Adopted Levels or Adopted Levels, Gammas datasets in ENSDF database

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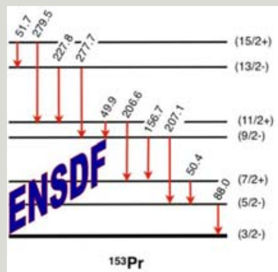
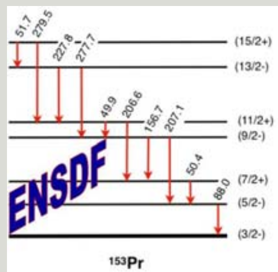


What is this dataset ?

- Each nuclide in ENSDF must have one ‘adopted’ dataset; even when there is none or only one decay or reaction dataset for a nuclide.
- Summary of all the evaluated data for characteristics of levels and gamma rays in a nuclide.
- Provides “Recommended” values of different parameters for all levels and gamma transitions.
- Many readers/users will consult only this dataset through NUDAT, ENSDF or NDS



ADOPTED LEVELS dataset Pa-230: no gamma-ray data

Until 2012, only the g.s. and 17763(18). 0^+ IAS of ^{230}Th were known

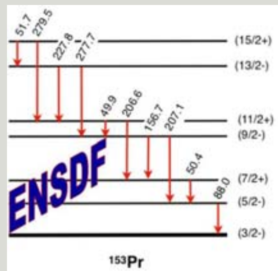
2014 update of ^{230}Pa in ENSDF:

^{231}Pa(polarized d,t): 2013Ko11: PRC 87, 044322 (2013).

~85 levels and several 2-qp bands known.

But no gamma rays known in this nuclide.

Thus the dataset is “ADOPTED LEVELS”



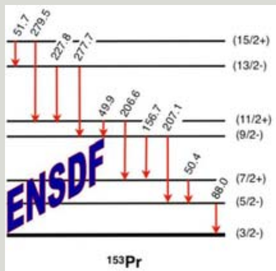
Levels and Gammas: ^{62}Zn

About 150 levels up to 43 MeV excitation and ~200 gamma rays known in this nuclide.

The dataset is ‘ADOPTED LEVELS, GAMMAS” in NDS-2012.

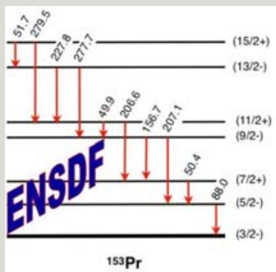
Since then 2012Ge04: PRC 86, 034304 (2012)

460 γ-rays, ~250 levels: all kinds of band structures



Adopted dataset: why needed?

- This is the dataset where you provide your general assessment about the experimental structure data for a nucleus, inconsistencies or disagreements between different experiments, and deficiencies (or gaps) in knowledge about a nuclide. Suggestions can be made for future experiments.
- This dataset is primarily the evaluator's own work with summary, recommendations, and best adopted values of different quantities derived from evaluated individual datasets based on different reactions and decay experiments.
- Thus this dataset needs your utmost attention and generally it requires most time, care, effort and critical judgement.



Adopted dataset: ^{31}Ar: only the g.s. known

Adopted Levels

S(n)=18270 *SY*; S(p)=440 *SY*; Q(α)=−8160 *SY* 2012Wa38.
ΔS(n)=540, ΔS(p)=280, ΔQ(α)=450 (syst,2012Wa38).
S(2p)=130 *210*, Q(εp)=18060 *210* (syst,2012Wa38).

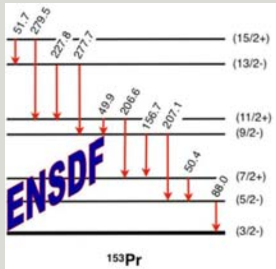
1986La17: First identification of ^{31}Ar isotope in reaction: Ni(^{40}Ca,X) E=77 MeV/nucleon; LISE–GANIL facility.
1987Bo36: ^{31}Ar from fragmentation of ^{36}Ar, measured delayed protons and ^{31}Ar half–life.
1989Re02: ^{31}Ar from reaction: Mg(^{3}He,X) E=110, 135 MeV. Measured delayed one–proton and two–proton spectra, mass excess.
1990Bo24: ^{31}Ar from Ca(p,xn3p) reaction, measured delayed protons, pp coin.
1991Bo32: ^{31}Ar from fragmentation of ^{36}Ar, measured delayed two–proton decay, half–life.
1992Ba01: Measured delayed three–proton decay and half–life.
1999Th09, 1998Ax01, 1998Ax02, 1998Mu06: ^{31}Ar from Ca(p,X) E=1 GeV, measured delayed 2–proton spectra, angular correlations, recoil energy shift.
1999Fy01: Measured Eβ, Ep, delayed multi–proton branching ratios, upper limit for 3–proton branch.
2000Fy01 (also 2000Bo59): Measured delayed protons, 2–proton decay, p–p energy and angular correlations, ^{31}Ar half–life.
2002Fy01, 2002Bo29: measured Ep, pβ coin, recoil energy shift.
2002Fy01, 2002Bo29, 2000Fy01, 1999Fy01, 1999Th09, 1998Ax01, 1998Ax02 and 1998Mu06 are by the same group at ISOLODE–CERN facility.

^{31}Ar Levels

Cross Reference (XREF) Flags

A ^{9}Be(^{32}Ar,^{31}ArX)

E(level)	Jπ	XREF	$T_{1/2}$	Comments
0.0	5/2+	A	14.4 ms *6*	%ε+%β^+=100, %εp=62 6, %ε2p=8.5 4 (2000Fy01), %ε3p<0.0011 (1999Fy01), %$\varepsilon\alpha$p<0.38 (1998Ax02); %$\varepsilon\alpha$<0.03 (1998Ax02); %2p<0.0006 (1998Ax01). %εp is primarily β^+p (ε decay mode being negligible), the value is deduced by the evaluator from observed proton branches by 2000Fy01. Others: %ε2p=7.2 *11* (1998Ax02), ≈12 (2002Fy01), %ε3p=2.1 10 (1992Ba01) is not supported by measurement of 1999Fy01 giving upper limit of 0.0011 (at 99% confidence limit). Summed β^+(and ε) branch is 85% *9*. Missing delayed proton branch of 15% *9* is attributed by 2000Fy01 to undetecte one or two–proton decays. Jπ: spin from β–recoil energy shift (2002Fy01,1999Th09,1998Ax01); parity from log *ft*=4.9 to (3/2)+. $T_{1/2}$: from weighted average of 14.1 ms 7 (2000Fy01) and 15.1 ms +*13*–*11* (1992Ba01).



Extensive dataset for ^{31}P

Adopted Levels, Gammas

Q(β^-)=−5398.02 *23*; S(n)=12311.3 *3*; S(p)=7296.55 *2*; Q(α)=−9668.75 *10* 2012Wa38.
S(2n)=23630.7 *6*, S(2p)=20813.8 *9* (2012Wa38).
2012Zh06: ^{9}Be(^{40}Ar,X) E=57 MeV/nucleon, measured fragment yield, momentum distributions at HIRFL facility; deduced target dependence on production cross section.
2010Ka30: Q(β^-) from Penning–trap measurement.
2009Kw02: mass measurement using LEBIT Penning–trap spectrometer; IMME analysis.
2008Re16 (also 2006Re19): measured cyclotron frequency ratios, atomic masses. Cryogenic Penning trap.

^{31}P Levels

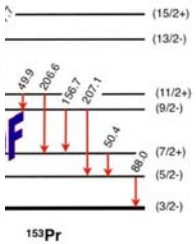
Penning trap mass measurement (2006Re19).
Other reactions:
1988Bh09: ^{31}P(pol d,d) E=16 MeV, measured $\sigma(\theta)$, Ay(θ). Deduced optical model parameters.
1985Br05: ^{31}P(pol d,d) E=33 MeV. Measured $\sigma(\theta)$, Ay(θ) Deduced optical model parameters.
1982Ve13: ^{31}P(^{3}He,^{3}He) E=25 MeV. Measured $\sigma(\theta)$ Deduced optical model parameters, matter and charge radii.
1983Gl07: ^{31}P(n,n) E=thermal, measured phase shift, scattering length.
Level energies in reactions labeled with XREF=Y in the table of Cross Reference flags:
^{31}Si β^- decay (157.36 min): 0, 1266.
^{32}Cl εp decay (298 ms): 0.
^{20}Ne(^{12}C,p): 0, 1266, 2234.
^{28}Si(^{18}O,^{15}N): 0, 1270, 2230, 3100, 3300, 3410, 3510, 4430.
^{28}Si(^{19}F,^{16}O): 0, 1270, 2230.
^{30}Si(α,^{3}H): 0, 1266, 2234.
^{30}Si(^{16}O,^{15}N): 0, 1270, 2230, 4430.
^{31}P(d,d'): 0, 1265, 2232, 3133.
Coulomb excitation: 0, 1270, 2230.
^{32}S(n,d): 0, 1270, 2230.
^{32}S(^{13}C,^{14}N): 0.
^{34}S(p,α): 0, 3260, 4730, 7240, 7970.

36 reactions
38 pages of NDS text

Cross Reference (XREF) Flags

A ^{31}S ε Decay (2.5534 s)
B ^{12}C(^{20}Ne,pγ),^{16}O(^{16}O,pγ)
C ^{24}Mg(^{16}O,2αpγ)
D ^{27}Al(α,γ): Resonances
E ^{27}Al(α,p): Resonances
F ^{27}Al(^{6}Li,^{2}H)
G ^{28}Si(α,p),^{4}He(^{28}Si,p)
H ^{28}Si(α,pγ),^{4}He(^{28}Si,pγ)
I ^{29}Si(^{3}He,p)
J ^{29}Si(α,d)
K ^{30}Si(p,γ)
L ^{30}Si(p,p): Resonances
M ^{30}Si(p,α): Resonances
N ^{30}Si(d,n)
O ^{30}Si(^{3}He,d),(pol ^{3}He,d)
P ^{31}P(γ,γ')
Q ^{31}P(e,e')
R ^{31}P(n,n'γ)
S ^{31}P(p,p')
T ^{32}S(γ,pγ')
U ^{32}S(e,e'p)
V ^{32}S(d,^{3}He),(pol d,^{3}He)
W ^{33}S(p,^{3}He)
X ^{33}S(d,α)
Y Others:
^{34}S(p,α)

^{31}Si β^- Decay (157.36 min)
^{32}Cl εp Decay (298 ms)
^{20}Ne(^{12}C,p)
^{28}Si(^{18}O,^{15}N)
^{28}Si(^{19}F,^{16}O)
^{30}Si(α,^{3}H)
^{30}Si(^{16}O,^{15}N)
^{31}P(d,d')
Coulomb Excitation
^{32}S(n,d)
^{32}S(^{13}C,^{14}N)

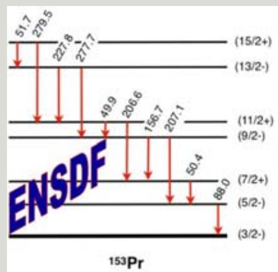


Prerequisites for Adopted Dataset

- Evaluate all individual decay and reaction datasets. Any changes made later in an individual dataset need to be carried over to the "adopted" dataset.

- Search NSR database and cross references in publications thoroughly so that no relevant studies get missed.

- Distinguish between primary and secondary sources of data.



Adopted Datasets

Collect all evaluated individual datasets for a nuclide:

A. Decay #1

B. Decay #2

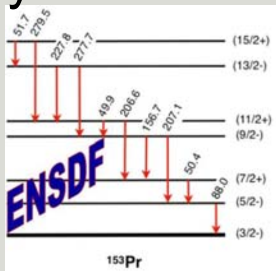
C. Reaction #1

D. Reaction #2

………………

Adopted dataset: either manually level by level; and for each level; gamma transitions – energies, branching ratios normalized To 100 for the most intense transition……..

Or run PANDORA code on composite data file of all the decay and reaction datasets



Adopted dataset

PANDORA outputs several files:

PANDORA.ERR : physics and other errors

.GAM: file ordered by gamma energy across all datasets

.LEV: file ordered by level energies, JPI, half-lives

.GLE: file ordered by levels, gamma-ray branching ratios

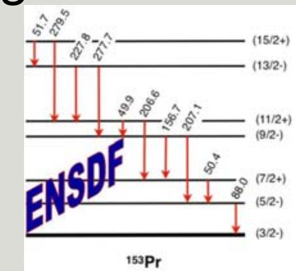
.XRF: cross referencing of levels populated in different datasets

.RPT: changes made to the input file

.RAD: Beta radiation tables.

Use PANDORA to create a first draft Adopted dataset.

Go over problems related to closely spaced levels, conflicting JPI assignments, branching ratios, etc.



Adopted Dataset

- RUN other codes on the Adopted dataset:

FMTCHK

BrIcc

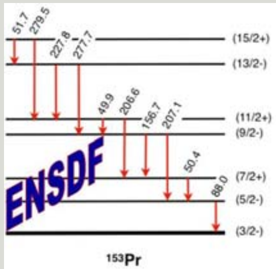
GTOL

RULER: to deduce BELW values (need to check output)

RUN PANDORA again for a composite file of all

Datasets for a nuclide including Adopted dataset.

Run ENSDAT to look at NDS-style output

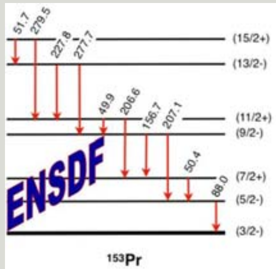


What is provided in an Adopted dataset

(Units: some are pre-defined and not entered in dataset; such as all energies are assumed in keV, unless otherwise noted; magnetic dipole moment in μ_n and electric quadrupole moment in eb or b, etc.)

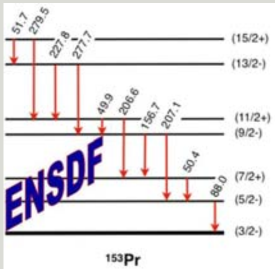
General Properties:

- Beta and Alpha decay Q values (from AME or newer mass measurements)
- Neutron and proton separation energies (from AME or newer mass measurements). May give S(2n), S(2p), beta-delayed neutron or proton decay Q values.
- Measured static Magnetic dipole (μ) and Electric quadrupole moments (Q); units are pre-defined in ENSDF; not given in dataset)
- Evaluated charge radius for g.s. from 2013An02



Levels

- Energies: from gamma-ray studies when available, otherwise from particle-transfer data.
- Decay modes for (unstable) ground states and long-lived isomers.
- Half-lives or total widths (note in ENSDF half-lives given <u>not</u> mean lifetimes).
- Spins and Parities: Confirmed, tentative or none, depending on what evidence is available from all the relevant datasets. Supporting arguments for “adopted” spins and parities.
- Cross-reference (XREF): reaction or decay a level is populated in.
- Band assignments, level sequences, orbital configurations.



Gamma Rays

- Energies: best “adopted values” from all datasets. Check systematic deviations in energies in different datasets and adjust if necessary. Resolve and point out discrepancies between different datasets in gamma-ray placements and ordering of cascades, especially in high-spin spectroscopy.

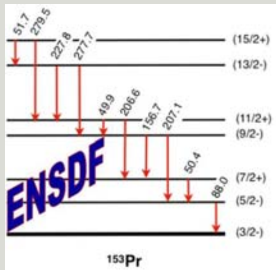
- Relative photon branching ratios: generally normalized to 100 for the most intense transition. Best “adopted values” from all datasets.

- Multipolarities and mixing ratios: Best “recommended assignments”

  Distinguish between assignments supported by experimental data and assumed values, the latter are given in square brackets.

  Quite often the assignments in papers are not based on actual measurements such as internal conversion, polarization, angular distribution, etc. but simply implied from their assigned J^{π}.

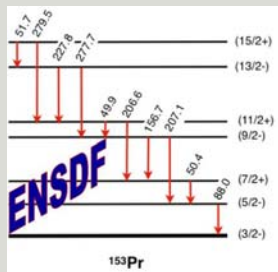
  Refer to “NDS policies” document.



Gamma rays

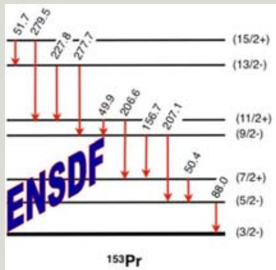
- Conversion coefficients when significant (>0.001 or so, depending on the precision of quoted intensity).
- Theoretical values from BrICC code are used for assigned multipolarity and mixing ratio, except when E0 admixtures are involved.

- Reduced transition probabilities: B(E2), B(M1), B(E1) in W.u. when level half-lives are known (For E0 transitions, electron or pair conversion intensity and other parameters such as ρ^2(E0): consult 2005Ki02). evaluation.



Levels and Gamma rays

- All associated uncertainties are given, when possible (Generally rounded to max of “25”)
- Easily traceable source (a dataset name and/or NSR reference key-number should be specified for each quantity.

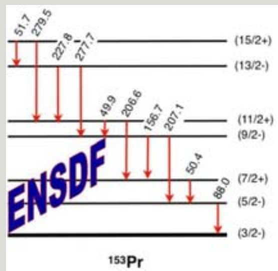


Q values

- In formatted ENSDF records: all energy are in keV, unless otherwise stated
  Beta decay Q values: Q(β)
  Neutron and proton separation energies: S(n), S(p)
  Alpha-decay Q value: Q(α).
  Source reference (s) (maximum 2): example: 2012WA38,…….

- In comment records:
  Estimated uncertainties if values above are systematic trends.
  Delayed-particle decay Q values (if this decay mode is allowed)
  Two-neutron and two-proton separation energies (optional).

- If more precise mass measurements are available since AME-2012, use these to deduce, at least the beta-decay Q values.



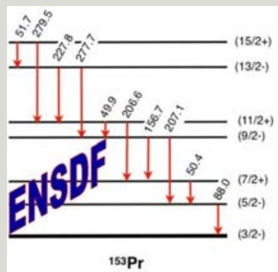
Half-lives, decay modes and J^{π} of ground states and isomers (> ~100 ns)

These properties are of general interest to a variety of users, not just nuclear physicists, thus much care is needed in their evaluation. Since radioactive decays connect nuclides of neighboring neutron or proton number, thus it is useful to carry out such an evaluation at the start.

For J^{π} assignments follow the bases for ‘strong arguments’ and those for ‘weak arguments’ in the general policies. An assignment is given without parentheses only if supported by ‘strong’ rules.

Example: a level has 3/2+ assignment. Argument: spin=3/2 from atomic beam method, parity from log*ft*=5.6(1) for beta to 5/2+ level

- When directly measured spins are available, method and source reference should be given. Compilations: 2013Ma15: NDS 114, 397 (2013) or 1976Fu06 may be cited, preferably with original references where measurements were made.



Levels: static moments

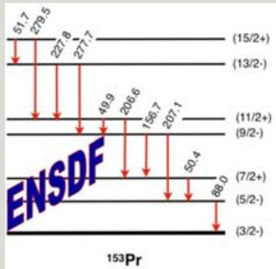
- Static Moments: magnetic-dipole and electric quadrupole moments: use 2014StZZ compilation, but check for newer references. Avoid using older evaluations 1978ShZM, 1978LeZA, 1976Fu06 or 1969Fu11.

- Units are not given in ENSDF, taken to be nuclear magneton μ_n and eb, respectively. Convert the units for quadrupole moment, if necessary. The measured g factors are converted to magnetic moment.

- Methods of measurements should be quoted, together with references for these measurements. (Note: optional but recommended.)

- Adopted values are given in data continuation records in ENSDF. Other measured values can be given under comments.

- Take averages <u>only</u> when you are sure that the authors have applied all relevant corrections.

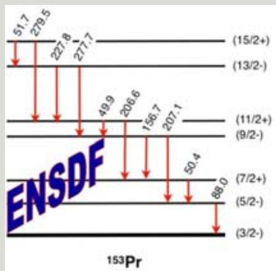


XREF: population of a level in a decay or reaction dataset

- Each level should be cross referenced with an individual dataset where it is populated even when there is only one dataset
- There may be ambiguities in associating a particular level energy with (corresponding) levels in individual reactions. Generally policy is to adopt minimum number of levels consistent with individual datasets.
- But consider and resolve (if possible):

  a. Systematic differences in energies of corresponding levels between different datasets; some adjustments may be needed.

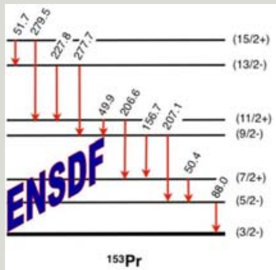
  b. Level energies may match, but population patterns may differ, when spins are unknown. Examples: a low-spin level of unknown spin populated in a reaction such as single-particle transfer would not correspond to the one populated in high-spin reactions.



Level energies

- **Levels derived from gamma-ray studies:**
  First deduce best gamma-ray energies from individual datasets. Use these energies to deduce level energies from GTOL code. Note: in some cases (especially in the low-mass region) authors give only level energies not gamma-ray energies.

- **Levels from reactions with no gamma rays:**
  Average values which are available from different datasets, but check for systematic differences.



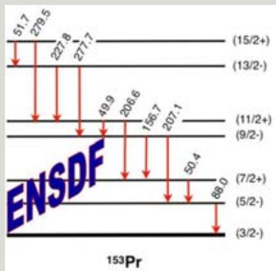
Level spins and parities

- spin and parity assigned to each level must carry supporting arguments:
  Without parentheses if the arguments are strong according to rules given in “NDS policies”, which have evolved over the last 50 years or so.
  In parentheses, if the arguments are weak such as “gamma to a certain level of spin J, model considerations, etc. Generally up to 3 spin choices.

Examples: E1 γ to 5/2-; logft=5.6(2) from 1/2+ parent gives 3/2+
L(d,p)=2 from 0+ target; M1+E2 γ to 1/2+ gives 3/2+

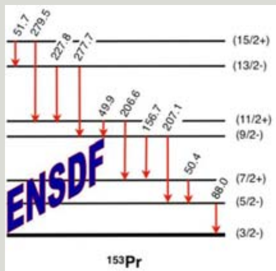
(E2+M1) γ to 7/2+ gives (5/2+,7/2+,9/2+)
In square brackets (example: [2]), if assumed for some reason.

- Gamma-ray multipolarities serve as arguments for many J^{π} assignments.
- In making these judgments, one has to make sure that one is dealing with the same level in different reactions in collecting all possible evidences leading to assignment of its spin and parity. In some cases matching energy of a level in different reactions may not be sufficient.
- Note that ENSDF criteria of assignments of spins and parities may differ from those in research papers.



Half-lives of excited (short-lived) levels:

- For a certain level, collect all independently measured values in different reactions (including values from different studies in the same dataset). For excited states, most authors give mean lifetimes. Include also values deduced from BEL(up) values in Coulomb excitation (e,e’); (γ, γ’), etc. Use averaging methods such as in V.AVELIB to find the best mean lifetime, then convert it to half-life. The uncertainty may be given up to a maximum of “35” or “42”, so that one can reproduce the mean lifetime from the quoted half-life as closely as possible.



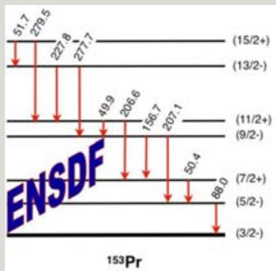
Half-lives of ground states and long-lived (>0.1 μs or so) isomers: guidelines (draft version: A. Nichols (Surrey), B. Singh

1. Accumulate ALL published measurements of the half-life of the specified nuclear level(s)

2. Ensure that all of the above half-life data and origins (NSR key-numbers) are listed systematically in the *Comments* area in **Adopted Levels, Gammas data set.**

3. Consider any other features of each specific measurement for either rejection based on experience and subjective judgements. Examples include the following:

3a) acceptance or rejection of *grey* references (secondary publications that may not have been fully peer reviewed: laboratory reports; conference proceedings),



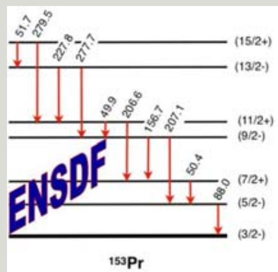
Adopted Half-lives:

3b) measurement techniques

3c) recognised difficulties and complications (e.g. impact of impurities, detector limitations, background subtraction, dead-time losses, relative to “standards”),

3d) known reliability or improvements in a particular measurement technique

3e) regular measurement programme of certain half-lives applications (normally a policy in metrology labs), may lead to rejecting all but the most recently reported value;

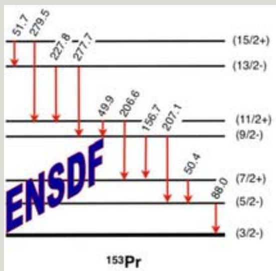


Adopted Half-lives:

- if the same author(s)or lab determines a particular half-life based on the same measurement technique/apparatus, only consider the most recent value in deducing the recommended value

4. Identify outliers, document and discard, based on the criteria adopted in least-squares analysis codes. Numerous averaging techniques have been proposed and developed (see V- AVELIB on NNDC webpage). Examples include:

- Unweighted average.
- Weighted average (WM);
- limitation of the relative statistical weight (LRSW or LWM);
- normalised residuals method (NRM);
- Rajeval Technique (RT)



Adopted Half-lives

-Expected-value method (EVM) by M. Birch

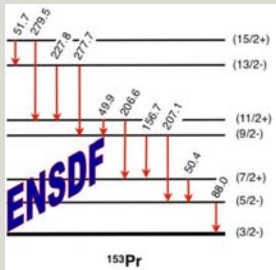
-BootStrap

-Mandle-Paule method (developed at NIST)

These techniques use different methods to handle the uncertainties, identify outliers, and derive the mean value and uncertainty.

LRSW, NRM and RT occasionally inflate the uncertainties to accommodate discrepant data; all three of these methods should be used to identify outliers (i.e. defined as such if at least two of the methods identify a data point as an outlier).

Boot-Strap method does not identify outliers.



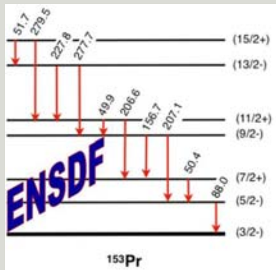
Adopted Half-lives

Software codes are available to run these methods of analysis simultaneously/together for direct and speedy comparison. There are eight different averaging methods in the Visual Averaging Library code (V.AVELIB) developed by Michael Birch at McMaster. This code handles asymmetric uncertainties. Note that AVETOOLS does not handle asymmetric uncertainties.

5. All acceptable half-life data to be analysed by means of these techniques

- may need to define which method is the most appropriate – WM, LRSW, NRM, RT, EVM, Boot-Strap, others, and so adhere to consistency in the selection of the recommended half-life value and uncertainty,

- role of reduced χ^2 as compared to critical χ^2 in such analyses needs to be better defined, implemented and used to develop a more rigorous understanding of the data set adopted for full analysis.



Adopted Half-lives

No one method works every time when input data are discrepant.

Not every time one needs to take averages of all available data.

Some input values may need to be corrected or adjusted (increased) uncertainties prior to statistical handling.

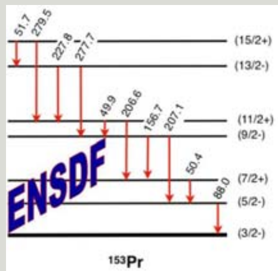
Example: free neutron half-life

Neutron half-life (?)

- First radioactive nuclide is "free neutron"
- PDG (2013): τ=880.0(9) s
- PDG (2008,2010): τ=885.7(8) s

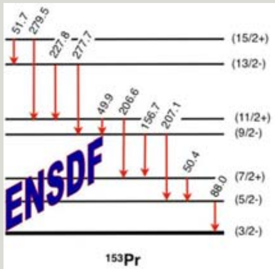
- Comment in PDG (2008,2010) : "The most recent result, that of Serebrov 05, is so far from other results that it makes no sense to include it in the average. It is up to workers in this field to resolve this issue. Until this major discrepancy is understood our present average of 885.7(8) s must be suspect."

Comment in PDG-2012, 2013: "There seems little better to do than to again average the best seven measurements. The result, 880.0 +-0.9 s (including a scale factor of 1.8), is 5.6 s lower than the value we gave in 2010- a drop of 7.0 old and 5.1 new standard deviations."



Neutron half-life data in PDG-2013

VALUE (s)	DOCUMENT ID	TECN	COMMENT
880.0± 0.9 OUR AVERAGE	Error includes scale factor of 1.4. See the ideogram below.		
881.6± 0.8± 1.9	[11] ARZUMANOV 12	CNTR	UCN double bottle
882.5± 1.4± 1.5	[12] STEYERL 12	CNTR	UCN material bottle
880.7± 1.3± 1.2	PICHLMAIER 10	CNTR	UCN material bottle
886.3± 1.2± 3.2	NICO 05	CNTR	In-beam n, trapped p
878.5± 0.7± 0.3	SEREBROV 05	CNTR	UCN gravitational trap
889.2± 3.0± 3.8	BYRNE 96	CNTR	Penning trap
882.6± 2.7	[13] MAMPE 93	CNTR	UCN material bottle
• • • We do not use the following data for averages, fits, limits, etc. • • •			
886.8± 1.2± 3.2	DEWEY 03	CNTR	See NICO 05
885.4± 0.9± 0.4	ARZUMANOV 00	CNTR	See ARZUMANOV 12
888.4± 3.1± 1.1	[14] NESVIZHEV... 92	CNTR	UCN material bottle
888.4± 2.9	ALFIMENKOV 90	CNTR	See NESVIZHEVSKII 92
893.6± 3.8± 3.7	BYRNE 90	CNTR	See BYRNE 96
878 ±27 ±14	KOSSAKOW... 89	TPC	Pulsed beam
887.6± 3.0	MAMPE 89	CNTR	See STEYERL 12
877 ±10	PAUL 89	CNTR	Magnetic storage ring
876 ±10 ±19	LAST 88	SPEC	Pulsed beam
891 ± 9	SPIVAK 88	CNTR	Beam
903 ±13	KOSVINTSEV 86	CNTR	UCN material bottle
937 ±18	[15] BYRNE 80	CNTR	
875 ±95	KOSVINTSEV 80	CNTR	
881 ± 8	BONDAREN... 78	CNTR	See SPIVAK 88
918 ±14	CHRISTENSEN72	CNTR	



Neutron half-life

- 2013Yu07: PRL 111, 222501 (2013): NIST: improved measurement of fluence of neutron beam:

  Updated τ=887.7 +-1.2(stat) +-1.9 (syst) s

  Beam experiments: τ=888.0 +-2.1 s

  Cold-neutron bottle method: τ=879.6 +-0.8 s

  Difference=8.4 +-2.2 s (3.8 σ discrepancy)

Simple yet tricky examples for ENSDF Adopted datasets

^{31}Cl : *rp* process in astrophysics

Current ENSDF: Feb 2013 (C, Ouellet, B, Singh)

0.0, 3/2+ level: half-life:

Adopted value=190(1) ms from 2011SaZM thesis and communications.

Open publication: 150(25) ms (1982Ay02)

Adopted S(p)=282.8(44) vs 300(50) in AME-12. 284(7) (2009Wr03: IMME)

First excited state: ^{30}S(p,γ)^{31}Cl

~750 ? (1/2+): 1998Ax02: NP-A634,475

2000Fy01 (same group as 1998Ax02): NP-A 677, 38: rejected this peak since no evidence.

2009Wr03: PR-C 79, 045808: adopted this level in from 1998Ax02 in thermonuclear reaction rates; did not cite 2000Fy01 who omitted this level.

Extensive communications with Chris Wrede and Maria Borge. Suggested further experiments.

1998AX02
Peak #1: 750

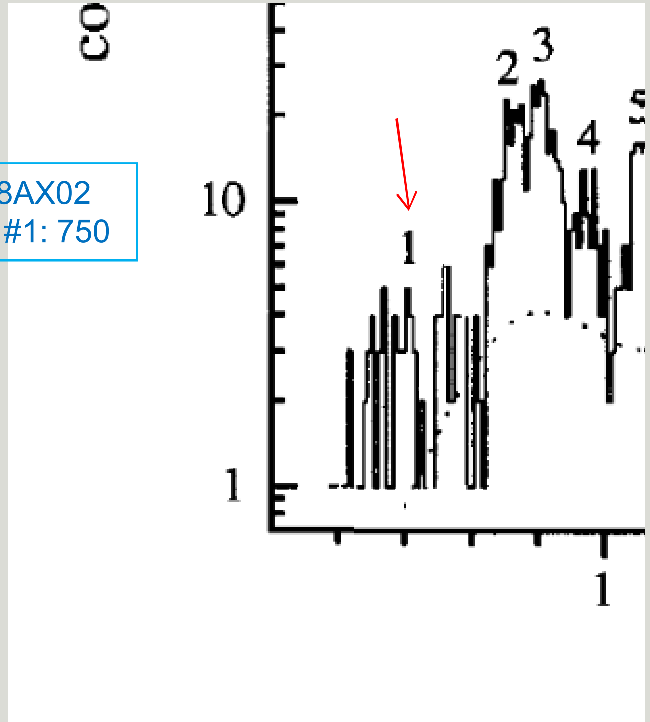


Fig. 3. Proton spectrum of ^{31}Ar.

^{31}Cl example:

1998Ax01 (2000Fy01) conducted experiment in 2010, results not yet in.

C. Langer et al, PRC 89, 035806 (Mar 20, 2014): GSI: ^{31}Cl levels from Coulomb breakup of ^{31}Cl radioactive beam with Pb and C targets.

747(15) keV in 1998Ax01, 782(32) in 2014La.

Second excited state in 2000Fy01:

Adopted in ENSDF at 1746(5) keV.

2014-Langer have this one at 1793(26)

Seems to be a shift of ~30 keV?

There are 17 more levels from 2000Fy01, including IAS at 12314 keV

Question: what to do about level energies?

THERMONUCLEAR REACTION ^{30}S(p,γ) . . .

PRC 89, 035806 (Mar 20, 2014)

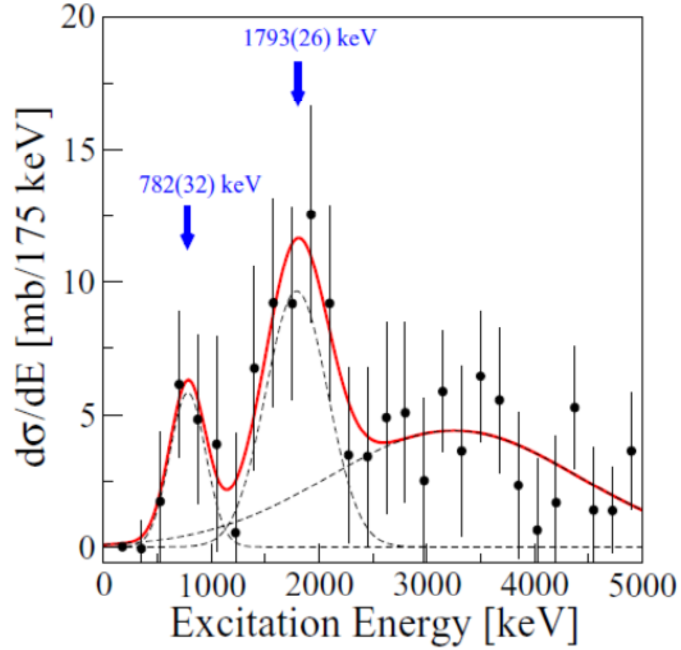
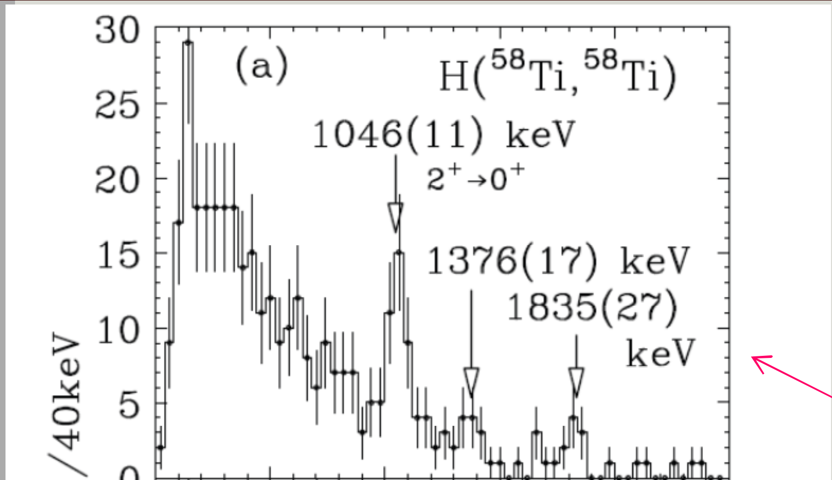


FIG. 6. (Color online) Energy-differential excitation spectrum of ^{31}Cl after subtraction of nuclear contributions. A fit, composed of

^{58}Ti example



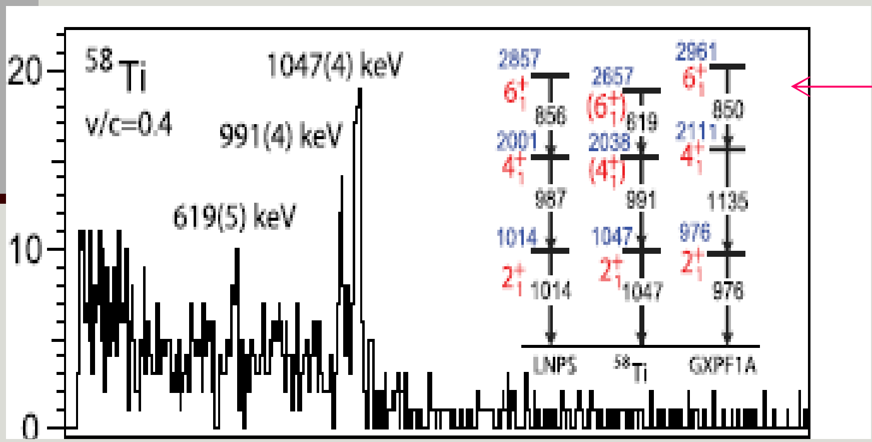
Current ENSDF: Jan 2010: C.Nesaraja, S. Geraedts, B. Singh.

0.0, 0^+

1046(17) ? (2^+) level (tentative 2+ level based on 2008Ao01 (NP-A805, 400c): RIKEN

2013Su20: PRC 88, 024326 (2013): RIKEN.

Levels proposed at 1046(11), 2422(22)(?), 2881(33)



2014-Gade et al: PRL 112, 112503 (Mar 21, 2014): NSCL-MSU using GRETINA array:

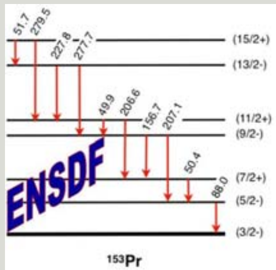
Reaction: Be(^{61}V,^{58}Ti): nucleon removal reaction

Gamma peaks at 1047, 991, 619; but not at 1376 and 1835 keV as in 2013Su20.

Question: do all four levels above 1047 exist?

Consider reaction mechanism as

Suggested by 2014-Gade et al.



^{256}Rf example

Current ENSDF: Oct 1998: Y. Akovali

0.0, 0+

51(35) (2+)

Above ^{256,257}Rf, no γ-ray data known.

2009Je01: PRC 79, 031303(R): three K-isomers from ^{208}Pb(^{50}Ti,2n),E=243 MeV

LBNL $T_{1/2}$: (recoil)(ce)(ce)(fission)(t)

~1120 keV, 25(2) μs (2-qp), ~1400 keV, 17(2) μs (2-qp), >2200 keV, 27(5) μs (4-qp)

2011Ro20: PRC 83, 064311: only one isomer from ^{208}Pb(^{50}Ti,2n),E=242.5 MeV

ATLAS-ANL $T_{1/2}$: (recoil)(ce)(fission)(t)

17(4) μs: weakly populated possible 4-qp

PHYSICAL REVIEW C 79, 031303(R) (2009)

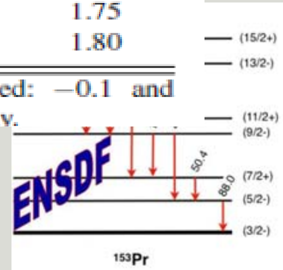
TABLE I. Calculated configurations and excitation energies of low-lying high-K two-quasiparticle states in ^{256}Rf.

K^π	Configuration	E_x (MeV)
8^-	$\nu^2([734]9/2^- \otimes [613]7/2^+)$	1.16
10^+	$\nu^2([734]9/2^- \otimes [725]11/2^-)$	1.36
7^+	$\nu^2([613]7/2^+ \otimes [624]7/2^+)$	1.66
7^-	$\pi^2([624]9/2^+ \otimes [512]5/2^-)$	1.41
8^-	$\pi^2([514]7/2^- \otimes [624]9/2^+)$	1.45
6^+	$\pi^2([514]7/2^- \otimes [512]5/2^-)$	1.53
8^+	$\pi^2([624]9/2^+ \otimes [633]7/2^+)$	1.64

TABLE I. 2-quasiparticle energies ($E_{2\text{-qp}}$) calculated for ^{256}Rf with the universal Woods-Saxon energies and the Lipkin-Nogami procedure for pairing (see text for details).

K^π	Configuration	$E_{2\text{-qp}}$ (MeV)[a]
8^-	π 7/2[514] π 9/2[624]	0.93
5^-	π 1/2[521] π 9/2[624]	1.06
6^+	π 7/2[514] π 5/2[512]	1.34
3^+	π 7/2[514] π 1/2[521]	1.34
4^-	ν 9/2[734] ν 1/2[620]	1.40
6^-	ν 9/2[734] ν 3/2[622]	1.49
10^+	ν 9/2[734] ν 11/2[725]	1.75
8^-	ν 9/2[734] ν 7/2[613]	1.80

[a]Residual nucleon-nucleon interactions are included: −0.1 and 0.1 MeV for singlet and triplet spin states, respectively.



^{256}Rf example

2013Ri07: PRC 88, 044313: LBNL.

Do not cite 2011Ro20 study from ANL!

TABLE VII. Calculated 2-QP configurations for ^{256}Rf.

Configuration	K^π	$E_x^{calc.}$
$\pi^2(1/2^-[521] \otimes 9/2^+[624])$	5^-	1062
$\pi^2(7/2^-[514] \otimes 9/2^+[624])$	8^-	1102
$\pi^2(7/2^-[514] \otimes 5/2^-[512])$	3^+	1346
$\nu^2(9/2^-[734] \otimes 1/2^+[620])$	5^-	1350
$\nu^2(9/2^-[734] \otimes 7/2^+[613])$	8^-	1390
$\pi^2(7/2^+[514] \otimes 5/2^-[512])$	6^+	1411
$\pi^2(7/2^+[514] \otimes 1/2^+[521])$	4^+	1425
$\nu^2(9/2^-[734] \otimes 3/2^+[622])$	6^-	1446
$\nu^2(9/2^-[734] \otimes 11/2^-[725])$	10^+	1455
$\pi^2(9/2^+[624] \otimes 5/2^-[512])$	7^-	1507

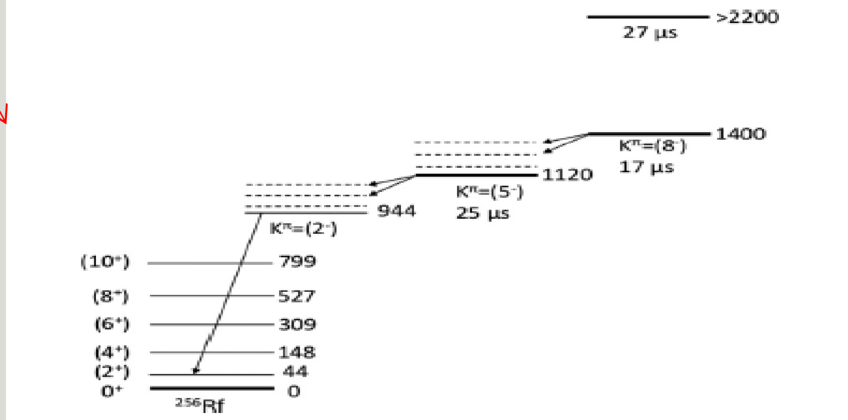
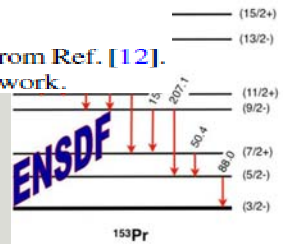


FIG. 10. Possible decay scheme for ^{256}Rf, adopted from Ref. [12]. The spin assignments for isomeric states are from this work.



^{256}Rf example

2012Gr12: PRL 109, 012501:JYFL

^{208}Pb(^{50}Ti,2n),E=242 MeV: JUROGAM-II.

First detailed γ-ray study: g.s. band members up to (20+)

ENSDF should be updated.

First excited state: 44(1) is a better estimate than 51(35) keV in current ENSDF. Higher members of g.s. band are simple to include.

Question: what to do about proposed so-called K-isomers?

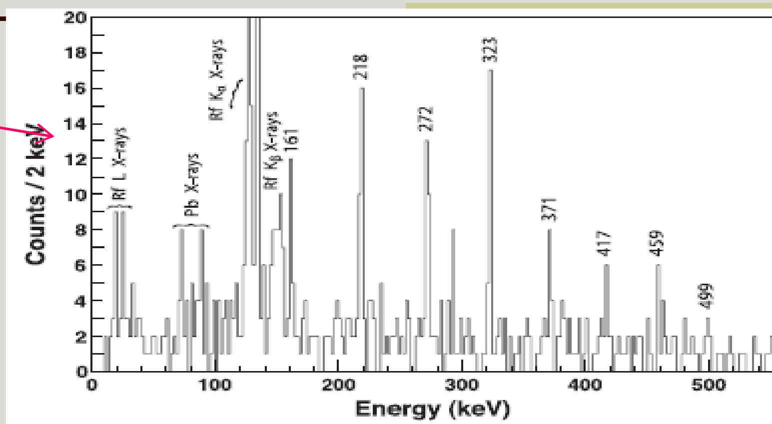
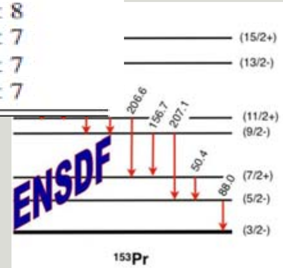


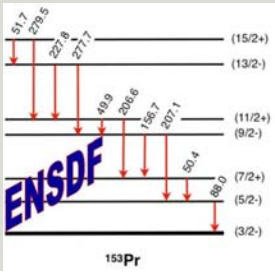
FIG. 2. Energy spectrum of prompt singles γ rays associated with fission-tagged ^{256}Rf recoils.

TABLE I. Calculated energies of the 4^+ to 2^+ and 2^+ to 0^+ transitions, measured transition energies and tentative transition assignments for the rotational band of ^{256}Rf. The last column shows the relative intensities of the transitions corrected for efficiency and internal conversion.

E_γ (keV)	Transition assignment	Relative intensity (%)
44 ± 1	$(2^+ \rightarrow 0^+)$	
104 ± 1	$(4^+ \rightarrow 2^+)$	
161 ± 1	$(6^+ \rightarrow 4^+)$	100 ± 30
218 ± 1	$(8^+ \rightarrow 6^+)$	80 ± 20
272 ± 1	$(10^+ \rightarrow 8^+)$	53 ± 12
323 ± 1	$(12^+ \rightarrow 10^+)$	49 ± 11
371 ± 1	$(14^+ \rightarrow 12^+)$	22 ± 8
417 ± 2	$(16^+ \rightarrow 14^+)$	20 ± 7
459 ± 2	$(18^+ \rightarrow 16^+)$	18 ± 7
499 ± 2	$(20^+ \rightarrow 18^+)$	16 ± 7



THANK YOU



51.7
279.5
227.8
277.7
49.9
206.6
156.7
207.1
50.4
88.0
(15/2+)
(13/2-)
(11/2+)
(9/2-)
(7/2+)
(5/2-)
(3/2-)
ENSDF
153Pr