Ra17,1987Be33) **μ:** nuclear orientation (1987Be33). See also 2005St24 compilation of moments. α decay theory: 2006Me15, 2003Gu13.
108.094 *7*	5/2-	2.80 ns *11*	A DEF	μ=-1.08 *13* (1989Ra17,1977VaZJ,1977GrZF) **μ:** from integral PAC (1976Ba26,1976Ba59). Others: -1.23 17 (1976Ba26,1976Ba59,1989Ra17), -[illegible] 2005St24 compilation of moments. **Jπ:** M1+E2 γ to 7/2- and γγ(θ) in ^{151}Tb ε decay. **$T_{1/2}$:** weighted average of 3.00 ns 10 (ceγ(t), 1972Af03), 2.60 ns 13 (ceγ(t), 1970Mo14), 2.72 ns 25 1969BoZR).
379.30[c] *3*	9/2-		B DEF	**Jπ:** from γ(θ), γ(pol) data in (α,xnγ) and M1 γ to 7/2-.

Adopted Gammas

γ(^{151}Gd)

E_{level}	E_γ[#]	I_γ[#]	Mult.[&]	δ[&]	α	Comments
108.094	108.088 *10*	100	M1+E2	-0.85 *1*	1.729	B(M1)(W.u.)=1.3×10^{-3} *1*; B(E2)(W.u.)=42 *3* α(K)=1.185 *17*; α(L)=0.422 *7*; α(M)=0.0972 *16*; α(N+..)=0.0250 *4* α(N)=0.0219 *4*; α(O)=0.00301 *5*; α(P)=7.87×10^{-5} *12* **Mult.,δ:** from ce and γγ(θ) in ^{151}Tb ε decay.
379.30	271.2 *3*	0.7 *1*	[E2]		0.0825	α(K)=0.0620 *9*; α(L)=0.01599 *24*; α(M)=0.00364 *6*; α(N+..)=0.000941 *14* α(N)=0.000822 *12*; α(O)=0.0001157 *17*; α(P)=3.80×10^{-6} *6*
	379.39 *4*	100.0 *4*	M1(+E2)	<0.25	0.0509 *10*	α(K)=0.0431 *9*; α(L)=0.00609 *10*; α(M)=0.001320 *20*; α(N+..)=0.000354 *6* α(N)=0.000304 *5*; α(O)=4.71×10^{-5} *8*; α(P)=3.16×10^{-6} *7* **Mult.,δ:** ce data in (α,xnγ).
395.445	287.357 *10*	100 *3*	M1+E2	+0.21 *2*	0.1056	B(M1)(W.u.)=2.0×10^{-3} *2*; B(E2)(W.u.)=0.6 *1* α(K)=0.0892 *13*; α(L)=0.01284 *18*; α(M)=0.00279 *4*; α(N+..)=0.000748 *11* α(N)=0.000642 *9*; α(O)=9.94×10^{-5} *14*; α(P)=6.56×10^{-6} *10* **Mult.,δ:** from γγ(θ) and ce data in ^{151}Tb ε decay.
	395.444 *10*	38 *1*	E2		0.0265	B(E2)(W.u.)=1.1 *1* α(K)=0.0211 *3*; α(L)=0.00425 *6*; α(M)=0.000952 *14*; α(N+..)=0.000249 *4* α(N)=0.000216 *3*; α(O)=3.14×10^{-5} *5*; α(P)=1.378×10^{-6} *20* **Mult.:** from γγ(θ) and ce data in ^{151}Tb ε decay.
426.688	318.60 *3*	8.8 *3*	M1(+E2)	<2	0.069 *13*	α(K)=0.057 *13*; α(L)=0.0094 *4*; α(M)=0.00207 *5*; α(N+..)=0.000549 *20* α(N)=0.000473 *14*; α(O)=7.1×10^{-5} *5*; α(P)=4.0×10^{-6} *11* **Mult.,δ:** from ce data in ^{151}Tb ε decay.
	426.692 *10*	100 *3*	M1		0.0380	α(K)=0.0322 *5*; α(L)=0.00450 *7*; α(M)=0.000974 *14*; α(N+..)=0.000262 *4* α(N)=0.000224 *4*; α(O)=3.49×10^{-5} *5*; α(P)=2.36×10^{-6} *4*

Before you start

- “Finalize” decay and reaction datasets
  (might have to go back and revise)

- Double check NSR for publications, particularly non-reaction or decay papers

- Personal note: set aside sufficient time for creating the Adopted Levels and Gammas

The Top of the File

Q values:

- From most recent mass evaluation
- Can incorporate results from newer mass measurements
- Indicate systematic uncertainty
- Optional: S(2n), S(2p), other energetically allowed decay modes

$^{70}_{27}Co_{43}$–1 NUCLEAR DATA SHEETS

Adopted Levels

$Q(\beta^-)$=12290 *300*; S(n)=4820 *350*; S(p)=15150 *SY*; $Q(\alpha)=-1.26\times10^4$ *3* 2012Wa38. ← In format

ΔS(p)=500 (2012Wa38). ← As Q comments

S(2n)=11140 *300*; S(2p)=33200 syst *590*; $Q(\beta^-n)$=4990 *300* (2012Wa38). ←

2015Pr10: ^{70}Co produced in fragmentation of a ^{76}Ge beam at E=130 MeV/nucleon on a ^{9}Be target separated with the A1900 fragment separator and identified through ΔE–TOF measurements. Measured Eγ, Iγ, $\beta\gamma$, $\beta(t)$, $\beta\gamma(t)$ using 16 detectors of the segmented Ge array (SeGA) for γ's and a planar Ge double-sided strip detector for β's. Measured $T_{1/2}$ from time correlation between implantation events and β events in the planar Ge, including decay curves gated by γ rays.

2011Da08: ^{70}Co produced in fragmentation of a ^{86}Kr beam at E=57.8 MeV/nucleon on a natural Ta target. Isotopes separated with the LISE2000 spectrometer and identified through ΔE and time-of-flight measurements. Measured $T_{1/2}$ from time correlation between implantation and β events in a DSSD detector.

2005NiZZ: ^{70}Co produced in fragmentation of a ^{86}Kr beam at E=63 MeV/nucleon on a ^{9}Be target. Reaction products separated with the RIPS spectrometer and identified using trajectory, ΔE, and TOF measurements using 4 position sensitive PPACs, a single-sided strip detector and two scintillators. Measured $T_{1/2}$ using implant-β(t).

The Top of the File

General comments:

- Production/identification reference descriptions (for newer nuclides)
- References where nucleus was studied but no “usable” data
- References for mass measurements, isomer shift measurements, …
- Lists of theoretical papers, T1/2 measurements, …

$^{70}_{27}Co_{43}$–1 NUCLEAR DATA SHEETS

Adopted Levels

Q(β⁻)=12290 *300*; S(n)=4820 *350*; S(p)=15150 *SY*; Q(α)=–1.26×10^4 *3* 2012Wa38.
ΔS(p)=500 (2012Wa38).
S(2n)=11140 *300*; S(2p)=33200 syst *590*; Q(β⁻n)=4990 *300* (2012Wa38).
2015Pr10: ^{70}Co produced in fragmentation of a ^{76}Ge beam at E=130 MeV/nucleon on a ^{9}Be target separated with the A1900 fragment separator and identified through ΔE–TOF measurements. Measured Eγ, Iγ, βγ, β(t), βγ(t) using 16 detectors of the segmented Ge array (SeGA) for γ's and a planar Ge double–sided strip detector for β's. Measured $T_{1/2}$ from time correlation between implantation events and β events in the planar Ge, including decay curves gated by γ rays.
2011Da08: ^{70}Co produced in fragmentation of a ^{86}Kr beam at E=57.8 MeV/nucleon on a natural Ta target. Isotopes separated with the LISE2000 spectrometer and identified through ΔE and time–of–flight measurements. Measured $T_{1/2}$ from time correlation between implantation and β events in a DSSD detector.
2005NiZZ: ^{70}Co produced in fragmentation of a ^{86}Kr beam at E=63 MeV/nucleon on a ^{9}Be target. Reaction products separated with the RIPS spectrometer and identified using trajectory, ΔE, and TOF measurements using 4 position sensitive PPACs, a single–sided strip detector and two scintillators. Measured $T_{1/2}$ using implant–β(t).

Cross Reference (XREF) Flags

- All DSID's must be included, even if not associated with a level
- Can extend XREF's past O:Others, if wanted
- Order based on 1) decay datasets 2) increasing target mass. However, not a strict rule; more extensive datasets can come earlier.

$^{70}_{30}Zn_{40}$–1 NUCLEAR DATA SHEETS

Adopted Levels, Gammas

Q(β^-)=−654.6 *16*; S(n)=9218.4 *21*; S(p)=11117.5 *24*; Q(α)=−5983.3 *24* 2012Wa38.
S(2n)=15700.5 *21*; S(2p)=20679 *4* (2012Wa38).

^{70}Zn Levels

Cross Reference (XREF) Flags

A ^{70}Cu β^- Decay (44.5 s)	G ^{70}Zn(p,p'γ)	M ^{208}Pb(^{64}Ni,Xγ)
B ^{70}Cu β^- Decay (33 s)	H ^{70}Zn(α,α')	N ^{238}U(^{76}Ge,Xγ)
C ^{70}Cu β^- Decay (6.6 s)	I ^{70}Zn(n,n'γ)	O Others:
D ^{70}Ga ε Decay	J ^{70}Zn(e,e')	^{70}Zn(d,d')
E ^{68}Zn(t,p)	K Coulomb Excitation	^{70}Zn(^{3}He,^{3}He')
F ^{70}Zn(p,p'),(pol p,p')	L ^{71}Ga(d,^{3}He)	^{73}Ge(n,α)

Adopted Levels

- Take a bottom's up approach
- Fixing lower levels aids in understanding higher level properties
- It gets easier as you go !!!

$T_{1/2}$

- Specify source
- Comment on discrepancies

E_{level}	J^{π}#	$T_{1/2}$ b	XREF	Comments
0.0	7/2-	269 y *3*	ABCDEFGHIJ KLM	%β^-=100 μ=-1.588 *15* (1996Kl04) Q=-0.12 *3* (1996Kl04) $<r^2>^{1/2}$=3.408 fm 11 (2004An14,evaluation). **μ,Q:** collinear LASER spectroscopy (1996Kl04). Other: μ=-1.3 3 (1967Tr12,optical method). $\Delta<r^2>(^{38}Ar,^{39}Ar)$=0.04 fm^{-2} 7 (1996Kl04) **J^{π}:** spin from optical hyperfine structure (1967Tr12); parity from L(d,p)=L(d,t)=3. **$T_{1/2}$:** from 1965St09. Other: 265 y 30 (1952Ze01). Adopted (1977En02) neutron pick-up spectroscopic factor (S)=1.2 2. Adopted (1977En02) neutron stripping spectroscopic factor (S)=0.64 12. Additional documentation [1]

Spin and Parity Assignment

- Must be provided for every Jpi assigned
- Use few and best arguments
- If directly measured, state the method (2013Ma15)

Adopted Levels

Decay mode, moments on continuation record
Quadrupole moment: MOME2 (in eb units)
Magnetic Moment: MOMM1 (in μ_n)

Decay mode: include all expected

E_{level}	J^{π}#	$T_{1/2}$b	XREF	Comments
0.0	7/2-	269 y *3*	ABCDEFGHIJ KLM	%β^-=100 μ=-1.588 *15* (1996K104) Q=-0.12 *3* (1996K104) $\langle r^2\rangle^{1/2}$=3.408 fm 11 (2004An14,evaluation). **μ,Q:** collinear LASER spectroscopy (1996K104). Other: μ=-1.3 3 (1967Tr12,optical method). $\Delta\langle r^2\rangle(^{38}Ar,^{39}Ar)$=0.04 fm^{-2} 7 (1996K104). **J^{π}:** spin from optical hyperfine structure (1967Tr12); parity from L(d,p)=L(d,t)=3. **$T_{1/2}$:** from 1965St09. Other: 265 y 30 (1952Ze01). Adopted (1977En02) neutron pick-up spectroscopic factor (S)=1.2 2. Adopted (1977En02) neutron stripping spectroscopic factor (S)=0.64 12. Additional documentation [1]

Magnetic and Quadrupole Moments

- Summarized in 2014StZZ, 2016St14
- Specify experimental technique
- Mention standards and/or corrections

Adopted Levels

- Take a bottom's up approach
- Fixing lower levels aids in understanding higher level properties
- It gets easier as you go !!!

E_{level}	J^{π}#	$T_{1/2}$ b	XREF	Comments
0.0	7/2-	269 y *3*	ABCDEFGHIJ KLM	%β^-=100 μ=-1.588 *15* (1996Kl04) Q=-0.12 *3* (1996Kl04) $\langle r^2\rangle^{1/2}$=3.408 fm 11 (2004An14,evaluation). **μ,Q:** collinear LASER spectroscopy (1996Kl04). Other: μ=-1.3 3 (1967Tr12,optical method). $\Delta\langle r^2\rangle(^{38}Ar,^{39}Ar)$=0.04 fm^{-2} 7 (1996Kl04). **J^{π}:** spin from optical hyperfine structure (1967Tr12); parity from L(d,p)=L(d,t)=3. **$T_{1/2}$:** from 1965St09. Other: 265 y 30 (1952Ze01). Adopted (1977En02) neutron pick-up spectroscopic factor (S)=1.2 2. Adopted (1977En02) neutron stripping spectroscopic factor (S)=0.64 12. Additional documentation [1]

Other information
- Charge radii, isotope shift, isomer shift
- Configuration
- Isospin
- ....

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Adopted Levels

Sorting through excited levels

The old fashioned way

With a little help: PANDORA

EG	RI +- DRI		MULT	MR	CC	PARENT	SPIN	DAUGHTER		ID
884 2	100.00	0.00				884	2+	0	0+	238U(76GE,XG)
884.9 1	100.00	0.00				884.8	2+	0.0	0+	70ZN(N,N'G)
884.88 9	100.00	0.40	E2		3.97E-4	884.89	2+	0.0	0+	70CU B- DECAY (44.5 S)
883.7 7	100.00	0.00	E2			884.9	2+	0.0	0+	COULOMB EXCITATION
884.88 9	100.00	5.00	E2		3.97E-4	884.95	2+	0.0	0+	70CU B- DECAY (33 S)
884.88 9	100.00	2.00	E2		3.97E-4	884.95	2+	0.0	0+	70CU B- DECAY (6.6 S)
885.4	100.00	0.00				885.4	2+	0	0+	208PB(64NI,XG)

Adopted Levels

Level energies

- With gammas: first determine recommended gamma-ray transition energies, then run GTOL

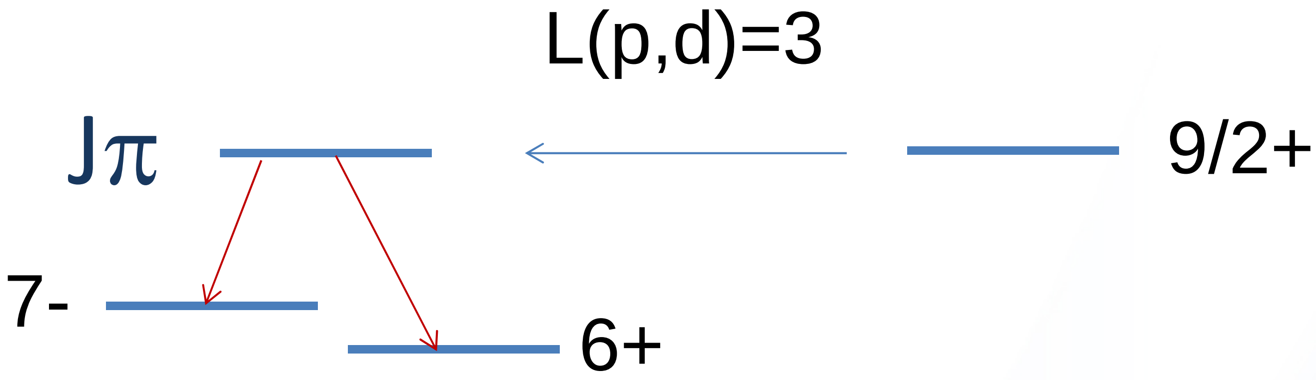
- Without Gammas: Again, provide best recommended values, generally either through weighted average or selection of a particular dataset.

XREFS

- If unsure of assignment to particular level, use XREF(*)
- If assignment unclear due to poor energy match, use XREF(energy)

From γ transitions		XREF	(p,t): XREF=B		(p,p'): XREF=C	
Energy	Jπ		Energy	L	Energy	L
1375.4(3)	2+	B(1377)C(*)	1377(5)	2	1378(10)	?
1378.7(4)	3-	C(*)				

Example Jπ assignment



3665.3 *13*	(5,6,7)-	<5 ns[&]	P H	**Jπ:** L(p,d)=3 from 9/2+ gives J=2 to 8, π=-; γ to 6+.

- "γ to" is a weak argument
- In "γ to" the Jπ is relevant, not level energy
- Parent/target Jπ is essential to argument
- Few and best arguments

More on Half-lives

121.7818g 3 | 2+ | 1.403 ns 11 | ABCDEFGHIJ KLMNOPQRST UVW

1st excited level in ^{152}Sm

Additional documentation [0]

μ=+0.82 4 (1967At04,1992De29,2005St24)

μ: from g=+0.411 19, a weighted average of 0.419 25 (muonic atom, 1967At04) and 0.40 3 (13-y Eu ε decay, 1992De29).

Q=-1.683 18 (1978Ya11,1979Po04,2005St24)

Q: weighted average of -1.702 17 (1978Ya11) and -1.666 16 (1979Po04).

J$^\pi$: E2 γ to 0+.

$T_{1/2}$: weighted average of $T_{1/2}$=1.396 ns 8 from 13-y ε decay and 1.420 ns 12 from B(E2)=3.451 8 with α=1.155 17. The B(E2) value is a weighted average of values from Coulomb excitation and muonic atom. Other: 1.47 ns 4 from 4.12-min Pm β^- decay.

Isotope shift: 1995Be19, 1994Ji08.

- Specify source dataset, not keynumber
- Clearly state averaging procedure and give measurements not included in average as “Others”
- Doesn’t always need to be an average
- For g.s. and long lived isomers, consult document by A. Nichols and B. Singh
- Also consult 2016Pr01 for first excited 2+

Miscellaneous Notes

- Use flagged footnote for repetitive comments
  such as E(a)$From (p,t).
- Use Band flag for indicating bands
  BAND(A)$Yrast band
- Do not include unplaced gammas (can reference dataset in a comment if many)
- Even if level energies match, consider physics before assigning XREFS
- Don't forget that this is the most important part of the evaluation!!

Adopted Gammas

- Energies: Best values, could be average of multiple datasets or selection from single dataset
- Intensities: Generally scaled so strongest branch = 100

$\gamma(^{70}Zn)$

E_{level}	E_γ#	I_γ#	Mult.	δ	α	$I_{\gamma+ce}$	Comments
884.90	884.88 *9*	100.0	E2		0.00040		α(K)=0.00035 *1* B(E2)(W.u.)=16.5 *9*
1070.24	185.85 *3*	100	[E2]		0.0645		B(E2)(W.u.)=37.3 *19* α(K)=0.0564 *17*; α(L)=0.00610 *19*
	1068.3		E0			<0.3	**$I_{\gamma+ce}$:** for 100 transitions of 184γ as measured in (p,p'γ) (1977Re04). **Mult.:** from internal conversion data in (p,p'γ) (1977Re04).
1758.76	874.33 *8*	100 *9*	M1+E2	+0.75 *15*	0.00036 *1*		B(M1)(W.u.)=0.06 +*8*-*4*; B(E2)(W.u.)=69 +*102*-*44* **δ:** from 1997De21. α(K)=0.00032 *1*
	1759.6 *2*	68 *7*	E2				B(E2)(W.u.)=2.4 +*23*-*12*

Single decay : no uncertainty
Multiple decay paths: each carries own uncertainty

Adopted Gammas

Multipolarities and mixing ratios

- Best recommended assignments and values
- Distinguish between measured and assumed

$\gamma(^{70}Zn)$

E_{level}	E_{γ}[#]	I_{γ}[#]	Mult.	δ	α	$I_{\gamma+ce}$	Comments
884.90	884.88 *9*	100.0	E2		0.00040		α(K)=0.00035 *1* B(E2)(W.u.)=16.5 *9*
1070.24	185.85 *3*	100	[E2]		0.0645		B(E2)(W.u.)=37.3 *19* α(K)=0.0564 *17*; α(L)=0.00610 *19*
	1068.3		E0			<0.3	**$I_{\gamma+ce}$:** for 100 transitions of 184γ as measured in (p,p'γ) (1977Re04). **Mult.:** from internal conversion data in (p,p'γ) (1977Re04).
1758.76	874.33 *8*	100 *9*	M1+E2	+0.75 *15*	0.00036 *1*		B(M1)(W.u.)=0.06 +*8-4*; B(E2)(W.u.)=69 +*102-44* **δ:** from 1997De21. α(K)=0.00032 *1*
	1759.6 *2*	68 *7*	E2				B(E2)(W.u.)=2.4 +*23-12*

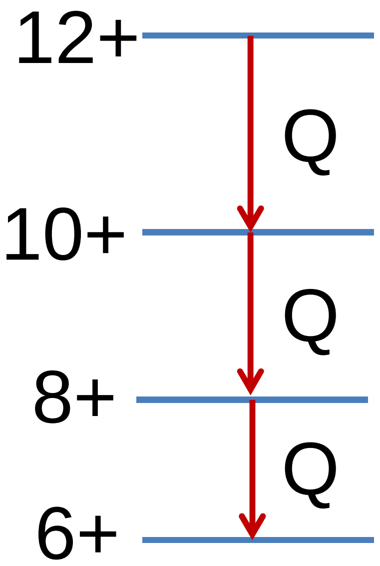
- Square brackets indicates assumed character

M1+E2 or M1,E2 : are they the same?

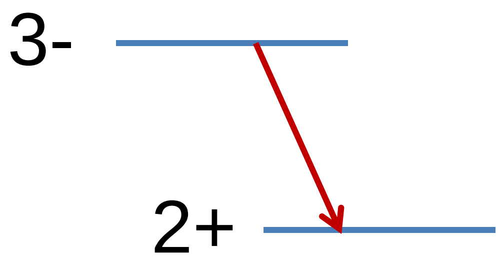
Adopted Gammas

Multipolarities and mixing ratios

- You can add physics input here



Q from R(DCO)



Jπ from (p,t)

No additional mult info: [E1]

D from angular correlation analysis

E1 with comment

Mult: D from $\gamma\gamma(\theta)$ in β- decay, $\Delta\pi$= yes from level scheme

Adopted Gammas

Conversion coefficients

- Generally taken from BrIcc
- Exception is when E0 admixtures are involved, then adopt experimental value

γ(^{70}Zn)

E_{level}	E_γ[#]	I_γ[#]	Mult.	δ	α	$I_{\gamma+ce}$	Comments
884.90	884.88 *9*	100.0	E2		0.00040		α(K)=0.00035 *1* B(E2)(W.u.)=16.5 *9*
1070.24	185.85 *3*	100	[E2]		0.0645		B(E2)(W.u.)=37.3 *19* α(K)=0.0564 *17*; α(L)=0.00610 *19*
	1068.3		E0			<0.3	**$I_{\gamma+ce}$**: for 100 transitions of 184γ as measured in (p,p'γ) (1977Re04). **Mult.**: from internal conversion data in (p,p'γ) (1977Re04).
1758.76	874.33 *8*	100 *9*	M1+E2	+0.75 *15*	0.00036 *1*		B(M1)(W.u.)=0.06 +*8*-*4*; B(E2)(W.u.)=69 +*102*-*44* **δ**: from 1997De21. α(K)=0.00032 *1*
	1759.6 *2*	68 *7*	E2				B(E2)(W.u.)=2.4 +*23*-*12*

Adopted Gammas

Transition strengths

- Include when level half-lives are known
- Ensure consistency with RUL
- Only give useful limits
- For E0 transitions, see 2005Ki02

γ(^{70}Zn)

E_{level}	E_γ#	I_γ#	Mult.	δ	α	$I_{\gamma+ce}$	Comments
884.90	884.88 *9*	100.0	E2		0.00040		α(K)=0.00035 *1* B(E2)(W.u.)=16.5 *9*
1070.24	185.85 *3*	100	[E2]		0.0645		B(E2)(W.u.)=37.3 *19* α(K)=0.0564 *17*; α(L)=0.00610 *19*
	1068.3		E0			<0.3	**$I_{\gamma+ce}$:** for 100 transitions of 184γ as measured in (p,p'γ) (1977Re04). **Mult.:** from internal conversion data in (p,p'γ) (1977Re04).
1758.76	874.33 *8*	100 *9*	M1+E2	+0.75 *15*	0.00036 *1*		B(M1)(W.u.)=0.06 +*8*-*4*; B(E2)(W.u.)=69 +*102*-*44* **δ:** from 1997De21. α(K)=0.00032 *1*
	1759.6 *2*	68 *7*	E2				B(E2)(W.u.)=2.4 +*23*-*12*

Adopted Gammas

Transition strengths: special cases (i.e. Don't run RULER blindly !!!)

E(level)	Eγ[†]	Iγ[†]	Mult.[‡]	δ[‡]	α[§]	Comments
104.831	100.02 *1*	72 *5*	M1(+E2)	<0.02	1.689	α(K)=1.431 *20*; α(L)=0.203 *3*; α(M)=0.0436 *7*; α(N)=0.00989 *14*; oc=0.001481 *21*. pc=9.13×10^{-5} *13*; α(N+..)=0.01146 *16*. B(E2)(W.u.)<0.16; B(M1)(W.u.)>0.0059. Mult.,δ: from ce data in ^{151}Pm β^-.
	104.84 *1*	100 *7*	M1+E2	−0.12 *3*	1.483 *22*	α(K)=1.248 *18*; α(L)=0.185 *5*; α(M)=0.0399 *12*; α(N)=0.0090 *3*; oc=0.00134 *4*. pc=7.93×10^{-5} *12*; α(N+..)=0.0104 *3*. B(E2)(W.u.)=6 *3*; B(M1)(W.u.)=0.0079 *10*. Mult.,δ: from ce and γγ(θ) in ^{151}Pm β^-.

δ < 0.2 B(E2) < 0.16, B(M1)>0.0059

Give average of B(M1)(δ=0) and B(M1)(δ=0.2)

Adopted Gammas

Transition strengths: special cases (i.e. Don't run RULER blindly !!!)

RUL: Recommended Upper Limit

Character*	Γ_γ/Γ_W (Upper Limit) A=6–44[a§]	A=45–150[b,c]	A>150[d]
E1 (IV)	0.3[#]	0.01	0.01
E2 (IS)[e]	100	300	1000
E3	100	100	100
E4	100	100[†]	
M1 (IV)	10	3	2
M2 (IV)	3	1	1
M3 (IV)	10	10	10
M4		30	10

2602.495	1470.71 *2*	100	E1+M2	+0.05 *2*	4.84×10^{-4} *8*	B(E1)(W.u.)=0.00125 *11*; B(M2)(W.u.)=7 *6* α(K)=0.000242 *5*; α(L)=2.81×10^{-5} *5*; α(M)= α(N)=1.030×10^{-6} *19*; α(O)=9.00×10^{-8} *16*; α(

Unsolved Puzzles

$T_{1/2}$ of first excited state in ^{41}K

Reaction	Keynumber	Half-life
40Ar(p,γ)	1971Pi12	76 fs *+21-14*
d(40Ar,nγ)	1977Sc11	0.35 ps *14*
37Cl(α,γ)	1981BuZY	> 6.9 ps
39Cl(t,pγ)	1976Me09	0.29 ps *+21-10*
38Ar(α,pγ)	1976Li17	3.5 ps *10*
40Ar(d,nγ)	1978Ra13	0.25 ps *+14-10*
40K(p,p'γ)	1986St10	>2.4 ps

B(E2)=0.0016 *4*
B(E2): weighted av of 0.0024 4 from (e,e') and 0.0029 10 and 0.00139 20 both from Coulomb Excitation.
$T_{1/2}$: the measured $T_{1/2}$ values cluster into groups of values which differ significantly. The evaluators have adopted the weighted average of 0.35 ps 14 from $^{2}H(^{40}Ar,n\gamma)$, 0.29 ps *+21-10* from $^{39}K(t,p\gamma)$, and 0.25 ps *+14-10* from $^{40}Ar(d,n\gamma)$ as they form the most consistent set of measured values. There are also several measurements which indicate a larger half-life including>6.9 ps from $^{37}Cl(\alpha,\gamma)$: 3817 Resonance, 3.5 ps 10 from $^{38}Ar(\alpha,p\gamma)$, and >2.4 ps from $^{41}K(p,p'\gamma),(p,p')$. Other: 76 fs *+21-4* from $^{40}Ar(p,\gamma)$.
J^{π}: from $L(d,n)=L(^{3}He,d)=L(d,^{3}He)=L(t,\alpha)=0$.

Final polishing and checking

Run standard codes

- GTOL
- BrIcc
- RULER
- FMTCHK
- PANDORA

```
PANDORA Errors and Warnings [version 7.1 as of 17-May-2012]

<W>70ZN(N,N'G)                  NUCLIDE= 70ZN30 **CHECK G placemnet or JPI values
*****LEVEL=2140.4     JPI=0+              LEVEL=1786.5     JPI=4+                  CONNECTING TRANSITION=354.0      MULT=

<W>70ZN(N,N'G)                  NUCLIDE= 70ZN30 **CHECK G placemnet or JPI values
*****LEVEL=3038.5     JPI=5-              LEVEL=884.8      JPI=2+                  CONNECTING TRANSITION=2153.7     MULT=

<W>208PB(64NI,XG)               NUCLIDE= 70ZN30 **CHECK G placemnet or JPI values
*****LEVEL=3039.7     JPI=5-              LEVEL=885.4      JPI=2+                  CONNECTING TRANSITION=2154.3     MULT=
```

Run JAVA-NDS and check output

- Review band drawings

Pandora Output

Many files in PANDORA output

- PANDORA.ERR : physics and other errors
- PANDORA.GAM: ordered by gamma-ray energy
- PANDORA.LEV: ordered by level energies
- PANDORA.GLE: gamma-ray info, ordered by level energy
- PANDORA.XRF: cross referencing of levels from datasets
- PANDORA.RPT: changes made to the input file
- PANDOR.RAD: Decay radiation tables