Guidelines for Nuclear Structure Evaluators

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Abstract

This document sets forth the policies and procedures for preparing mass chain evaluations for the Evaluated Nuclear Structure Data File (ENSDF). Also included are some appendices which are referred to or augment material in the guidelines. See section on Appendices for details and references to additional material.

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Appendices

1.   SourceDatasets (Decay and Reaction)
1.1   Extraction of Data

Mass-chain evaluations and updates usually begin with a list of references from the Nuclear Structure Reference file (NSR) maintained by NNDC at BNL. The references come with pre-assigned keynumbers and fall into two categories, primary and secondary. Primary references are refereed, published papers and have keynumbers of the form 2019Da32, that is, the year, the first two initials of the lead author's last name, and a running number. Secondary references consist of lab reports, conference proceedings, theses, and other unrefereed materials with keynumbers of the form 2019DaZZ. They are thus differentiated from primary keynumbers by running letters rather than numbers. For secondary sources, evaluators should try to contact the author, or the supervisor in the case of a thesis, to find out the current status of the data. If contact cannot be made and the data cannot be verified, the data should be treated as tentative.

Note: If an evaluator receives a reference from outside the NSR system, for example a preprint or a private communication, the evaluator can assign a temporary keynumber to the document These temporary keynumbers should use running letters beginning with "AA" to avoid confusion with the secondary source keynumbers which use letters at the end of the alphabet. A list connecting the temporary keynumbers with theircitations should accompany the mass chain submission, and if the document is not from a journal normally scanned at NNDC a copy should also be enclosed. NNDC will assign a "valid" keynumber to these temporary keynumbers and will make the appropriate replacementss throughout the mass chain.

1. In any experiment the author's basic measured quantities should be quoted as given, except as noted in Comment 2, or unless the data can be converted by the application of known numerical factors from the author's units to units used by convention in ENSDF. Examples of the latter are the conversion of mean-life to half-life, or energy units of MeV to keV.

2. Give what was actually measured and not what the author quotes, in cases where they differ.

Example 1: A measurement of I / I might be quoted by an author as I (gs), which, for the author's decay scheme, should be equivalent to the absolute I determination but is not as fundamental a quantity. If the decay scheme were to change, the I (gs) could change, whereas the absolute I measurement would still be valid. This distinction is an important one, and failure to make it is a particularly common source of confusion when I normalization conditions are being stated.

Example 2: A measurement of I ±/I might be quoted by an author as I +/I . The ratio should be expressed in terms of the annihilation radiation since I +/I implies that the positron spectrum was measured.

Example 3: From angular distribution and angular correlation experiments, the resulting character can be determined only as dipole, quadrupole, dipole+quadrupole, ie., D, Q, D+Q, etc. An author will sometimes convert these to M1, E1, E2, M1+E2 etc., with or without parens, based just on the proposed level scheme or perhaps on a theoretical model. It is important to retain the D, Q etc., assignment in the source datasets. Note that for J assignments, the argument mult=D is strong, whereas

mult=(M1) or (E1) is weak. Sometimes mult=D is sufficient as part of an argument, and this is one reason why it is important to keep track of what was experimentally determined.

Note: If the half-life of a level is known, and for example mult=Q is determined for a deexciting transition, then if mult=M2 can be excluded by RUL the assignment Q=E2 can be made for that transition in all datasets. See Section 1.10, Multipolarities, mixing ratios, conversion coefficients, Comment 4. Also, a large value of for D+Q might also allow M2 to be ruled out, so that the multipolarity can be assigned as M1+E2. In either case the justification should be stated.

3. Document any and all changes made in data quoted from an author. When correcting an author's value for a quantity, for example a misprint in E , give the corrected value in the E field and mention the uncorrected value in a comment. Do not give the uncorrected value in the E field and rely on the comment to explain what the correct value is.

4. When extracting data from an author's paper, note any assumptions, standards, or constants that enter into derived values and if possible correct for more recent values of these quantities. Any changes should be documented.

Example 1: An I /I branching ratio for a ground-state or metastable-state decay for one nuclide might depend on the value for the daughter nuclide; thus, a comment such as "I /I =XXX if I /I (daughter)=YYY" would be appropriate.

Example 2: In a decay dataset, a conversion coefficient might be given relative to a standard value. A comment such as " K=XXX if K(standard)=YYY" would be appropriate.

5. Check the bibliography in each article against the NSR file. This is a valuable cross check to help ensure that references have not been overlooked. An author may quote data received as a private communication. These data should be tracked down if possible. Any new references obtained in this manner should be communicated to the manager of the NSR file.

6 Do not rely on an author to extract older data correctly. Even if an author collects such data in a table, the original articles should be checked. This is especially important in view of 4. above.

7. Be sure to distinguish between values measured by an author and those assumed by the author based on data from other work.

Example 1: In a particle transfer reaction, an author might adopt L values for some levels based on the known J or on L values determined by other work in order to establish characteristic ( ) distributions for levels whose J has not been established. These "assumed" L values should be given in square brackets with a comment such as "From XXX" or "From known J ".

Example 2: In determining E or E(level), an author might adopt values from other work as internal calibration standards. These standards should be checked and noted. If newer values for the calibration standards are available, it might be possible to correct the author's energies. The quality of the data will dictate whether or not that is worth doing.

1.2 Manipulation and Presentation of Data
1.2.1 Comments

Comments can allow the evaluator to make important contributions to the evaluation. The wording and placement of comments should be carefully thought through. See the ENSDF manual for a complete discussion of the formats for comments. The following is a summary of the main points.

1   Comment formats: All comments require a lower-case "c ", "t ", or "d" in column 7. Older mass chains may contain upper-case letters in column7, which tell the output editor to translate the contents of the comment, thus "137CS" would be converted to "^{137}Cs", "G" to "γ", etc. The "upper-case C" format is being phased out and all old ENSDF files will be converted to the "lower-case "c" format. This format should be used for all new evaluations. In this mode, one must use the special character set given in the ENSDF manual. This character set consists of control characters and normal characters, thus "|g" gives "γ", "|9" gives "Σ", "{B{+238}Pu}" gives "^{238}Pu" in bold font, etc.

> Note: The lower-case "c" and "t" conventions apply only to comments and tables. They do not apply to continuation records such as DSID, XREF, FLAG, FL etc.

A "t" in column 7 indicates to the output program that the comment should be reproduced "as is" and any extra blank spaces should not be squeezed out. This format is useful for presenting data in tabular form.

A "d" in column 7 tells the output program that the comment is a documentation record and should not be reproduced. The document records are ignored in the analysis programs.

2. Comment Types: There are several different comment types that the evaluator can use to determine where a comment will appear within a dataset. All require a "c"or a "t" in column 7.
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> a)   No entry in column 8 . These comments apply to the dataset as a whole and in the output will appear at the head of a dataset following the ID record but preceding the first level record. In Adopted datasets they would also follow the Q records.

> b)   A record type such as "L", "G", or "B" in column 8, with no data type modifier in column 10, such as "L", "G" or "B". These comments appear in the output at the head of the respective level, gamma, or beta listing within a dataset.

> c)   Same as b). but with a data type modifier in column 10, such as "E", "RI", or "CC". These modifiers should be followed by the delimiter "$" to separate the modifier from the comment text, thus "E$" etc. If entered at the head of a dataset (before the first level, gamma etc., record), these comments appear as footnotes on the respective column headings. If entered within a data listing, the comment appears in the Comments column on the same line as the quantity being commented on.

> d)   Same as b). but with a flagged modifier in column 10, such as "E(A)", "RI(B)", "CC(D)" or "E(E),RI(E)" and entered at the head of a dataset. The delimiter "$" is needed. By using a "FLAG=A$" continuation record on a data entry within a data listing (Eγ, Iγ etc.), a symbol is added to that entry and the corresponding comment appears as a footnote. An alternative method is to put the flag symbol in column 77 of the data entry.

Note: The use of the flagged comment format (or column 77 format for the case of a single flag) is recommended whenever the same comment applies to many data entries, especially if the comment is long and involved. This avoids having the Comments column filled with repetitions of the same comment.

3.   Required comments: In all datasets there should be comments of type 2. a) for each keynumber that contains data or information used in that dataset. These comments should list what was measured and should be listed in reverse chronological order, that is, beginning with the most recent. This policy aids in locating a specific keynumber in what can sometimes be a long list of references. Including what was deduced is optional. The deduced quantities are often obvious by looking at what was measured, but there might be special cases where such information is useful. In cases where the same data (same experimental group) are given in more than one publication, don't give a separate entry for each such reference but rather choose the most complete reference for the group and on the same line state something like "Also reported in XXX". Superceded references should also be included so that a reader who may be familiar with the earlier work but not the later, can focus on the more recent version. See Example in b) below. In listing the keynumbers, each should be given on a separate line rather than running them together across the page. This improves the readability. References listed as "Others" do not need detailed information or separate lines.

Example 1:   1992MaXX: Measured E, Iγ, $\gamma\gamma$, $\beta\gamma$(t). Also reported in 1993MaYY
               1975WiXX: Measured E, Iγ, Eβ, Iβ, $\gamma\gamma$, $\beta\gamma$
               Others: 1984DuXX, 1982HiYY, !963FaZZ

Example 2:   2010AlXX: Measured E(level), L, C^{2}S. FWHM=5-6 keV
               2009AlYY: Superceded by 2010AlXX

Every column heading should have a footnote giving the source of the data and a definition of the data in the columns. unless these are obvious from the data type itself or from other general comments. For Iγ listings for example, one might have the following:

Example 3:   Iγ: "Relative photon intensity normalized to Iγ=100 for the 254.6γ. The data are weighted averages from XXX, YYY, and ZZZ".

Example 4:   Iγ: "Relative photon branching from each level. Except where noted otherwise, data are from XXX. Others:YYY, ZZZ.

a) For decay datasets there should be a general comment stating which references have contributed to the adopted decay scheme. The decay scheme should be traceable to its source, so as much detail as is needed to accomplish this should be included. For the case of a simple decay scheme, Example 1a) below is sufficient. In a more complicated case see Example 1b).

Example 1): "The decay scheme is that proposed by XXX based on extensive $\gamma\gamma$ data".

Example 2): "The decay scheme is that proposed by XXX based on extensive coincidence data using the E and Iγ data of YYY, The 1263 level was added by the evaluator on the basis of the agreement in energy and branching of the 576 and 1263 γ's with those reported in (p,2nγ). The 1420 level is proposed by ZZZ and is also reported in (p,2nγ)"

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Note 1: Comments on $\gamma\gamma(\theta)$, $\gamma(t)$, $\gamma(\theta)$, $\gamma(\theta,H,T)$ etc., in a given dataset should normally be given with the listing for which the information is relevant. $\gamma(t)$ and $\gamma(\theta,H,T)$ would normally appear with the levels listing since the information usually derived from experiments of these types, $T\frac{1}{2}$ and g-factors, respectively, are properties of the level. Comments on $\gamma\gamma(\theta)$ and $\gamma(\theta)$, including the distribution coefficients, A_2, A_4, or DCO ratios etc., from which the multipolarity and δ might be derived, should be given with the transitions involved. If information on J is also deduced, that J value should be given with the level listing, with a cross reference to the γ listing, for example "J=3/2 from $\gamma\gamma(\theta)$ in 2.3-h β^- decay".

For the β^-, β^+, and ε intensity listings there should be a comment or footnote stating how the values were obtained, for example, "Unless noted otherwise, the I(β's) are from the requirement of an I(γ+ce+ipf). balance at each level" .

For the gamma listing, there should be a comment stating how the normalization was obtained, and a footnote defining the Iγ entries, for example, "Relative intensities normalized to Iγ(256γ)=100", or "% branching from each level" etc.

b) For reaction datasets the comments for each keynumber should include the bombarding energy and particle energy resolution. If the energy resolution is not given explicitly in a paper, the evaluator should attempt to estimate it from the author's spectrum.

> Example: 1983AlXX: E(pol t)=17 Mev, FWHM=25 keV, θ=10° to 60°
> 1971IgYY: E(t)=20 Mev, FWHM=17 keV, θ=16° to 80°
> 1970IgZZ: Superseded by 1971IgYY
> 1963AkUU: E(t)=18 Mev, FWHM$\approx$30 keV, estimated by the evaluator from author's spectrum in Fig. 1
> Other: 1966BjWW

> Note 1: The resolution is an important consideration when comparing the results from two or more experiments of the same type, or when making level associations in Adopted Levels.

> Note 2: Don't put the bombarding energy on the ID record unless needed to distinguish otherwise identical dataset ID's such as E=TH and E=RES for (n,γ). The beam energy should be given in the comments for each keynumber.

Other information, such as angular range for $\sigma(\theta)$ measurements, might be included since small angles are often needed to establish L=0 transfers and the angular range studied might lead to a preference of one experiment over another in cases of discrepancies. Except for even-even targets, J^π(target) should be given, or J^π of the beam for radioactive beam experiments

c) For grouped reactions, such as (HI,xnγ) in Example 3 below, the specific reaction should be given, and for Coulomb excitation in Example 2 below, the distinction between particle detection, (x,x') and

gamma detection, (x,x'γ) should be made. For (γ,γ') datasets as in Example 4 below, the source and the E used to excite the level are required.

Example 1: ^{207}Pb(d,p),(pol d,p)
    J^{π}(target)=½$^{-}$
    2001Va04: E(d), E(pol d)=22 Mev, FWHM=5-6 keV
    2006He21: E=22 Mev, FWHM=3 keV
    Others: 1968Do04, 1967Ba41, 1962Mu05

Example 2: Coulomb excitation
    1969Ba51: (x,x')   x=α, E=17-19 Mev; x=^{16}O, E=69 Mev
    1972Ha59: (x,x'γ) x=α, E=15, 18 Mev
    1959Bi10 : (x,x'γ) x=p, E=2.8 Mev, pulsed beam
    1971Di02:   (x,x'γ) x=^{40}Ar, E not given, recoil distance

Example 3: (HI,xnγ)
    1983Ba70: ^{130}Te(^{27}Al,5nγ), E=154 Mev
    1995Pe16: ^{146}Nd(^{11}B,5nγ), E=66 Mev

Example 4: (γ,γ')
    1963Fl04:   source = ^{56}Fe(n,γ), E=7279
    1973Sw01: source = Doppler-broadened 7117γ from ^{19}F(p,αγ)
    1977Co10: source = bremsstrahlung, E(max) = 6600, 9700

For the levels listing, there should be a footnote on the E(level) heading giving the source. This footnote could also include mention of levels that are not adopted, for example broad peaks, or could include any other general points the evaluator wishes to make.

Example 1: "For levels with γ's, the excitation energies are from a least-squares fit to the adopted E data. For other bound levels the energies are weighted averages from all reactions, except where noted otherwise. For proton resonances the excitation energies have been calculated from E(p) using S(p)=XXX"

Example 2: "In addition to the levels listed, broad peaks are reported in (d,n) at 2540 *80*, and 3720 *120*. Above about 2500, the association of levels seen in the different reactions is uncertain. The evaluator has chosen to show separate levels in such cases; however, it is possible that where the energies overlap these reactions may be populating the same level".

1.2.2   Combining Datasets

It is sometimes convenient to combine two or more reactions in a single dataset. This approach is useful when the reactions are similar in nature and where data in the reactions are sparse, or where one reaction is

verycomplete with little information in the others. The following are two situations where this might be appropriate. For exceptions, see 3. below.

1. Inelastic particle scattering experiments, (p,p'), (d,d'), (α,α') etc., can sometimes be combined into a single dataset as (x,x'). If this is done, then of course it is important to specify in which reaction and reference a property such as E, L or S was determined. If there are two or more experiments of comparable precision it is best to create separate datasets so that the different sets of transition energies, relative intensities, multipolarity assignments etc., can be displayed. The following is an example of a combined dataset.

^{152}Sm(x,x')
      x=n:
      1985Fe04: E=2.47, 2.75 Mev, σ(θ); coupled channel analysis; levels 122, 366, 1086

      x=p, pol p:
      1993Pe01: E(pol p)=20.4 Mev, σ(θ), analyzing power; levels 0, 122, 366, 707, 963,
        1041, 1221
      1989Ob02: E=24 Mev, FWHM=18 keV, σ(θ); levels 0, 122, 366, 707

      etc.
> Note: The notation for inelastic scattering, (x,x'), includes the case of elastic scattering, so there is usually no need for a separate (x,x) dataset. One exception is resonance work, where information on resonances in the compound nucleus can be obtained and may be of importance. See Section 1.5. Resonances. Information on nuclear shapes, charge densities, etc., deduced from elastic scattering can be given, or referred to, in Adopted Levels without the need for an (x,x) source data set.

2. In a similar fashion to inelastic scattering in 1. above, different heavy ion in-beam reactions can sometimes be combined into a single dataset as (HI,xnγ). This can be done in cases where there is one rather complete and detailed experiment, and several others with limited sets of data. If there are two or more different experiments of comparable precision it is best to create separate datasets so that the different sets of transition energies, relative intensities, multipolarity assignments etc., can be displayed.

> Note: Iγ data from different in-beam experiments can be combined only via branching ratios. There is no such thing as an adopted/ recommended set of relative intensities for in-beam works, even with two experiments studying the same reaction..

3. Reactions that lead to different types of states or proceed by different reaction mechanisms should not be combined,

> Example 1: (e,e'), (γ,γ'), and Coulomb excitation should each have its own dataset.

> Example 2: In-beam γ-ray experiments such as (p,nγ) or (α,nγ) should not be combined with heavy-ion induced reaction datasets.

Example 3: Particle transfer reactions (d,t) and (^{3}He,α), for example, should be kept separate since the former populates preferentially low spin states and the latter higher spin states.

1.2.3   Documentation of data within Datasets

The sources for the data in all data listings, E(level), Iγ, δ, L, etc., should be given in footnotes on the corresponding column heading (or in comments) unless there is only one reference for that dataset. In this case, the reference can be given with the ID record, and/or a comment can be given stating "All data are from XXX". Keep in mind that all the data presented should be readily traceable to their source. When more than one keynumber is included on an ID record or in the heading comments, it is important to state from which keynumber the individual pieces of data are taken. If a reader wants to check an E, an Iγ, or a δ, for example, that reader should be able to go directly to the relevant reference, or references. If the E(level) values come from a least-squares adjustment to the E values, this should be stated explicitly.

1.2.4   Placement of gamma records

Gamma transitions deexciting the levels as well as unplaced transitions should be entered in order of increasing energy. This policy applies to all datasets, source and Adopted Gammas. FMTCHK will give a warning if transitions are out of order. Unplaced transitions of course must be entered before the first level record and note that they should not be included in Adopted Gammas.

1.2.5   Significant digits

When converting values from one set of units to another, for example, mean-life to half-life , or when re-normalizing Iγ values, enough digits should be retained so that the inverse operation will reproduce the original values. Note that in some cases this will result in more digits being quoted in the converted value than in the original value. Another way of stating this principle is that the fractional uncertainty in the original value should be preserved (to the same number of significant digits) in the converted value. This procedure is especially important when dealing with quantities determined with fairly high precision.

Example 1: From BE2=0.384 *4* one should give T½=7.27 ps *8*, not 7.3 ps *1*, and from τ=32 ps *1*, one should give T½=22.2 ps *7*, not 22 ps *1*.

Example 2: Note that, except for Adopted Gammas datasets, it is not necessary to re-normalize data to Iγ=100 for the strongest transition. Some re-normalization may be useful when averaging two or more sets of values, but in a case where there is just one set of values and the author does not assign Iγ =100 to any of the transitions, there is no need to re-normalize the data. Consider a case where the author has assigned Iγ=90 *3* to the strongest transition. A re-normalization to Iγ=100 gives 100.0 *33*, and will result in extra digits being required throughout. If these data are then used in Adopted Gammas, there will be an additional re-normalization required to get branching ratios Re-normalizations should be kept to a minimum.

Note: As a special case of Example 2:, if an author gives absolute intensities in a decay dataset, these should be reported as given by the author and not re-normalized in that source dataset.

1.2.6 Data roundoff

1. Our present suggested upper limit for rounding off uncertainties is "35". There are cases where this cutoff should be increased.

Example 1: When two or more values are being averaged, and the uncertainties are comparable, with some just below the cutoff of "35" and some just above, then the average should be taken before rounding off the values.

Example 2: When the uncertainty on a value gives a lower limit close to zero, a roundoff may be misleading. A value for some quantity of 4.2 *36* does not overlap zero, whereas a rounded-off value of 4 *4* does includes zero.

2 Do not replace numerical values with large uncertainties by approximate values.

Example: An "isomer" energy of 230 *300* allows for the possibility that the "isomer" may lie below the "ground state" by 70 keV. If the energy is replaced by $\approx$230, the possible energy inversion will not be evident.

1.2.7 Multiplets

1. In a reaction spectrum, a peak labeled by the author as "doublet" or as "complex" should be entered as a single peak and labeled appropriately. That is, just one "level" entry should be made, even though the individual components of the multiplet might be known or inferred from other sources.

Note 1: In the case of a peak suspected on the basis of work from other sources of being made up of two levels with known J^{π}, say $J^{\pi}=1/2^{+}$ and $5/2^{-}$, a value of J^{π} for the single "level" entry can be entered as"$J^{\pi}=1/2^{+}$ and 5/2-" or as "$J^{\pi}=1/2^{+}$ & $5/2^{-}$". The probable level association should be explained in a comment. The form "$J^{\pi}=1/2^{+}$ and $5/2^{-}$" denotes a doublet each member of which has a known J^{π}. The "and" or "&" differentiates this case from "$J^{\pi}=1/2^{+}$, $5/2^{-}$" which is the notation for a single level with two possible J^{π} values.

Note 2: When stating that a peak is a multiplet, the basis for this claim should be given. For example, it is important to distinguish between experimental arguments such as "peak is broad", and theoretical arguments such as "C^2S is too large for a single level on the basis of shell model expectations".

2 In a gamma experiment, a multiply placed transition seen as a single peak in the spectrum should be treated as one transition with multiple possible placements. The measured E value should be used in each placement. Do not "resolve" such peaks by using energies taken from the level/decay scheme. Of course the intensity should be divided among the several placements if possible.

Note 1: If the intensity can be divided, for example on the basis of $\gamma\gamma$, or from a branching ratios in other dataset, then an "@" should be entered in column 77. Comments such as "From $\gamma\gamma$" or "From $I\gamma/I\gamma_n$ in XXX decay" should be given, where "$I\gamma$" is the intensity of the component of the multiplet from the level in question and "$I\gamma_n$" is the intensity of another transition from the level. If the intensity cannot be divided, then the full intensity with uncertainty should be given for each placement, along with an "&" in column 77. The entries "&" and "@" will automatically generate footnotes explaining that the transitions are multiply placed and that the intensities are not divided (for "&"), or are suitably divided (for "@").

Note 2: In source datasets for cases where the intensity is not divided, do not enter these intensities as limits. The converse is true in Adopted Gammas, where multiply-placed $I\gamma$ values should be entered as upper limits. See Section 3.3. $I\gamma$, Comment 2, Note 2.

Note 3: When stating that a gamma transition is a multiplet, the basis for this claim should be given. For example, the gamma peak might be broad, coincidence data might suggest that a peak is a multiplet or a comparison of $I\gamma$ branching with other transitions from the same level as determined in other datasets might suggest a multiplet.

3. A multipolarity determined for a multiplet will not necessarily be correct for each, or perhaps even any, member of the multiplet. For example, depending on the relative strengths of the components, the $I\gamma$ and Icek for a doublet consisting of an El and Ml component could simulate mult=E2. The multipolarity deduced for the doublet should be given in a comment, but should not be entered in the multipolarity field of the individual components unless additional information is available that justifies the assignment.

Note: In a case where $I\gamma$ but not the corresponding Icek (or vice-versa) is resolved, and the multipolarity of one component of a doublet is known from other sources, it may be possible to deduce the multipolarity for the other component.

Example: The author reports E=1411.48 *9* with $I\gamma$=1.01 *3* placed from levels A and B, with $I\gamma$ divided between the two placements based on $\gamma\gamma$. Mult=M1+E2 with δ=+4.3 *+9-13* for the component from level B is known from other work. From these data and α_k(exp)=0.00083 *14* for the doublet, mult=E1 can be deduced for the component from level A.

1.2.8   α decay

1. The energies, intensities, and hindrance factors of all measured α branches should be given. See Comment 4. below.

Note: In the case of an even-even parent, if the intensity of the branch to the first 2+ level is not known, systematics should be invoked to estimate its probable intensity so that a better value can be adopted for the gs branch. See Appendix E, Comment 2 b).

2. If the energies of the daughter levels being fed are not known, the E(level)=0+x style should be used. This procedure allows relative level energies to be presented in the daughter mass chain..

3. The energy calibration standards used by the author should be checked for possible newer values and the Eα's corrected accordingly. The evaluation by Rytz, 1991Ry01, is still a useful starting point for checking calibration standards but recent mass chains should also be consulted for possible newer precise values. In this regard, see the comments by D. Abriola, Section 3.4 of the IAEA report *Summary Report of a Specialised Workshop on Nuclear Structure and Decay Data (NSDD) Evaluations*, INDC(NDS)-0688, April, 2015.

4. For hindrance factors see Appendices A and E.2020Si16[*] for an evaluated list of r_0 parameters for all even-even alpha-emitting nuclides and describes the program ALPHAD_RadD which calculates these parameters for the odd-A and odd-odd-A nuclides from the even-even evaluation. This reference replaces the earlier review by (1998Ak04)[**].

[*] 2020Si16. S. Singh, S. Kumar, B. Singh, A. K. Jain, Nucl. Data Sheets 167, 1 (2020)
[**] 1998Ak04, Y. A Akovali, Nucl. Data Sheets 84, 1 (1998)

1.2.9 β^-, $\varepsilon+\beta^+$: energies, feedings, logft

1. Measurements of Eβ or Eε should be given in comments rather than in the energy field. All of our programs deduce these quantities from the Q value and the level energies.

Note: If a new accurate measurement of Eβ or Eε appears in the literature and that value has not been included in the latest mass adjustment, then it should be compared with the input values in that adjustment. If it is of comparable accuracy, an attempt should be made to see if it alters significantly the adjusted output value. If it does, an updated Q value can be adopted. In this regard, correspondence with the atomic mass center is advised.

2. The β^- and $\varepsilon+\beta^+$ feedings usually come from intensity balances at each level, and the logft's are then calculated based on these feedings. For transitions that from the spin/parity change are expected to be non-negligible, such as those for J=0 or 1, or J=2, $\Delta\pi$=yes, when the feedings are consistent with zero, the logft's should be expressed as lower limits.

Example 1: For a feeding of 3% *3*, the logft should be calculated for a feeding of 6% and expressed as a lower limit.

Example 2: For a feeding of -5% *7*, the logft should be calculated for a feeding of 2% and expressed as a lower limit.

3. When J=2, $\Delta\pi$=no and for ΔJ>2, the logft systematics give a lower limit of 12.8. For such transitions, any feedings that give logft$\lesssim$12.8 should be set to zero, with an appropriate comment, since such feedings imply an error in the decay scheme, Perhaps the decay scheme is incomplete, with missing γ feedings from

unobserved high lying levels . An exception to this policy of omitting "unphysical" branches occurs when the initial or final J is in question and it is not clear whether it is the spin or the feeding that is questionable. In such a case, the feeding should be shown with a "?", and the problem pointed out in a comment.

4.   The combined feeding to two or more levels connected by γ transitions whose total intensities are not known, or known only as limits, can sometimes be determined even though the individual feedings cannot. Such combined feedings should be given in a comment.

>   Example: "Iβ^- to the X and/or Y levels is 6.2% *2* giving logft=XXX". This could be given as a flagged footnote on both level X and level Y.

1.2.10   BEλ, BMλ, βλ

1.   In Coulomb excitation and (e,e'), two reactions where electromagnetic excitation probabilities can be determined, the quantities BE2, BE3, etc., should be quoted on continuation level records. Data quoted as matrix elements should be converted to BE2 etc. The fact that a matrix element had been determined should be added as a comment.

>   Note 1: $BE\lambda(J_i \rightarrow J_f) = (2J_i+1)^{-1}|<J_i||ME\lambda||J_f>|^2$, where $<ME\lambda>$ is the Eλ matrix element and J_i is the spin of the initial state. Note that $BE\lambda(J_f \rightarrow J_i) = (2J_i+1)(2J_f+1)^{-1} x BE\lambda(J_i \rightarrow J_f)$

>   Note 2: All BEλ and BMλ data should be given with the levels. If an author gives BEλ↓ data with the gammas, these should be converted to BEλ↑ and given with the corresponding level. The appropriate place for BEλ↓ or BMλ↓ data is in Adopted Gammas where such values are given in single-particle units calculated using adopted Eγ, T½, α, δ, and branching.

>   Note 3: It is not necessary to give T½ deduced from BE2 in the source dataset, but if done, then adopted values for E, branching, α, and δ should be used. It is often more convenient to collect the T½ values from the various source datasets in Adopted Levels in which case one can state "From BE2=XXX in Coulomb excitation" for the value from that dataset.

2.   In inelastic reactions other than those governed by the electromagnetic interaction, the appropriate interaction strengths to quote are the deformation parameters, βλ or βλR, where R is the nuclear radius, $R_0A^{1/3}$. An author may convert the deformation parameters to BEλ's, but this is a model-dependent procedure and unless the author quotes only BEλ's, the deformation parameters are what should be entered from these experiments.

1.2.11   (γ,γ')

1.   The most common type of measurement in these experiments is scattering, which, for the case of photons scattered elastically from a thin target, yields the quantity $gW(\theta)\Gamma(\gamma_0)^2/\Gamma$ where $g=(2J+1)/(2J_0+1)$, J being the spin of the γ-resonance level and J_0 the gs spin, W is the usual angular correlation function (See Note 1), and $\Gamma(\gamma_0)/\Gamma = I\gamma_0/\Sigma I(\gamma+ce+ipf)$ is the photon branching ratio to the gs from the resonance level. This quantity is what most authors measure. An author may quote various quantities from this expression depending on what is

known. For example $\Gamma(\gamma_0)^2/\Gamma$ or Γ. might be given. Whatever the quantity quoted, it can be put in a re-labeled "S" field. See Section 1.2.16, Miscellaneous, Comment 17. If anything other than the full expression is quoted, it is important to check to see what the author adopted for the "missing" quantities, for example J and/or branching and to correct the final result using adopted data. See Comment 2 below.

Note:measurements are usually done at 127° where W=1 for all dipole transitions, independent of J_0, J, or J_i . For mixed transitions, W depends on the mixing ratio and on the J's

2. If J, W, and the branching $\Gamma(\gamma_0)/\Gamma$ are known, the level width (or T½) should be given. For levels above particle decay separation energies, then the total width should include the additional modes of decay. That is, in general, $\Gamma=\Gamma_\gamma+\Gamma_p+\Gamma_\alpha+...$ The branching used should be the adopted value. If given in units of milli-electron volts, be sure that the heading translates as "Mev" and not "Mev"

3 If the branching, $\Gamma(\gamma_0)/\Gamma$, is measured, it can be given in the RI field for the relevant γ or as a comment on branching given with the corresponding level. .Occasionally, self-absorption experiments are performed. These can yield the quantity $gW\Gamma(\gamma_0)/\Gamma$, or an author may have measured the branching directly.

4. For inelastic scattering, the term $\Gamma(\gamma_0)^2$ in the numerator should be replaced by $\Gamma(\gamma_0)\Gamma(\gamma_i)$, where (γ_i) refers to the deexciting transition to excited level "i". To extract the level width (or T½), in addition to the gs branching, the ratio $I\gamma(\gamma_i)/I\gamma(\gamma_0)$, would be needed

1.2.12   Isomers, isomeric decay, delayed gammas

1. All levels with T½> 100 ns should be marked with an "M" in column 78-79, thus, M1, M2, etc. The isomer marker for this level should be put in all dataets. in which the level is seen.

2.   When a level with a measurable half-life has been produced and studied as a separate source, then an isomeric decay dataset for that parent level should be created. When delayed gammas are seen in an in-beam experiment, creating an isomeric decay dataset is sometimes a convenient way of presenting the delayed data, as discussed in 3. below.

3.   When an in-beam experiment gives data on both prompt and delayed transitions from, say level X, one way of presenting the data is to create two datasets, one labeled with the modifier "prompt gammas" and the other with the modifier "delayed gammas" where the data for the delayed decay of level X can be presented. For cases where there is more than one level whose delayed deexcitation has been observed, a separate "delayed gammas" dataset can be prepared for each such level. See also the following comment.

4.   An alternate mode of presentation for delayed gammas is to create an isomeric decay dataset for level X . This alternative is especially recommended if there is more than one source contributing data. Creating a single IT data set which combines the results from all the relevant sources is preferable to creating multiple delayed-gammas data sets for the same level X in each of the sources.

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Note: In cases where only a few pieces of data come from the delayed spectrum, such as a multipolarity for one or perhaps a few transitions, the data could be included with the prompt data with appropriate comments. For example. "Mult: From α=XXX from an intensity balance at the YYY level in a delayed spectrum".

1.2.13 Gamma-ray Normalization

1. The normalization factors in decay data sets or in (n,γ) datasets are defined, singly or in combination, to yield intensities per 100 decays of the parent nucleus for decay datasets, or to Iγ per 100 neutron captures for (n,γ).

NR: This factor converts relative Iγ's to Iγ's per 100 decays of a particular parent decay branch, for example the β^- branch, which itself may or may not be 100%. Thus, NRxIγ(rel) yields photons per 100 β^- decays. For (n,γ) datasets NR converts the relative Iγ's to Iγ's per 100 neutron captures.

NT: Defined the same as NR and applies to the TI column data, that is to I(γ+ce+ipf). It is recommended that the RI and TI data be entered on the same scale so that NR=NT.

BR: For decay datasets this factor converts intensities per 100 decays of a particular branch to 100 decays of the parent . For a 30% β^- branch BR would be 0.30, and NRxBR or NTxBR would convert the data to intensities per 100 decays of the parent. This factor should be taken from the adopted levels for the parent,

NB: This factor converts relative Iβ^- and I(β^++ε) intensities to 100 decays of a particular decay branch. The combined factor NBxBR converts the relative intensities to intensities per 100 decays of the parent.

Note: See the ENSDF manual for a more complete discussion of NB and its combination with BR.

2. The normalization condition giving NR and NT, should always be stated. If the decay scheme cannot be normalized, this fact should be pointed out. Be sure to account for all relevant factors. A footnote is automatically generated for each decay data set stating "For absolute intensities per 100 decays multiply by XXX". The value in this footnote takes the relevant quantities from the normalization record. BR comes from the adopted branching given with the parent level in Adopted Levels.

Note 1: If the normalization condition involves a measured quantity for which no uncertainty is quoted by the author, for example, Iβ^-(gs)=30%, then the resulting NR should be given as approximate. If NR is given with no uncertainty, GTOL will generate level feedings, and RadList will generate absolute intensities that reflect only the uncertainties in the relative intensities.

Note 2: In the 30% example in Note 1:, if the evaluator chooses to assign an uncertainty, ΔIβ^-, that uncertainty can be explicitly added to the Iβ's in the listing, with an appropriate comment, or simply referred to in the normalization statement, for example "NR: The evaluator has assigned an uncertainty of x% to the intensity of the gs β^- branch in order to get an overall uncertainty for NR". Of the two approaches, the second is recommended since it preserves the accuracy of the listed relative feedings. Note that when the gs branch has a small intensity, say a few percent, then even a large assigned

uncertainty can result in a rather precise NR as calculated from $\Sigma I(\gamma+ce$ to gs$)=100-I\beta^-(gs)$. See Section 1.4. Uncertainties, Comment 2, Note 1.

Note 3: In a case where the Iγ's in the RI field already include all the uncertainty appropriate for absolute intensities, such as when an author determines and quotes absolute values (including absolute uncertainties), then no additional uncertainties should be given with the normalization factors. That is, NR and, NT should be given on the "N" record with no uncertainty. The same applies to BR. There is no requirement that the uncertainty in BR given in Adopted Levels be carried over to the "N" record in a decay data set, although the value itself must be the same.

1.2.14 Parent records

In the parent record, the fields where data are known should be filled in, and the data should be the same as in the adopted dataset. For parents outside the A chain being evaluated, for example an alpha decay dataset, the parent information should be taken from ENSDF unless the evaluator is updating those data also. Comments on "P" record data, such as sources, are not needed unless the evaluator is modifying them. The appropriate place for comments on any of the quantities appearing on the "P" record is in the adopted data set for the parent nuclide.

1.2.15 Half-lives*

For decay datasets the adopted T½ should be entered for all levels. Values measured in that dataset should be given in comments, along with the method and the keynumber. For reaction datasets, measured values should be given in the T½ field. Measurements from other datasets do not need to be added unless needed for some special reason.

Note 1: Footnotes on the T½ column can be used to cut down on repetition of the method/keynumber requirement. For example, a footnote stating "T½ values given in the comments are from $\gamma\gamma(t)$ (keynumber) except where noted otherwise" would be appropriate.

Note 2: In the absence of a measured T½, an author will sometimes give a lower limit based on the observation that the reaction products have passed through the target to detector with a known transit time. Such limits should not be put in the T½ field; however, a comment giving that information could be included. If the products do not pass through the system then an upper limit based on the transit time is a useful piece of information that should be entered in the T½ field.

* See Appendix G for procedures/guidelines on handling T½ data for ground states and long-lived isomeric states.

1.2.16 Miscellaneous

1. The symbol "/" should not be used when proportionality of more than two values is being expressed. The expression K/L/M is mathematically equivalent to KM/L. Use ":" instead, thus K:L:M.
2. Try to resolve discrepancies. If they cannot be resolved, then at least state this fact.

Example: If δ=+0.38 *4* is adopted for a certain transition, based on solid evidence, and a value δ=+1.2 *3* has been determined in one of the source data sets, then, if the reason for the difference cannot be determined, the evaluator should point out the discrepancy. This can be done with a comment in the source data set, where it could state that the value differs from the adopted value, or with a comment in Adopted Gammas, where the discrepant value could be mentioned. If the discrepancy is not pointed out, a reader familiar with the discrepant value might think that it had been overlooked and might thus question the adopted value.

3. Use the word "uncertainty" rather than "error" to refer to what we call the standard deviation in a measured quantity. The word "error" should be reserved for mistakes, such as typos, or inconsistencies in values given for the same quantity within a paper.

4. Note that TI is translated in the ENSDF output as I(γ +ce), not I(ϵ+β^+) even though the fields have the same name. When I(ϵ+β^+) is what is meant, it must be spelled out unless the context makes it obvious.

5.   A level designated as an isomer in one data set should be treated as an isomer in all data sets, that is, columns 78 and/or 79 should be filled in for that level in all datasets.

6.   Do not use "CA" in the uncertainty field when a numeric uncertainty can be calculated.

Example: If Iγ is calculated from I(γ+ce+ipf) and α, the uncertainty in Iγ from the combined uncertainties in I(γ+ce+ipf) and α, not the symbol "CA", should be put in the uncertainty field. A comment is needed to explain the source of the Iγ value.

7. When calculating or correcting quantities that depend on other properties, for example calculating T½ from BE2 which depends on E, branching, δ, and α, or calculating Γ from g$\Gamma(\gamma_0)^2/\Gamma$ which depends on J and the γ branching to the gs, See Section 1.2.11, (γ,γ'), adopted values should be used for all relevant quantities.

Note: In a dataset in which BE2 has been measured, if T½ is deduced from that BE2 value it should be done using the adopted values for E, γ branching, δ, and α. Note, however, as mentioned in Section 1.2.10, BEλ, BMλ, $\beta\lambda$, Note 2, that it is not always necessary to convert BE2 to T½ in the source dataset. That conversion can be done in Adopted Levels.

8. When working with data in any dataset, a comparison with values in other datasets should be made to check for inconsistencies or to incorporate more detailed information.

Note 1: A γ might be multiply placed in dataset A but resolved in dataset B. The branchings from B can sometimes be used to divide intensities in A. This should be done whenever possible.

Note 2: It is recommended that E(level) data in each dataset be checked against values for the same quantity obtained in other datasets. This cross checking will sometimes show that data in one dataset are shifted relative to those in other datasets. In such a case a comment should be made pointing this out, and the shift should be taken into account in making level associations in Adopted Levels, and in arriving at adopted energies.

9.   Measurements of $P_k\omega_k$ = Ik x-ray should be given. They can be entered on a continuation "E" record. These quantities are of direct interest to some researchers and of course they provide a direct measurement of the K x-rays, either for branches to individual levels, or an average for the whole decay scheme, depending on the case. The $P_k\omega_k$ should be compared with the $_{K\text{ x-ray}}$ intensity as calculated by RadList.

10. If numerical data are quoted in comments, the uncertainty should be included, unless the value is being used only as a label, thus "T½: From BE2=0.240 *6*", or "µ : From g=1.62 *3* in (α,2nγ)". This is not to imply that the actual numerical value is needed in all cross references, but only that if quoted, the uncertainty should be included.

11. When changing the sign of a mixing ratio which has an asymmetric uncertainty, note that δ = A +a-b becomes δ = -A +b-a.

12. The ground state should be included in all data sets of the type (X,X') or (X,X'γ).

13. It is recommended that cross sections, analyzing-power values, and angular- distribution coefficients be given explicitly. They can be of importance in justifying any conclusions based on such data. The conclusions themselves, of course, should be given.

> Note 1: The angular-distribution coefficients should be given in the form A_2, A_4, not A_2/A_0, A_4/A_0. That is, we define the angular distribution function as $W(\theta)=1+A_2P_2(\cos\theta)+$, not as $A_0+A_2P_2(\cos\theta)+$.

> Note 2: When giving DCO ratios, the character of the gating transition (dipole or quadrupole) must be included.

14. Separate data sets for experiments with no specific level data but with some useful general information can be included at the evaluator's discretion. Such data sets would consist only of comments. The following are examples:

$$^{208}Pb(e,F)$$
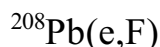
1976Dr01, 1977Ke11   E=28-44 Mev
1976Tu03   E=38-50 Mev
1976Dr01 and 1977Ke11 determine level density parameters and give a fission barrier of 27.6 Mev *5*.
1976Tu03 determine the fission barrier to be 23.6 Mev *15*

$$^{154}Sm(\alpha,^6He)$$
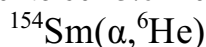
1974BoZF,1974BoZN E=50 Mev. Measured $\sigma(E(^6He),\theta)$

15.   In some cases the information measured in a reaction could be included directly in Adopted Levels without the need for a separate dataset, for example where T½ for a single excited state was determined. Keep in mind, however, that unless a dataset is created for such a reaction, there is no convenient way to search and retrieve that reaction and thus to indicate to the reader that such a reaction was studied. If that reaction seems important then it should have its own dataset. If a reaction was studied but no "useful" information is available, then it can be simply listed under "Other reactions" as a comment in Adopted Levels.

-   16. If the energy of a deexciting transition is such that it overlaps more than one final level, then the correct final level must be specified. This is done with a continuation record "FL=xxx" (No uncertainty required). Note that the energy of the final level must match exactly the energy in the dataset; however, GTOL keeps track of these values and if rerun, it changes the FL value in the continuation record if necessary. FMTCHK will issue a waqrning if this situation occurs.

    Example: 156GD2_G_FL=346.2$

17. The standard label of a formatted field can be changed (re-labeled). For example, the "S" field for a level record,with default definition of "spectroscopic factor", can be changed to "dσ/dΩ" or to "Γn" for example as follows

      Example 1:   156GD_CL_S$LABEL=SIGMA/OMEGA

      Example 2:   208PB_CL_S$LABEL=WIDTHN

18. If the reaction or reactions for a dataset (DSID) do not fit into columns 10 -39 of the Identification record, then a continuation record can be used to complete the DSID information. Columns 1 to 9 of the continuation record will be the same as on the first record except that column 6 will contain an alphanumeric character. Columns 10-39 will contain the DSID continuation, and columns 40-80 will be blank. The DSID on the first record must end with a comma. (*See the ENSDF manual, page 10)*

19. ENSDF does not have standard units for level widths, even though these have units of energy. A convenient unit for giant resonance widths is Mev, and for level widths from (γ,γ') is Mev. In these cases the units must of course be specified.

1.3   Systematics, horizontal evaluations

1. Use should be made of systematics whenever possible, the extent to which they can be applied in any given case being determined by how reliable they are for the mass region under consideration. The evaluator is usually in a better position to know how and when to apply systematics of a given quantity than the typical reader who is generally looking at just one, or perhaps a few, nuclides.

      Note: The network evaluators already make extensive use of systematics. The strong arguments for J^{π} assignments which rely on logft's, the strong arguments for multipolarities which rely on RUL, and extrapolations from the measured data in the mass adjustment (which are in fact called systematics values) are perhaps the prime examples.

2.   The gross beta decay $T\frac{1}{2}(\beta^-)$ and $T\frac{1}{2}(\epsilon+\beta^+)$ estimates from 1973Ta30can be used to estimate β^- or $\epsilon+\beta^+$ branching fractions. These half-life estimates have been found to be reliable to better than a factor of about 3 for nuclides not too far from stability; thus, while an estimate of % $\beta^- \approx 50$, and thus branching for the alternate modes $\approx 50\%$, is perhaps of marginal usefulness, an estimate of % $\beta^- \approx 0.1$ can be used to assign the alternate mode(s) as essentially 100% with a high degree of confidence. A more recent source containing many calculated nuclear properties is 2019Mo01**.

    * 1973Ta30, K. Takahashi, et al., At. Data Nucl. Data Tables 12, 101 (1973),
    ** 2019Mo01, P. Moller et al., At. Data Nucl. Data Tables 125, 1 (2019).

      Example: [106]Te has been observed to decay by a single α group to the gs of [102]Sn. $T\frac{1}{2}=70$ us *17* for this α branch. Decay via an $\epsilon+\beta^+$ branch is also allowed energetically but has not been observed. From the

graphs in 1973Ta30 one gets $T\frac{1}{2}(\varepsilon+\beta^+)>0.1$ s which leads to $\%(\varepsilon+\beta^+)<0.09$. It is thus reasonable to adopt $\%\alpha=100$.

3. Systematics of alpha-decay hindrance factors can be used to deduce a variety of quantities, depending on what is known about a particular decay branch. These quantities include J^π and configurations, total alpha branching and branchings of individual groups, and the excitation energy of the level fed in the daughter nucleus. Each evaluator (or center) responsible for a mass region in which alpha decay occurs is encouraged to build up such a set of systematics. See 1980Sc20* for a further discussion of these and other types of systematics.

*1980Sc20,M. R. Schmorak, Nuclear Data Sheets 31, 283 (1980)

Example 1: For α-decay of an even-even parent, the gs branch is defined as having a hindrance factor HF=1. Other hindrance factors are defined relative to this value. In the mass region A>214, the HF's for 0^+ even-even parents to the 2^+ first excited daughter states vary smoothly as a function of A from 0.9 to 4.0. Note that for the case discussed in the Example in 1. above, given E(2+)=1472 keV for ^{102}Sn, one gets $\%\alpha<2\times10^{-6}$ for a possible α branch to this state. It is thus safe to assign $I(\alpha)$=100% to the observed α group.

Example 2: Prior to 2002, for ^{110}Xe α decay, only Eα had been measured. From systematics of r_0 values, a partial $T\frac{1}{2}$ for α decay of ^{110}Xe is estimated to be $T\frac{1}{2}(\alpha)$=0.06 s *+10-3*. From 1973Ta30 (see Comment 1. above) one estimates $T\frac{1}{2}(\beta^+)$=0.5 s +5-3. From these partial $T\frac{1}{2}$ values one gets $\%\alpha$=87 *+10-32* and $\%(\varepsilon+\beta^+)$=13 *+32-10* and thus $T\frac{1}{2}(^{110}\text{Xe})$=54 ms *+84-28* (see 1998Ak04). Measured values for these quantities for ^{110}Xe from 2002 reported in the 2012 version of the Nuclear Data Sheets are $T\frac{1}{2}$=93 ms *3* and $\%\alpha$=64 *35*. These measurements indicate the usefulness of the interim values adopted based on systematics.

Example 3: For ^{172}Os, measured values for $\%\alpha$ were, prior to 2004, 1.0 *2* and 0.2 with no uncertainty. The smaller value gave a radius parameter r_0 inconsistent with the value expected from systematics whereas the larger value was consistent. On this basis the larger value was adopted. In 2004 $\%\alpha$ was re-measured as 1.4 *3*, confirming the interim choice adopted by the evaluator on the basis of r_0 systematics.

4. In cases where a certain shell-model state or Nilsson-model orbital, or a pair of such states or orbitals gives rise to the appearance of isomeric states over a reasonably large mass range, the reduced transition probabilities for the isomeric transitions usually fall within a narrow range of values. Such values can be used to estimate properties for the "same" transition in nuclides where one piece of information, such as $T\frac{1}{2}$, IT branching, or E, is missing.

Example: In the region around mass A=95 there are many cases of $\frac{1}{2}^-$ to $9/2^+$ isomeric M4 transitions. In particular, for Nb, the BM4W values vary smoothly from 18.6 *3* for ^{91}Nb to 6.03 *21* for ^{97}Nb. The isomeric branch is not known for ^{99}Nb, but an extrapolation suggests a BM4W of 4.0 *10*. From this systematics value one extracts %IT=0.32 *8* In the A=99 mass chain evaluation %IT was adopted as

<3.8% based on the RUL limit of 30. The systematics of BM4W values in this region suggests a smaller non-zero limit.

5.   In cases where a ground-state β^- or ε branch is not known but the initial and final J^π for the branch are known, and there is no other way to determine the intensity normalization for the γ's, the systematic logft values can sometimes be invoked. Moreover, it might be possible to build up local systematics of logft values for similar transitions, that is, transitions involving the same configurations, that give a more restrictive range of logft values.

Example: For the $\varepsilon+\beta^+$ decay of ^{152}Ho, the intensity of the gs transition has not been measured. The transition is 2^- to 0^+, which from logf^{1u}t>8.5 gives I($\varepsilon+\beta^+$)<15%, and thus ΣI(γ+ce+ipf) feeding the gs must be >85%, or 92% *8* for calculational purposes; however, there are three similar transitions in nearby nuclides with logf^{1u}t values ranging from 8.8 to 9.9. If one uses a lower limit of 8.8, one gets an expected gs branch of <7%. which gives a normalization condition ΣI(γ+ce+ipf)>93%, or 96% *4*, The representation of the limit as a value with an uncertainty is done here just for the purpose of getting a value for the normalization. A normalization given as a limit is of course essentially useless.

6.   Horizontal evaluations: Members of the USNDP and NSDD networks are sometimes involved in horizontal evaluations. These involve evaluations of experimentally measured nuclear quantities that span nuclei across mass chains. Access to the results and ongoing activities of these evaluations can be found on the main ENSDF page under "Resources", "Evaluators' Corner", then "Repository of Horizontal Evaluations..A direct link is https://www.nndc.bnl.gov/nndc/evalcorner/horizontal.html.

1.4   Uncertainties

1. Experimental uncertainties should be included whenever given by an author.

Note: If an author gives a general statement, you should include this and then also explain how you interpret that statement.

Example: An author might state that uncertainties in the E values are 0.1 for the strong transitions increasing to 0.5 for the weak ones. After looking at the range of Iγ values listed, and perhaps the spectrum if given, a comment such as "The author states that the uncertainties in E are 0.1 for strong transitions increasing to 0.5 for weak transitions. The evaluator has assigned 0.1 to transitions with Iγ >10, 0.3 to transitions with Iγ=5 to 10, and 0.5 to transitions with Iγ<5" would be appropriate. Of course an evaluator could choose to make finer divisions if he/she wished.

2.   When experimental data are quoted without uncertainties, the evaluator should state explicitly that no uncertainties are given by the author. In general, the evaluator should not take on the responsibility of adding them. Some exceptions are given in Notes 1 and 2 below. An attempt should be made to contact the author to see if uncertainties can be provided. If a paper is relatively recent, authors will usually respond to such requests.

In the case of datasets with γ's, keep in mind that GTOL assigns an uncertainty of 1 keV to E when no uncertainty is given, so even for an input dataset with no uncertainties on E, the GTOL output will contain uncertainties on the output E(level) values. In such cases these uncertainties should be deleted, the energies should be rounded off appropriately, and a footnote added that says something like "No uncertainties are available for the E input. The E(level) values are from a least-squares fit to the E data with the assumption that the uncertainties are the same for all the E's"

> Note 1: The intensity normalization of a decay scheme may sometimes involves a measurement quoted with no uncertainty. As pointed out in Section 1.2.13, Normalization, Note 1, the normalization factor should be given as approximate; however, if that measurement is a β or ε feeding, it might be possible to invoke systematics to estimate a reasonable value for the quantity, as discussed above in Section 1.3, Systematics, Comment 4.

> Note 2: If there is only one paper in a dataset and no uncertainties are given, and the author cannot be contacted or does not respond to a request, it may be possible to estimate reasonable uncertainties by looking at earlier publications by the same group from the same laboratory using the same general experimental setup where uncertainties have been quoted. The decision as to whether or not this should or can be done in an individual case is at the evaluator's discretion. If done, the procedure followed by the evaluator should be explained.

3. The weighted average program, GTOL, and all other analysis programs that calculate uncertainties for the output values treat the individual uncertainties as statistical in nature. When the uncertainties are known to have a significant systematic component, say due to a calibration uncertainty, the output from the above programs should be modified as necessary. Where systematics uncertainties dominate, or where their contribution is unknown, the adopted uncertainty should be no smaller than the smallest of the input uncertainties.

> Note 1: In cases where each of the sources from which values are being taken for a weighted average give separately the statistical and systematic components of the uncertainties, one can take the average of the various sets with just the statistical part included. The smallest of the quoted systematic uncertainties can then be added in quadrature to get the total uncertainty.

> Note 2: No result obtained from a weighted or unweighted average program, or by any other method, should be quoted with an uncertainty smaller than the uncertainty(ies) in the calibration standard(s) used.

4. All uncertainties in extracted data should be accounted for, either explicitly or in comments. In addition to the uncertainties quoted in tables, an author occasionally state in table footnotes or in the text that additional uncertainties should be added to get absolute values. These should be taken into consideration.

> Note 1: In the case of energies, an author sometimes quote values relative to some standard, or a set of standards. In such cases the evaluator should check to see if those standards have changed, and if so, and if possible, revise the author's values to reflect the change in the standards.

Example: In ^{152}Eu decay, an author measured a precise E(411γ) relative to a 1986 value for a ^{192}Ir standard. The result was E=411.126 *3* from their measurement of ΔEγ=56.946 *2* relative to E=468.0715 *12* for the Ir standard. The value for the Ir standard as given in 2000He14***** is 468.06885 *26* which gives a revised value of E(411γ)=411.123 2.

*2000He14, Nuclear Instruments and Methods Phys. Res. A450, 35 (2000)

In cases where the author states that an additional x keV should be added in quadrature to the excitation energy uncertainties quoted in their table, it is recommended that this fact be included just as a comment in the source dataset and not added explicitly to the values in the table; however, if a value from this dataset is to be used in Adopted Levels, either by itself or as one value in a weighted average, then the additional uncertainty should be included. This policy preserves the more accurate level spacings in the source dataset, and gives the proper absolute energies in Adopted Levels.

Note 2: In the case of Iγ values, an author sometimes states that in addition to the uncertainties quoted in their table, an additional x% should be added in quadrature to account for the uncertainty in the efficiency calibration. This type of correction, which is independent of E or Iγ, can best be incorporated in NR for decay datasets or in a footnote for reaction datasets. Since transitions close in energy might be expected to have a common correction factor, intensity ratios can sometimes be deduced that are independent of x. The alternative approach to including x, namely including the x% explicitly in each Iγ not only entails more work at the input stage, but rules out the possibility of obtaining the more precise ratios, or at least requires "un-correcting" the relevant Iγ values to do so. As for the E case discussed in Note 1, if a value from this dataset is used in Adopted Gammas, the additional uncertainty should be included. In this connection see Comment 3, Note 1 above.

5. Uncertainty in the internal conversion coefficients: For pure multipolarities, the output from BrIcc combines the uncertainty assumed for the theory (1.4%) and that due to the uncertainty in E. For mixed multipolarities, BrIcc will also include the uncertainty in MR. The analysis programs do not add any additional uncertainty.

Note 1: When a multipolarity is determined to be mixed based on an experimental α value, that value with its uncertainty is what should appear in the CC and DCC fields. Once the multipolarity and MR are determined and BrIcc is rerun, the output α value might be slightly different due to roundoff. In such cases be sure to correct back to the original experimental value since this is the basic measured quantity.

Note 2: When doing a calculation "by hand" that involves the internal conversion coefficient, the uncertainty in α should be included.

6.   When normalizing a decay scheme in which a single γ transition feeds the ground state, so that Iγ(1+α+ipf)=100, the only uncertainty in the absolute intensity of Iγ will be from the uncertainty in α. The uncertainty in ipf will normally be negligible relative to that in α, but of course could be included.
and ipf.

7. In the relation between T½ and BE2, for the case of low transition energies with large conversion coefficients, the terms in the factor $[E\gamma^5 \times (1+\alpha+ipf)]^{-1}$ should be treated as a combined term since E and α vary inversely so that the combined term may have a smaller uncertainty than the E and α terms treated separately.

8. Uncertainties larger than 35 should, in general, be rounded off, and where feasible, data should be quoted in units such that this convention can be applied. For example, a measured value of T½=250 ps 50 could be given as 0.25 ns 5.

> Note 1: Quantities for which standard units are used in ENSDF should always be quoted in those units. For example, E, Eα, and E(level) are always quoted in keV, so E(level)=2560 *250* should not be expressed as 2.56 Mev *25*, but rather as 2.56E+3 keV *25* .

> Note 2: In general, the "35" roundoff recommendation applies to final values. Larger uncertainties should be kept for quantities appearing in intermediate steps in a calculation to avoid possible roundoff errors.

> Note 3: In a weighted average it is advisable to keep larger uncertainties for the individual input values and just round off the final average value.

1.5   Resonances

The following is the revised policy statement for inclusion of resonance data adopted at the NSDD meeting in April, 2011.

1. Charged-particle resonances.
In the source dataset the following quantities should be given as determined in that dataset:
   a) Excitation energies in absolute values and not, for example, as S(p)+E(p)
   b) Measured resonance energies in a comment record or in a re-labeled field See Section 1.2.16, Miscellaneous, Comment 17. The coordinate system, lab or center of mass, should be specified.
   c) J, π, L
   d) Total widths or T½
   e) Partial widths in comment records or in re-labeled fields
   f) Resonance strength in a comment record or in a re-labeled field
   g) Cross sections in comment records
   h) Reaction Q value in a comment record
   i) E
   j) Iγ, relative intensities or branching ratios
   k) Gamma-ray multipolarities, mixing ratios, coefficients for angular distribution, angular correlation, polarization, etc.

2. Neutron resonances:
Average resonance neutron capture data should be given. Inclusion of other resonance data is optional, but should be given if information on the bound levels can be extracted.

1.6 L Transfers

1.   A brief comment on the method used for obtaining the L values should be given. It is important to distinguish between L values deduced from a DWBA analysis, and L values based on a comparison of $\sigma(\theta)$ with shapes for levels with known J^{π}.

2.   Parentheses should be used to denote questionable or uncertain values. Square brackets can be used to indicate an assumed value, such as a value adopted by an experimenter (or by an evaluator) on the basis of known ΔJ^{π}, or a value taken from other work, in order to determine empirical angular distribution shapes for levels with known $J\pi$ so that L values for other levels can be determined. Square-bracket L values can also be used to denote $J\pi$ assignments assumed for the purpose of extracting S. A comment is needed in all cases where square brackets are used.

> Note: The L values should always be quoted as given by the author. The evaluator can then use his/her judgement as to their reliability when incorporating them into J^{π} assignments. For example, an author's L=2 which in the evaluator's judgement should be L=(2), should appear as L=2 in the source data set, but as L=(2) if used as a J^{π} argument. In such a case a comment is needed in the source dataset explaining that the evaluator feels the L assignment is tentative..

1.7 Spectroscopic Factors

1.   The exact label for the quantity given in the "S" field can be defined by using the "LABEL=name" format See Section 1.2.16, Miscellaneous, Comment 17.

> Note: In cases where the definition is complex, one could attach a footnote to the "S" column heading, for example,"S is defined by $d\sigma /d\Omega$ (exp)=$NSd\sigma/d\Omega$ (DWBA) with N=XXX". This format can be useful if there is any ambiguity about the details or if the definition is too long for a column heading.

2.   The method for obtaining the scale of S should be given. A footnote or comment such as "From DWBA", or "Values are normalized to 3.0 for the 1430 level", should be given.

3.   The shell-model, or other orbital designation involved in the transfer should be specified if needed for the extraction of S.

> Note: This can usually be done with a general comment such as "L= l, 3, and 4, are assumed to be $p_{3/2}$, $f_{5/2}$, and $g_{9/2}$ except where noted otherwise". An alternative method is to fill in the J field for the relevant levels along with a comment on the J heading such as "J : Value assumed by the author for the extraction of S". The former approach is preferred when practical.

4.   In cases where the J given by an author differs from the evaluator's adopted value, the author's value of S, which may thus be incorrect, should not be entered in the S field but given only in a comment. The reason for recommending that the incorrect value be given at all, is that a knowledgeable reader can perhaps estimate from the value calculated for the incorrect orbital what the value for the correct orbital would be.

1.8 J^π

1. For decay datasets, J^π values from Adopted Levels should be given. It is recommended that a footnote stating this be given on the J^π heading. Exceptions to this procedure should be noted. J and/or π values determined in such experiments should be given in comments along with their justification. This is especially important if such values are used as part of the J^π argument in Adopted Levels

> Example 1: Comments such as "$\gamma\gamma(\theta)$ consistent with J=7/2, not consistent with J=5/2, or 9/2", and "J=1 from $\gamma(\theta)$", are appropriate. See also Comment 5. below

> Example 2:   If quoting J^π values given by the author, some justification is needed. For example, "From XXX based on $\gamma(\theta)$ and proposed band structure".

2. For reaction datasets with γ's, J^π values as given by the author should be entered in the J^π field, along with the arguments used to justify these values. Discrepancies among the various reaction datasets should be pointed out in comments as should differences with the adopted values.

3. For reaction data sets without γ's and without J^π information, J^π values, should not be given, whether from Adopted Levels or from some other dataset, unless they are important in explaining some other aspect of the experiment. See the following for some examples.

> Example 1: In a dataset where J has not been determined but spectroscopic factors are presented, the J values used to extract C^2S factors could be given in the J field rather than in a comment. The source of the J values of course needs to be given. In most cases it would be "From Adopted Levels". See Section 1.7, Spectroscopic Factors, Comment 4, Note.

> Example 2: Same as for Example 1: but for a (γ,γ') dataset where J has not been determined in that dataset but where the J values used to extract widths are needed,,.

4. For reaction datasets without γ data but with J^π information, the deduced J^π values should be given in the J field along with a comment stating how they were determined.

> Note 1: J^π values that come directly from L values, such as $J=L\pm \frac{1}{2}$ for single-particle transfer on an even-even nucleus, or J=L in (p,t) on an even-even target, are redundant, and should not be given. In such cases the L value is sufficient.

5   Arguments used in the J^π assignments in Adopted Levels must be documented in the source data sets. The following are just a few examples.

J^π	Argument used in Adopted Levels
a) $3/2^-$	L(d,p)=l gives $\frac{1}{2}^-$, $3/2^-$. 392γ to $5/2^-$ is Ml
b) 1^-	Av. Res. (n,γ) gives 0^-, 1^-. γ to 0^+

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c) 3^+ El γ to 2^-. $\gamma\gamma(\theta)$ in XXX consistent with J=3, not with J=1 or 2.

d) $(5/2)^+$ L=2, C^2S in (d,p)

In a), the (d,p) data set should contain the L value referred to, with any explanation deemed necessary to justify or explain it. The Adopted Gammas data set should contain the justification for the Ml assignment to the 392γ.

In b), the Av. Res. (n,γ) data set should contain the value deduced in that data set, given in a comment.

In c), enough details on the $\gamma\gamma(\theta)$ experiment should be given in the source data set to justify the conclusion. Briefly, this section should mention the assumptions, that is, what J's for other levels and what δ 's for relevant gammas in the cascade were adopted, and should clearly state which values of J are allowed and which are ruled out. In the above example, it is only necessary to state that $\gamma\gamma$ (θ) is consistent with J=3, and rules out J=l and 2. Unless J=1 and 2 are specifically ruled out, consistency with J=3 by itself adds nothing to the argument and one would be left with the assignment J^π=1+,2+,3+ based just on the E1 γ.

In d), the (d,p) data set should contain the L and C^2S values for the level in question, along with a comment justifying the basis for the C^2S argument. For example, "$d_{3/2}$ strength exhausted by known $3/2^+$ levels. C^2S for the L=2, E=XXX level suggests $d_{5/2}$". Note that if C^2S were sufficiently large, and the possibility of the level being a multiplet can be ruled out, the argument for ruling out J=3/2 might be considered strong, giving J^π=5/2$^+$.

1.9 Iγ, I(γ+ce+ipf)

The abbreviation "ipf" refers to internal pair formation and occurs for Eγ>1022 keV. BrIcc calculates the ipf contribution along with the K-shell, L-shell etc., conversion coefficients and is included in the BrIcc output entry labeled "Tot". In the following, the notation will be simplified to Iγ(1+α) with the understanding that "α" includes "ipf".

1. Iγ data should be given as relative values rather than as branching ratios whenever possible. If both relative Iγ and independently determined branching ratios are available, both should be given. The branching ratios can be given in a re-labeled TI field. See Section 1.2.16, Miscellaneous, Comment 17.

> Note: If the TI field is already being used, say for Iγ(1+α) data, then the branching ratios can be put in comments.

2. For reaction γ's, the projectile energy should be given. The FWHM of the outgoing particle should also be specified in a work such as (t,$\alpha\gamma$) when the γ's are measured in coincidence with the α's, giving a rough estimate of the level energy from which the γ's are emitted.

> Note: Relative Iγ values measured under different experimental conditions, such as at a different bombarding energy or angle, should not be combined in the RI field. An exception would be where Iγ

for an unobserved transition or for a multiplet from level "X" can be deduced from its branching relative to other transitions from level "X" as determined in other works.

3. Gamma intensities reported as upper limits are important data measurements and should be included. As a special case of upper limits, if an author states that a specific transition was looked for but not seen, that statement should also be included. An $I\gamma$ given by an author as "weak" should be so noted in a comment or flagged footnote. The latter is preferable since a symbol will appear in the $I\gamma$ column and will be more likely to be noticed.

>Note 1: It is important to distinguish between the cases where $I\gamma$ is not given because it is weak and where it is not given because it is obscured by an impurity (and thus could be strong).

>Note 2: A value quoted by an author as $<A\pm\Delta A$ should be entered in the RI field as an upper limit with $I\gamma<A+\Delta A$ along with a comment giving the author's value of $<A\pm\Delta A$. Thus $I\gamma<3.2$ *5* should be entered as $I\gamma<3.7$ in the RI filed with a comment stating RI\$The author reports $I\gamma<A\pm\Delta A$.

4. For intensity data, the TI field should be used only if $I\gamma(1+\alpha)$ rather than $I\gamma$, is the quantity measured or deduced. Two common cases where this occurs are when $I\gamma(1+\alpha)$ is deduced from an intensity-balance argument, or by summing measured Ice data, such as for an E0 transition or for a low-energy highly converted transition.

>Note 1: When both $I\gamma$ and $I\gamma(1+\alpha)$ are known, then α should be used to deduce the multipolarity. When $I\gamma(1+\alpha)$ is known but no $I\gamma$ is available, then if α is known, the corresponding $I\gamma$ should be calculated and entered into the RI field. The uncertainty given for this deduced $I\gamma$ should include that in $I\gamma(1+\alpha)$ and α. A comment should be given stating that the $I\gamma$ comes from $I\gamma(1+\alpha)$ and α.

>Note 2: An $I\gamma$ deduced from $I\gamma(1+\alpha)$ and α may be given in the RI field even when a direct measurement of $I\gamma$ is available if the evaluator concludes that the deduced value is more reliable and/or is of higher precision than the measured value. The measured value, with reference, should be given in a comment.

>Note 3: When $I\gamma(1+\alpha)$ rather than $I\gamma$ is the basic measured or deduced quantity and is thus entered in the TI field, then BrIcc will output the K/T etc., format on the continuation record. K/T, for example, operates directly on $I\gamma(1+\alpha)$ to generate Icek (via RadList) and the resulting x ray intensities. Note that Bricc uses K/T etc., only when the TI field has an entry, This format avoids including some uncertainties twice, since $I\gamma$, if calculated from $I\gamma(1+\alpha)$ and α, will already have an uncertainty combined from these two quantities so that Icek, if calculated from $I\gamma$ and α_K would double count a portion of the uncertainty.

5. Do not put $I\gamma(1+\alpha)$ values in the RI field, even if a comment is included to explain what is being done.

6. For decay or in-beam (prompt γ's) datasets, the RI and/or TI field should be left blank for transitions that de-excite an isomeric state if the isomeric $T\frac{1}{2}$ value is such that the intensities from it are time-dependent. The isomer transitions, energies, intensities, and other information can be given in a separate IT decay or in-beam

(delayed γ's) dataset See Section 1.2.12 A comment should be included giving the % intensity (γ's +β's+ce's) feeding the isomer, with a cross reference to the dataset containing the information on the "missing" transitions.

7. $Ix\text{-ray}$ and $I\gamma^{\pm}$ data, unless given as absolute intensities, that is, as intensities per 100 decays, should be given as comments in the form $Ix\text{-ray}/I\gamma_i$ and $I\gamma^{\pm}/I\gamma_i$, where i is the transition to which the Iγ's are normalized. This procedure avoids the necessity of changing the comments if the Iγ's are later re-normalized. It is recommended that the program Radlist be run to compare the measured x-ray and Iγ intensities with those calculated on the basis of the adopted decay scheme. If the $Ix\text{-ray}/I\gamma$ or $I\gamma^{\pm}/I_{\gamma}$ measurements are needed to get the decay scheme normalization, note that RadList can be used in an iterative fashion to deduce NR.

8.   Internal conversion subshell ratios used to determine multipolarities should be given. In addition to establishing multipolarities, Ice ratios measured with a precision of better than about 3%, as well as values for transitions within about 2 keV of the binding energy, can be very useful in checking the validity of the BrIcc code. Other cases where the Ice should be given are

    a) Where no Iγ is given, or where the Ice are more precise, Ice values should be given in a comment and used to deduce Iγ and/or $I(\gamma+\alpha)$, if possible.

    b) For E0 and anomalously converted transitions.

9. For a transition whose intensity is given as an upper limit, the intensity, I<A should be converted to I=½A ± ½A for the purpose of calculating quantities that require the intensity of this transition, such as normalization factors, β⁻ and ε+β⁺ feedings, or branching ratios.

    Note 1: In a situation where Iβ(gs) is determined to be, say <6%, the intensity should be expressed as 3% *3* for the purpose of obtaining the gamma intensity normalization. That is, one should set $\Sigma I\gamma(1+\alpha$ to gs)=97 *3* and give the experimental Iβ(gs) limit in a comment. This procedure is preferable to any of the alternatives, namely setting $\Sigma I\gamma(1+\alpha$ to gs)=100, or $\Sigma I\gamma(1+\alpha$ to gs)>97. There is no justification for adopting the first alternative, and adopting the second alternative leads to lower limits being given for all the intensities. See the following note.

    Note 2: The usefulness of the procedure described in Note 1 depends of course on the value of the limit itself. If Iβ is known only to be <70%, then it is probably not worthwhile normalizing the decay scheme. If no normalization is adopted in this case, a comment could be given stating what the normalization factor would be for the extreme cases, namely for Iβ=0%, and Iβ=70%. The intensity of the gs β⁻ group should still be given as a limit in the β⁻ listing.

    Note 3: Iγ values given as limits should be converted to $I\gamma=\Delta I\gamma=\frac{1}{2}I\gamma$ for the purpose of obtaining β⁻ or ε feedings from intensity imbalances. GTOL treats limits in this fashion. This procedure may lead to some feedings with large uncertainties, but that correctly reflects the state of knowledge of the decay scheme.

10. For transitions whose placements are uncertain, that is, transitions with a "?" in column 80, for the purposes discussed in 9. above, Iγ should be handled like transitions given as limits. That is, Iγ=A ± ΔA should be taken as Iγ = ΔIγ = ½(A+ΔA). GTOL treats such transitions in this fashion.

1.10   Multipolarities, mixing ratios, conversion coefficients

As in the previous section, the notation (1+α) is used to mean (1+ce +ipf)..

1. For decay datasets, the multipolarity, δ, and α entries should be adopted values. The inclusion of such data is mandatory. See also comment 9. below.

> Note: If BrIcc is run on a dataset with a poorly defined value of Eγ, the BrIcc output may differ from the adopted value of α. In such a case the BrIcc output value of α should be changed back to the adopted value with a comment pointing out that the value of α corresponds to the adopted Eγ. This can be especially important for high Z nuclides and/or for low-energy transitions which can have large values of α.

2. In reaction data sets, multipolarity, δ, and α should be included only if needed or if measured in that dataset.

3. In any data set in which multipolarity, δ, or α are determined, the bases for such determinations should be stated. The sources of data used by the evaluator, such as $\gamma(\theta)$, α_k(exp), should be specified.. Normalizations used by an author may need to be revised if newer values for the standards become available. Multipolarity assignments from ce data should be those of the evaluator based on the output from BrIcc. Multipolarities deduced by an author (or by the evaluator) on the basis of $\gamma(\theta)$ to be "stretched" should be so noted. Comments such as "ΔJ=1 from $\gamma(\theta)$", or "Stretched Q from $\gamma(\theta)$" etc., are recommended. It is especially important that such conclusions be mentioned if they are used in Adopted Levels, Gammas. See Appendix F for a discussion of mixing ratio determinations in Heavy Ion reactions.

> Note 1: For a given dataset, α_k(exp) etc., data should be calculated using the adopted Iγ and Icek determined in that dataset. Do not average α_k(exp) data from the different references in that dataset. The normalization used to put relative Iγ and Icek values on the same scale should be stated.

> Note 2: Angular correlation or angular distribution data determine only the L component of the gamma character, thus mult=D, D+Q, etc. Further assumptions are needed to establish Δπ. These assumptions should be stated when D is converted to M1, or D+Q to M1+E2, etc., and it is recommended that this step be taken only in Adopted Gammas and only if needed, say for a J^π assignment or for the calculation of BE2W, BM1W, etc. See Adopted Gammas Datasets for further discussion. See Note 3: for an exception to this policy. If the polarization of a transition has been measured, then of course Δπ can be determined and mult= M1, E1, etc., as determined by an author should be given.

Note 3: If T½ is known, RUL can sometimes be invoked to eliminate one of the multipolarity choices, for example Q=M2, or D+Q=E1+M2 when δ is known. This should be done in Adopted Gammas using adopted T½ and δ data with an explanation such as "Mult =D+Q from XXX. The adopted T½ and δ rule out an M2 component". This mult can then be used in all the source datasets in which that γ is observed, flagged with the footnote "Mult: From Adopted Gammas".

Note 4: The A_2, A_4 coefficients from γ(θ), DCO, or pol data should be given as continuation records rather than as comments, thus "152GD2_ G_ A2=XXX" rather than "152GD_cG_ $A{-2}=XXX"

4. The entries in the multipolarity, mixing ratio, and conversion coefficient fields should be mutually consistent. In particular, the following guidelines should be followed.

a) If a single multipolarity is adopted, the MR field should be blank. If δ is given as a limit, there are two options.

i) Give the dominant component in the M field, with the corresponding CC, and give the MR limit in a comment.

ii) Give both components in the M field and give the δ limit in the MR field. In this case, CC should be the value corresponding to ½ δ(max) with an uncertainty chosen to overlap the δ=0 to δ=δ(max) range.

Note: Option i) is recommended when, in the evaluator's judgement, the admixed component is likely to be over-estimated. For example, an M3 is unlikely to compete strongly with an E2, so for mult=E2+M3 with say δ <0.5, a value that seems too large, the multipolarity should probably be entered as E2, with a comment stating "δ(M3/E2) < 0.5 from XXX". Since E2 and M1 can compete strongly, MI+E2 with δ <0.5 should be retained as a mixed multipolarity entry.

b) Same as a) but with a lower limit on δ. In this case consistency with known J^π values in the level scheme needs to be considered. Thus if mult=M1+E2 with δ>1.5 is deduced, but placement in the level scheme requires J=2, option i) should be chosen with a comment stating something like "Mult=M1+E2 with δ>1.5. Placement in the decay/level scheme requires J=2."

c) If two multipolarities are given but no δ is known, the corresponding α value should be the value calculated as in 8. a) below.

d) If the multipolarity field contains more than two multipolarities, for example, E1+M2+E3 or E0+MI+E2, the relevant mixing ratios should be given on continuation records. See the following section on E0 transitions for the format for the second case. For the first case, the format is MR(M2/E1)=XXX. and MR(E3/M2)=YYY. BrIcc will calculate α and enter it into the CC field and if T½ is known, RULER will calculate BE1W, BM2W, and BE3W and enter them on a continuation record.

e) If δ overlaps zero or infinity, the corresponding small multipolarity component should be in parens.

Example: For mult =M1+E2 with δ=0.3 *4*, the multipolarity should be entered as M1(+E2). For δ>10, the multipolarity should be entered as E2(+M1), except as noted in 5. b) above.

5. The mixing ratio notation M1+x%E2 occasionally used by an author should be converted to δ. In doing so be sure to use the constraint that the percentage of the two values must equal 100. Thus, M1 + 10±8% E2 gives δ^2=10/90 with a maximum of 18/82 and a minimum of 2/98, or δ^2=0.11 *+11-9* and thus δ = 0.33 *+17-14*. See Section 3.3. Iγ, Comment 3, Example, for another case.

6. If α_k, etc., data or conclusions from such data are quoted, the bases for the values used should be given. If from relative I(ce_k) and Iγ, the basis for the normalization of the relative scales should be stated. Be sure that the multipolarity for any transition used in the calibration is independently established.

7. In cases where Iγ is known and internal conversion is significant, but the multipolarity is not known (apart from level scheme considerations), and Iγ(1+α) is otherwise unobtainable from experiment but needed, for example to calculate intensity balances in a decay scheme, or to calculate BE2W etc., the following procedures can be used.

> a) If J and Δπ are known, one can enter, for example, mult=[E1] in the multipolarity field and enter the appropriate α. For a mixed mult case, for example mult=[M1+E2], one should enter a value of α with an uncertainty that covers the range from δ=0 to ∞ That is, α=Δα=½[α(δ=0)+α(δ= ∞)]. A footnote should be attached to the mult stating "Mult is from the level scheme. The theoretical α covers the range from δ=0 to δ= ∞". For the case of a single mult the footnote should simply state "Mult is from the level scheme".

> b) If J and/or Δπ are not known, one can still follow the procedure described in a) and set, for example, mult=[D,E2] (or mult=[E1,M1,E2]). Mult=M2 or higher are assumed here to be less probable, but could be included at the evaluator's discretion.

> The usefulness of either a) or b) depends of course on the range of values for the quantity (1+α) for the assumed multipolarities.

> Note 1: If J=0 or l, Δπ=no, excluding the transitions J=0 to J=1 or ½ to ½, then mult=[M1+E2] rather than mult=[M1] or mult=[E2] should be adopted, unless there are good arguments for believing that one of the two possible multipole components dominates. α for mult=M1+E2 is always "correct", although it may have a large uncertainty, whereas using α for mult=[M1], for example, may lead to misleading conclusions. The possible large uncertainty in α when δ is not known correctly reflects the state of knowledge concerning the total intensities.

> Note 2: The use of the mult=[ ] convention in source datasets should be restricted to cases where the internal conversion is significant for the purpose at hand, such as determining intensity balances for β^- or $\epsilon+\beta^+$ feedings or for estimating total transition intensities. Avoid filling up the multipolarity fields with square bracket multipolarities that are not needed.

8. The experimental α_k, etc., as well as ce ratios that are used to determine multipolarities should be given. As mentioned above, values measured with a precision of better than about 3%, as well as values for transitions within about 2 keV of the binding energy, can be very useful in checking the validity of the BrIcc code.

9. Since the CC field cannot accommodate asymmetric α values, such values must be symmetrized. In such cases the experimental asymmetric value should be given in a comment.

10. As discussed in Section 1.4, Uncertainties, Comment 5, Note 1, when a multipolarity is based on a measured α, and that multipolarity is determined to be mixed, then that experimental value of α is what should appear in the CC field. It is the basic measured quantity from which all details of the multipolarity assignment are derived.

11. Note the distinction between ( ) and [ ] for multipolarities. These are discussed in the introductory material to the *Nuclear Data Sheets*. Parentheses are used when there are some experimental data, but the data are not conclusive. The square brackets are used to denote a value deduced solely from level scheme considerations.

> Note: For the case where mult=D+Q is determined from angular correlation or angular distribution data, and the level scheme requires M1+E2 rather than E1+M2, then the multipolarity should be in parentheses, not square brackets, thus mult=(M1+E2), with a comment stating something like "Mult= D+Q from $\gamma(\theta$) in XXX, $\Delta\pi$ =no from the level scheme". Square brackets are not appropriate for this case, since the level scheme argument forms only part of the assignment. Also, the fact that mult=D+Q can be used as a strong argument for $\Delta J<2$, whereas mult=(M1+E2) is a weak argument for such a conclusion.

12. Do not give α as a lower limit in the CC field. This would result in TI=Iγ(1+α) appearing also as a lower limit, or, in the case of an E0 transition, as an indefinite quantity. For E0 transitions the basic data are usually a measured Icek and an upper limit on Iγ, say <X, which lead to α_k > Icek/X and α >Y. The recommended procedure for obtaining TI will depend on the relative magnitude of Ice and the Iγ limit. For Ice>>X, one should give TI=Ice + ½X with an uncertainty in X chosen as ½X. For X>>Ice, TI<[X+Ice] is an appropriate choice. For the intermediate case, the first alternative is recommended

> Note: For a transition adopted as pure E0, then TI=Ice+ipf and the RI field will be empty.

13. Angular correlation and angular distribution data usually give two solutions for δ. Unless one of these solutions can be ruled out, both should be given in a comment and no entry should be given in the MR field.

1.11. E0 transitions

1. RULER should be run to calculate the absolute monople strength, ρ^2(E0), for E0 transitions. In order to do this, the branching of the E0 component from a given level, along with the level half-life, must be known. See the Appendix D for relevant formulae.

2. In the general case of an E0+M1+E2 transition one needs the mixing ratio MR(E2/M1), given by δ, and the ratio I(E0)/I(E2), given by the square of the mixing ratio denoted by MR2(E0/E2). This latter ratio is usually denoted in the literature as q^2(E0/E2) and it includes internal conversion electron and electron-positron pair emission. Since the most common measurement of the relative E0 and E2 intensities is through K-shell internal conversion, and in order to keep the number of continuation record quantities to a minimum, all the I(E0)/I(E2) ratios should be given in terms of K-shell internal conversion, MR2K(E0/E2)=q^2_k(E0/E2)=Icek(E0)/Icek(E2). RULER will calculate the full intensity ratio from this quantity. For entry on continuation records and in the following text, these mixing ratios are defined by "MRE2M1=XXX" and "MR2KE0E2=YYY". From these two quantities, RULER will calculate ρ^2(E0), BE2W, and BM1W and put them on continuation records, and BrIcc will calculate the total conversion coefficient, α, and enter it in the CC field on the gamma record.

3. The following material on J^π=0+ to J^π=0+ and J_i = J_f, J≠0 transitions is taken from 2005Ki02*. In addition to the following examples involving intensity ratios, as pointed out in the above reference, ρ^2(E0) can also be determined from the form factor in inelastic electron scattering. This method has been used for E0 transitions in some light nuclides.

* T. Kibédi, R. H. Spear, Atomic Data and Nuclear Data Tables 89, 77 (2005)

a) J^π=0+ to J^π=0+ with no intermediate level: Nothing needs to done. The E0 transition has a branching of 100%, so if T½ is known, RULER will calculate ρ^2(E0) from the expression

$$\rho^2(E0) = \frac{\ln 2}{\Omega(E0) \times T_{1/2}}$$

and enter it on a continuation record. Ω(E0) is an electronic factor calculated by BrIcc.

b) J^π=0+ to J^π=0+ with an intermediate 2+ level: The ratio of the E0 K-shell conversion intensity to that of the competing J^π=0+ to J^π=2+ transition, MR2KE0E2, must be known. From this ratio RULER will calculate the total E0/E2 intensity ratio, including internal conversion electron and electron-positron pair emission, and then calculate ρ^2(E0) and BE2W.

Example 1:
I_k(E0) and I_k(E2), or their ratio, are known. This provides a direct determination of MR2KE0E2. This value should be entered on a continuation record. RULER will calculate ρ^2(E0) and BE2W, and will calculate α+ipf.

Example 2:
I_k(E0) and Iγ(E2), or their ratio, are known, and MR2KE0E2 has been deduced by the evaluator using the internal conversion coefficient α_k(E2). As in Example 1, MR2KE0E2 should be entered on a continuation record.

Example 3:

$I_\pi(E0)$ and $I_\pi(E2)$, or their ratio are known, where π here refers to electron-positron pair emission. In this case, one has

$$I_K(E0) = I_\pi(E0) \times \frac{\Omega_K(E0)}{\Omega_\pi(E0)} \quad \text{for E0, and}$$

$$I_K = I_\pi \times \frac{\alpha_K}{\alpha_\pi} \quad \text{for all other cases. Thus we have}$$

$$MR2KE0E2 = \frac{I_\pi(E0)}{I_\pi(E2)} \times \frac{\Omega_K(E0)}{\Omega_\pi(E0)} \times \frac{\alpha_\pi(E2)}{\alpha_K(E2)}$$

The electronic factors can be obtained from BrIcc to deduce MR2KE0E2. A simple modification of this expression can be used if one has measurements of $I_\pi(E0)$ and $I_k(E2)$, or $I_k(E0)$ and $I_\pi(E2)$.

Example 4: $I_L(E0)$ and $I_L(E2)$, or their ratio are known. In this case one has

$$MR2KE0E2 = MR2LE0E2 \times \frac{\alpha_L(E2)}{\alpha_K(E2)} \times \frac{\Omega_K(E0)}{\Omega_L(E0)}$$

As in example 5, BrIcc contains the Ω factors, and simple modifications of this expression can be made for any combination of shells for the E0 and/or the E2 components.

c) $J^\pi=0+$ to $J^\pi=0+$ with two intermediate 2+ levels:
   Example:
   $I_k(E0)$ and $I_k(E2')$, or their ratio, are known, where E2' denotes a transition other than 0^+_1 to 2^+_1, and the relative intensities of the two E2 transitions are known.

$$I_k(E2) = \frac{I_\gamma(E2)}{I_\gamma(E2')} \times \frac{\alpha_k(E2)}{\alpha_k(E2')} \times I_k(E2')$$

The deduced MR2KE0E2 can then be given. Note that this approach can be extended to cases where there are more than two intermediate 2+ levels, with the transition to the first 2+ level always being the reference.

d). J^π to J^π, $J\neq0$:
   Example:
   Z=64, E=586.27 7, $I\gamma$=14.5 3, α_k(exp)=0.0202 21, δ(E2/M1)=-3.05 14, α_k(theory)=0.01439 21 (M1), 0.00764 11 (E2), and 0.00829 13 (for δ=3.05 14).

These data give Icek(exp)=0.293 31 compared with Icek (from γ's)=0.120 3 and thus an E0 component I_k(E0)=0.173 31. The E2 contribution is $I\gamma \times \alpha_k$(E2) $\times \delta^2/(1+\delta^2)$=(14.5 3) x (0.00764 11) x (0.903 8)=0.100 3. One then gets MR2KE0E2=1.73 31. The evaluator would enter "MRE2M1=3.05 14\$ MR2KE0E2=1.73 31 " on a continuation record.

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Note: For the case where $I_K(exp) > I_K(M1$ or $E2)$ but the lower uncertainty overlaps, if the data are accurate and reliable one can give an upper limit on the E0 component, and if MRE2M1 is known, then an upper limit on $\rho^2(E0)$ can be given.

1.12 g-factors, electric and magnetic moments

1. Values of the magnetic dipole moment, μ, should be taken from the evaluation 2014StZZ*, and electric quadrupole moments, Q, from 2016St14** (or updates when available) and entered directly into Adopted Levels. There is no need to repeat these values, or the g-factors from which they may be derived, in source datasets; however, See Comment 2.

*2014StZZ,, IAEA report INDC(NDS)-0658 (2014)
**   ** 2016St14,Atomic Data and Nuclear Data Tables 111-112, 1 (2016)

Note 1: If the method of determining μ depends on T½, and if the value adopted by the evaluator differs from that used in 2014StZZ, then a correction should be made if possible. If the value cannot be readily corrected, then a comment should be included giving the T½ used in the 2014StZZ evaluation.

Note 2: For a new measurement, if the value is of comparable precision to that listed in 2014StZZ, the evaluator should contact the author of 2014StZZ to see if a new recommendation can be provided.

2. Values of μ or Q that appear in the literature after the cutoff for values in the above references should be added. New measurements of g-factors should be given in the appropriate source data set and the values should be corrected, where necessary, for the adopted T½. When corrected, a comment such as "The author reports g =XXX for T½ =YYY" should be given. A comment is also needed stating whether or not the diamagnetic correction has been applied (if the data are accurate enough to be affected by this correction).

2.   Adopted Levels
2.1 General

1. All distinct levels that are observed in any of the individual data sets, and that the evaluator feels are firmly established, should be included in Adopted Levels. Uncertain levels, that is, levels shown with a "?" in one or more of the individual data sets, can be included at the evaluator's discretion. Neutron and proton separation energies should not be included as levels. Isobaric analog states (resonances) should be included as should proton and neutron resonances as discussed in Section 1.5. Resonances.

2. Make use of the XREF entries to avoid unnecessary comments

Example 1: A comment such as "seen only in (d,p)" is not needed since XREF should already convey that information. An exception could arise, however, if the evaluator wishes to emphasize some doubt about the level.

Example 2: XREF can convey the "one level corresponds to many levels" situation so that comments that repeat only this information are not needed. Note, however, that comments such as "L(d,p)=l for E=3450", given for two or more Adopted Levels to which the (d,p) level could correspond, are still needed.

3. Important comments on level properties which appear in source data sets should be repeated in the Adopted Levels data sets. Comments such as "doublet", "possible contaminant", "not resolved from X", given in a source data set, are just as important in Adopted Levels.

4. If the evaluator adopts a Q value, say Q', that is different from the value given in the most recent mass adjustment, the mass adjustment value should be given in a comment for comparison. If the mass links are not too complicated, it may be possible to adjust the other entries on the Q record to reflect the change in the Q' value. If such is the case, and if the change in Q' is significant, that is, considerably outside the limits given by the mass adjustment, then giving the adjusted S(n), S(p), and Q(α) values would be a valuable contribution. Whether this is done or not, however, is left to the discretion of the evaluator.

Note: In cases where it is not feasible to attempt a readjustment, a comparison between the mass adjustment value and the adopted value at least allows the reader to judge qualitatively what the effect on the other Q values may be.

5. BE2 and T½ should not both be given as adopted properties of a level. These are equivalent pieces of data (if all quantities needed to convert from one to the other are known), and our policy is to give T½ (See Note 1: for an exception). The best BE2 value will then, by definition, be that deduced from the adopted T½ value and the adopted γ properties. We do not give this BE2 value explicitly except in the cases noted below.

Note 1: BE2 should be given if T½ is not known and cannot be deduced from BE2, for example if the γ branching is not known.

Note 2: If T½ and BE2 are both determined for a given level but the γ branching is not known independently, then T½ and BE2 can be combined to deduce the branching. T½ and BE2 would both be given, with a comment explaining why they are both needed. The deduced branching would appear in Adopted Gammas with a comment such as "Deduced from T½=XXX and BE2=YYY".

6. When giving the source of a value, include the name of the dataset. The data sources are much easier to locate with this information.

Example: "T½: From BE2=XXX in Coulomb. excitation (2014Be13)".

2.2 Excitation energies

1. The source for excitation energies must be given. This information is usually best given as a footnote on the E(level) heading although a comment at the head of a dataset can also be used. This footnote can be written in such a manner that footnotes on individual levels can be kept to a minimum. See Example 2.

> Example 1: "Unless noted otherwise, excitation energies for levels connected by gamma transitions are taken from a least-squares fit to the adopted gamma energies. Other excitation energies are based on best values from all available reactions"

> Example 2: Rather than flagging each level with its source, the following wording covers all the llevels. "E(level) data with $\Delta E < 0.5$ keV are from ^{208}Rn ε Decay. Other values with uncertaintiess are from ^{212}Fr α Decay. Values with no quoted uncertainties are from ^{209}Bi$(\alpha,5n\gamma)$".

> Example 3: "From a least-squares fit to the adopted Eγ's. Values for levels not deexcited by γ's are weighted averages from all reactions. Values from (p,d), from (^{3}He,d),(α,t), from (d,t),(^{3}He,α), and from (p,t) have been adjusted as noted n the source datasets. Above about 2500, the association of levels seen in the different reactions is uncertain, , except where Jπ is known. The evaluator has chosen to show separate levels in such cases; however, it is possible that some of these levels that overlap in energy are the same. For E(level)>15.6 MeV, energies are from ^{207}Pb(p,p'),pol p,p'). These levels are probable IAR's of levels in ^{208}Pb".

2. Uncertainties should be included where available. See Section 1.4. Uncertainties.

3. In cases where the presumed gs and a long-lived isomer are nearly degenerate, the mass adjustment should be consulted to see if it has information regarding the relative order of the two states. Sometimes a plot of the energy separation of these states in adjacent nuclides can suggest which is likely the gs. in the nuclide of interest. If the order cannot be established, then the notation 0+x and 0+y should be used for the two states.

4. To avoid the introduction of "extraneous" levels and to get a reliable set of input energies from which averages can be obtained, the calibration and general trend of energies for the data sets should be intercompared. If the energies in a particular dataset show a shift compared with values in other datasets, whether constant or energy dependent, this shift should be mentioned in a footnote, and the energies should be corrected before including them in Adopted Levels, whether for averaging or for assigning XREF's. This policy will help avoid the incorrect association of a level in one reaction with a level in another reaction based only on the agreement in energy and will help to ensure that the energy adopted for a level seen only in the reaction requiring an energy shift is as consistent as possible with other levels. The energies in the source dataset should not be changed.

> Example: A footnote on the E(level) column of a (p,p') dataset where the uncertainties are quoted as 1-2 keV, could say "A comparison of energies with those from (n,n'γ) and 3.2-h β^- decay shows

that the (p,p') values are 4 keV high at E=540 increasing to +10 keV at E=1358" The evaluator has applied a linear correction to the (p,p') energies when using them in Adopted Levels".

5. When levels from two (or more) reactions lie close in energy (that is, the values agree within the uncertainties) and the evaluator chooses to adopt both (or all) levels, the justification for assuming that the levels are distinct should be given, unless obvious from XREF or from other adopted level properties. Consider the following cases.

a) E=5000 *8*, J =3/2+ and E=5010 *9*, J =5/2+ are known from particle reactions, and E=5005.3 *2* is known from an (n,γ) experiment; however, it is not known to which of the two reaction levels the (n,γ) level corresponds, and there is no evidence to suggest that it is a separate distinct level. For this case, the reaction levels should be adopted, with a comment on each stating something like "E=5005.3 *2* from (n,γ) probably corresponds to the 5000 or the 5010 level". Note that there is no unambiguous way to include the accurate energy as an adopted energy. The evaluator should not adopt three levels, unless there is definite evidence that the (n,γ) level is distinct from the others.

b) E=596.7 *5* with J =0+,1,2 and E=597.1 *3* with J =l+,2,3 are known to be different levels, and l(p,d)=2, leading to J =l-,2-,3- with E=598 *2* is also known. Unless there is evidence to suggest that the (p,d) level is distinct, only two levels should be adopted, with a comment on each stating something like "E=598 2 with l =2 in (p,d) may correspond to either or both the 596.7 and 597.1 levels".

2.3 $\mathbf{J}^{\pi}$

1. J assignments should be based on the fewest and best arguments available. There are three reasons for adopting this "fewest and best" approach. First, the ^{J} arguments are easier to follow when redundancy is eliminated. Second, if more than one strong argument is used, the reader might question whether there is a problem with one of them, and third, and most important, alternate unneeded arguments can be used to build up systematics. This point refers to strong arguments. For levels where only weak arguments are available, then the more arguments that can be given, the more confidant one becomes in the assignment; however, no combination of weak arguments constitutes a strong argument.

Example: Consider the assignment of 1^{+} to a level based on the arguments "M1 γ to 0^{+}. Logft=4.4 from 0^{+}". Either argument by itself is sufficient. If the multipolarity argument alone is used, the logft value is then "freed up" and can be added to the logft systematics, that is, to the base of values from which the logft arguments are derived, thus helping to build up confidence in the application of such systematics to cases where other strong arguments are not available.

2. "Direct" measurements of J (atomic beam, etc.) can be found in 2013Ma15*. This reference contains all such direct measurements, with a literature cutoff date of February, 2013, and replaces1976Fu06**.

*2013Ma15. Allison MacDonald, Babak Karamy, Kiana Setoodehnia, and Balraj Singh, *Nuclear Data Sheets 114, 397* (2013)

** 1976Fu06. Gladys H. Fuller, *Journal of Physical and Chemical Reference Data, 5, 835* (1976)

3. Arguments should be detailed enough to convince the ENSDF user that the assignments are reliable and also to allow the reader to judge what the consequences would be if new data were to become available. See also 4. below.

> Example 1: The argument "From (α,xnγ)" is not of much use. More detail such as "Excit. in (α,xnγ)", and/or "$\gamma(\theta)$ in (α,xnγ)" are needed. See 5. below.

> Example 2: Consider an argument for the assignment ^{J}=2$^-$,3$^-$ expressed as "L(d,p)=l from 3/2+. γ to 4$^-$". If the γ transition were to be subsequently determined to be M1, it would follow that ^{J} could be assigned as 3$^-$. If the argument had been given only as a general statement such as "From L value in (d,p) and γ feeding", the consequences of the new piece of evidence would not be transparent.

4. Gamma-property arguments should be specific; thus "Ml γ to 2$^+$", "γ 's to 3/2$^+$ and 5/2$^+$", etc. The gamma energy is optional, ie., "326γ to 2$^+$ is Ml", etc., but is helpful in complex level/decay schemes where the level referred to as being fed may not be obvious. The vague statement "^{J} is based on γ-decay modes" is not of much use to the reader. Note that ^{J} values and γ-ray multipolarities referred to in these comments should be adopted values so mults and J's that are in parens should be so noted in the J arguments, thus "Ml γ to (3/2$^+$)", "(E2) γ to (4)$^-$" etc.

> Note: Include target/parent ^{J} when the target is not even-even. For example, "logft=5.4 from ½$^+$", or "L(p,t)=2 from 9/2$^+$".

5. For arguments that are common to several levels, there are two approaches that avoid writing the same full argument for each relevant level.

> a) The argument can be written as a flagged footnote with the flag attached to the assigned ^{J} of the relevant levels. See Section 1.2.1, Comments, Comment 2. d).This approach improves readability. For example, the footnote could state "From (α,xnγ) based on excit. and $\gamma(\theta)$", or "Member of band X based on energy fit and inertial parameter".

> b) The argument can be put as a footnote on the ^{J} heading itself. For example, the J argument could state "Assignments from (α,nγ) are based on excit and $\gamma(\theta)$. Assignments from (d,p) are based on L values and analyzing power". Then for the relevant level one need state only "From (α,nγ)" or "From (d,p)". This option is particularly useful in cases where the argument is long.

6. ^{J} arguments for two or more levels can be linked if they are interconnected in such a way that giving separate arguments for each level could be awkward, or could give the appearance of circularity.

> Example: Consider the β^- decay of a parent level with known $^J=7^-$ to a daughter level A followed by a γ cascade with known multipolarities through levels B and C to a level with known $^J=2+$, that is, the sequence $7^-(\beta^-)A(Ml)B(El)C(E2)2+$. The argument "Logft=5.1 from 7^- and the Ml-El-E2 γ cascade to 2^+ uniquely establishes $^J(A)=6^-$, $^J(B)=5^-$, and $^J(C)=4^+$". This argument can be given for one of the levels, say C, and then for the others, one can simply say "^{J}: See C level".

7. ^{J} arguments for the ground state of an even-even nucleus are not needed. A few such nuclides have been proven to have J=0 from the absence of alternating intensities in the spectrum of homonuclear diatomic molecules. See 1976Fu06 for details (citation on page 41), but for ENSDF, $^J=0^+$ for even-even ground states is accepted without an argument. An argument such as "$L(\alpha,\alpha')=0$ from 0+" merely shifts the burden of proof from the product nuclide to the target nuclide. The argument "No hyperfine structure seen in optical spectroscopy measurements" proves only that J=0 or that μ (or Q) is very small.

8. An L=0 component in a particle transfer reaction in which S=0 can be assumed leads to J=0, $\Delta\pi$ =no, even if other L components are present (see 10. below) . The same is true of an E0 component in a gamma transition.

9. Maintain consistency between source data and conclusions. For example, L(p,t)=2 from an even-even target gives $^J=2^+$, not $(2)^+$ or $2(^+)$.(S=0 assumed, but see 10. below). Similarly, if the argument is not considered strong for J, then it should not be considered strong for π; thus, L(p,t)=(2) gives $^J=(2+)$.

> Note: A reaction such as (α,d), with a measured L value, can be used as a strong argument for π, namely, $\pi=(-1)^L$, even though J is determined only as J=L or L±l.

10. In reactions such as (t,p), (p,t), and (p,p'), S=1 may occur in weak, high-energy states.

11. Expressions such as "preferred", or "consistent with" are not strong arguments. Avoid these expressions since they leave open the question of whether other alternative J values have been ruled out. These arguments are of course valid for weak assignments.

12. Configurations should be given, but note that "Conf=3/2$^-$[521]" is not a valid argument for ^{J}. All that this argument accomplishes is to shift the burden of proof from establishing $^J=3/2^-$ to establishing conf=3/2[521]. The configuration is usually deduced from ^{J}, not vice-versa, although of course sometimes the reverse is true, and sometimes the same argument can be used to assign both ^{J} and the configuration.

Note 1: The determination of L and analyzing power in a transfer reaction might give $^{J}=1/2^{-}$, and depending on the mass region it might be reasonable to assign this level as a $p_{1/2}$ orbital, but the ^{J} argument should be "From L and analyzing power in (d,p)", not "From conf=$p_{1/2}$". The configuration should normally be treated as a separate data type from ^{J} and put on a continuation record. Comments on "Conf" should also normally be given separately from comments on ^{J}.

Note 2: In the deformed regions, the cross sections and cross section ratios, for example in (d,t) and (^{3}He,α), can sometimes determine directly the combination of ^{J} and the Nilsson orbital, rather than just ^{J}, See, for example, 1971Bu01*,.In such cases, the configuration should be included in the ^{J} argument.

   *1971Bu01. Nucl. Phys. A161, 129 (1971)

Note 3: A measurement of μ can sometimes contribute to a determination of both J and the configuration.

13. Do not use data from multiply placed transitions in ^{J} arguments unless the connection with the level in question is definite.

Note: A multipolarity determined for a multiplet will not necessarily be the correct multipolarity for each member of the multiplet. See Section 1.2.7. Multiplets, Comment 3: however, if a component of a multiplet is definitely established as deexciting the level in question, then the ^{J} of the daughter level can be used in a ^{J} argument in the usual way, such as "γ to 2^{+}".

14. When the ^{J} choices are limited to three or fewer, it is recommended that they be spelled out rather than given as a range; thus $^{J}=5/2-,7/2-,9/2-$ rather than $^{J}=5/2-$ to 9/2-. There is less chance of values being misinterpreted when they are written out completely. and the space saved is not significant.

15. RUL is an argument for gamma-ray multipolarity, not for a ^{J} assignment.

16. Avoid inconsistent and/or confusing assignments such as 2+, (3-) which is perhaps meant to indicate that 2+ is very likely but 3- cannot be ruled out.   If that is the intent, then the assignment should be 2+,3-, or (2+,3-), depending on the strength of the argument.

17. The argument "γ to 0+" gives a parenthesized assignment of $(1,2^{+})$, not $1,2^{+}$ unless the parent level has a half-life such that RUL can be invoked to rule out higher multipolarities. Similarly, an argument such as "γ's to 4^{+} and 6^{+}" gives a parenthesized assignment of $(4^{+},5,6^{+})$, not $4^{+},5,6^{+}$ unless higher
multipolarities can be ruled out, in which case the parens can be removed.

18. When listing adopted ^{J} values it is recommended that the preferred value, if such exists, be given first. This policy is an aid to some users whose programs require a single value for ^{J} and who consequently select just the first value given in an ENSDF file. In general, and apart from this use of the file, if there is a preferred ^{J} value there should be a comment stating that fact, unless the wording of the arguments themselves give this information.

19.   It is recommended that the ^{J} choices assigned be limited to three.

2.4 Half-lives

1.   For ground states and long-lived isomers all comparably precise T½ values should be collected and summarized in Adopted Levels with explanatory comments as needed. For other levels, statements such as "From XXX" or footnotes on the column heading are sufficient.

2.   All values should be given at the 1σ level. An author may report an uncertainty as 2σ or 3σ. These uncertainties need to be divided by 2 and by 3, respectively, before averaging with the other values.

> ***** See Appendix G for procedures/guidelines on handling T½ data for ground states and long-lived isomeric states.

2.5 Other Level Properties

1.   For ground states, the following Q-values should be included. Q-, SN, SP, QA, S(2N), S(2P), Q(B-N), and Q(EC-P). The last two are required only when that branch is energetically allowed. These data should be taken from the published tables in the latest mass adjustment. Note that values from these tables, eg. 2017Wa10, differ slightly from the tables on the NNDC and AME web sites which are computer files provided by the AME. These differences are due to rounding. For the NNDC web site a link to the publication is given at the top of the page under "Q Value Calculator".

2.   When branching modes are given, for example "%IT=XXX", the bases for the values can be given in Adopted Levels or in the source data set, with a cross reference in Adopted Levels to the location of the arguments. There is no need to repeat the arguments, but they must appear in one place or the other. Also, all possible modes of decay should be accounted for, unless the reason for omitting a mode is obvious.

> Note: In a case, for example, where one has "%ε+% $β^+$=99.0 *1*; %IT=1.0 *1*" but $β^-$ is also energetically allowed, there should be a comment explaining why the $β^-$ branch is considered negligible; thus, for example, "%$β^-$ is negligible since the only available decay branch has J=2, Δπ =yes, for which, from log$f^{u}t$>8.5, one derives % $β^-$<1x10^{-4}". An experimentally determined limit of this magnitude should, of course, be included explicitly in the branching

statement. For more obviously negligible branches such as for a case where the only available branch has J=4, one can state simply "J=4 for possible β⁻ branch so % β⁻ is negligible".

3. BEλ values should be included in Adopted Levels for levels where T½ is not independently known and cannot be calculated from the BEλ due to missing information, such as a ground-state branching ratio.

4, Sources of data should be stated unless obvious, that is, unless there is only one keynumber associated with the dataset. General comments are usually sufficient; thus, "From X unless noted otherwise" or "Weighted average of values from A, B, and C".

3.   Adopted Gammas
3.1 General

1. For gamma records, all available first-card data should be included.

2. Discrepant data should not be adopted. The data chosen for Adopted Levels should be self consistent.

> Example: If a gamma multipolarity disagrees with the adopted ΔJ^{π}, and the J^{π} are considered well established, the discrepant multipolarity should not be adopted, and the discrepancy should be pointed out in a comment. It is recommended that a flagged comment be used so that a footnote symbol will appear in the multipolarity field and will alert the reader.

3.2 Eγ

Sources for all data should be stated. This can usually be done with a general footnote on the column heading.

> Example 1: "Except where noted otherwise, the E quoted to tenths of keV are from β⁻ decay. The E quoted to the nearest keV are from reaction data".

> Example 2: "Except where noted otherwise, E from levels below 6570 are weighted averages from (α,xnγ) and (HI,xnγ). E for higher levels are from (^{48}Ca,xnγ)".

3.3 Iγ

1. Sources for all data should be stated. This can usually be done with a general footnote on the column heading. See examples under E above.

2. As stated in the introductory section to the Nuclear Data Sheets, the Iγ should be given as relative photon branching from each level. Any deviation from this policy, such as quoting branching ratios in %, should be stated. The program JGAMUT will calculate adopted γ-branchings utilizing Iγ values from all datasets with gammas. The strongest photon branch should be set to 100 except in the following cases.

    a) The strongest branch is an unresolved multiplet.
    b) The strongest branch is given as a limit.

    Note 1: An uncertainty should be included in the normalization value of Iγ=100 if there is an uncertainty given for the original intensity, unless there is only one transition deexciting the level, in which case the uncertainty has no meaning and should not be given.

    Note 2: Iγ for a multiply-placed transition where the intensity has not been divided should be given as a limit in the RI field, thus Iγ given by the author as $A \pm \Delta A$, should be entered as Iγ<$A+\Delta A$) for each placement, and the author's value Iγ=$A \pm \Delta A$ should be given in a comment.

    Note 3: For a level with a single deexciting transition, Iγ=100 should be entered in the RI field. This has no meaning as a relative number, but some non-network programs require a value even in this case.

3. When calculating averages to obtain the relative branchings, take note of cases where the source intensities are given as % branchings, since the uncertainties in these data are correlated.

    Example: Consider the case where one wants to get a weighted average of the intensity ratio of two transitions, γ_1 and γ_2. Some sources may provide relative intensities, and others may quote % branchings, for example, Iγ_1=42% *3* and Iγ_2=58% *3*. Here the uncertainties are correlated by the constraint that the sum must be 100, thus the ratio is 42/58 with a maximum of 45/55 and a minimum of 39/61 giving Iγ_1/Iγ_2 =0.72 +*10-8* rather than 0.72 *7* for the case of uncorrelated uncertainties. The correlated uncertainties must be used when this result is averaged with other data. See Section 1.10. Multipolarities, etc., Comment 6, for another example.

    Note: For the case of two transitions suppose one gets Iγ_1/Iγ_2=0.265 *10* as the average from several sets of values. One then has the choice of setting Iγ_1=26.5 10 and Iγ_2=100, or assigning an uncertainty to the stronger transition and subtracting that fractional uncertainty from the other branch, thus, for example, Iγ_1=26.5 *6* and Iγ_2=100 *3*. The second approach could be used to reflect the accuracy with which the best relative value for the stronger transition is known, if that is the evaluator's preference.

4 For a transition that has no measured Iγ, or for which just a limit is known, I(γ+ce+ipf) should be given, if available. The most common case would be for an E0 transition or for a low-energy

transition for which I(ce) but no Iγ or α is available. I(γ+ce+ipf) should be given in the same scale as the Iγ values for other transitions in that dataset.

3.4 Multipolarities, mixing ratios, conversion coefficients

See also Section 1.10, Multipolarities, etc.

1. Sources for all data should be stated and all assignments justified.

> Example: When a multipolarity is based on measurements that yield only D, D+Q etc., such as γγ(θ), and M1+E2 rather than El+M2 is adopted, the basis for this choice must be stated. In some cases the choice will need parens.

2. See Section 1.10. Multipolarities, etc., Comment 5, for requirements on consistency among the multipolarity, δ, and α entries. α is not needed for transitions with mixed multipolarity and unknown δ, even though such values may have been used in a source data set, for example to get intensity balances.

3. The relation between BE2 and T½ allows δ (and/or α) to be deduced in cases where BE2 and T½ are independently known, and the ground-state branching is known. Conversely, the ground-state branching can be deduced if all the other quantities are known.

4. γ(θ) and γγ(θ) lead, in general, to two solutions for δ. Both should be accounted for. In particular, if it is not known which is correct, then both should be put in a comment. Do not put one value in the MR field and the alternate value in a comment.

5. In addition to the use of square brackets as discussed in Section 1.10. Multipolarities etc., Comment 8, this convention is also useful in cases where the multipolarity has not been measured, but ΔJ^{π} is known and you wish to show the multipolarity because you wish to give, a reduced transition probability. This is mainly useful when a single mult can be deduced, for example. [E1[, [E2], since for amy mixed mult, only limits can be deduced. In this regards See Section 3.5, Reduced transition probabilities, Comment 1, Note 1.

> Note 1: Do not assign mult=[XXX] just because the multipolarity can be deduced from the level scheme or simply because this convention may have been used in a source dataset. Use only when needed. Its primary use in Adopted Gammas is where a reduced transition probability can be given, that is, where the parent level T½ is known.

Note 2: For the case J=2, assigning mult=[E2] in order to give BE2W is preferable to giving no mult and stating "BE2W=XXX if mult=E2"in a comment. since an entry in the multipolarity field might catch a reader's attention more than would a comment.

6. When making the assumption that, for example, mult=D is probably E1, the E1 should be in parens.

Note: This step should not be taken unless necessary. An assignment of mult=D is strong, whereas that of mult=(E1) is weak, and for a ^{J} assignment the fact that a transition is known to be dipole may be of more use than assuming it might be E1. One case where assigning D as (E1) might be necessary would be where $I(\gamma+ce+ipf)$ is needed and α is significant.

3.5 Reduced transition probabilities

1. Reduced transition probabilities should be given whenever possible. For mixed transitions, values for each multipole component should be given. For an exception see Note 1:

Note 1: When δ is consistent with zero or infinity, the reduced transition probability for only the dominant component is required. The limit for the other component is optional, but could be given in certain cases. Thus, in the case of an M1(+E2) transition, BE2(W.u.)<1000 is not of much interest; however an unusually small value, say BE2(W.u.)<$l0^{-3}$, might be significant.

Note 2: For a transition whose multipolarity has not been established but where all other needed data are available, it is recommended that the reduced transition probability be given when the probable γ character can be determined from the level scheme as [E1], [E2], [M2] or [E3] etc. Strictly, these should be given as upper limits to allow for possible L+1 components; however, except possibly for E1, these are not expected to be significant.

Note 3: When one or more of the relevant pieces of information needed to calculate reduced transition probabilities is missing, the calculation should be carried out if reasonable assumptions can be made that will fill in the gaps.

Example 1: If a level has one or more branches with small gamma fractions but unknown multipolarity, and if any reasonable multipolarity, say D or E2 would lead to the total branching also being relatively small, such branches should be estimated so that reduced transition probabilities for the strong transitions can be calculated.

Example 2: For a transition whose total intensity is known only as an upper limit, then provided that this intensity limit is not the dominant branching mode for the level, it is recommended that the branching for this transition be treated as $\frac{1}{2}I(\gamma+ce+ipf) \pm \frac{1}{2}I(\gamma+ce+ipf)$ for the purpose of calculating the reduced transition probabilities for the other transitions.

3. When T½ itself is available only as an upper limit, it is recommended that the resulting lower limits on the reduced transition probabilities be given. When T½ is a lower limit, the resulting upper limits on the reduced transition probabilities are usually not very interesting: however, see 1. Note 1: above.

4. When a level T½ has been adopted from a measured BE2, the reduced transition probability (BE2W in this case) for the corresponding transition should be calculated directly from this measured BE2 rather than via the adopted T½. This procedure depends only on a numerical factor and the spins, and thus avoids the double counting of uncertainties. This procedure can also be followed in cases where BE2 is known but branchings and/or mixing ratios are not known so that T½ for the corresponding level cannot be calculated, The relationship is

$$BE2W = 1.6835 \times 10^5 A^{-4/3} \times (2J_i+1)(2J_f+1)^{-1} \times BE2(up)$$

5. In cases where E is poorly known and α is significant, note that the combined factor $E\gamma^{2L+1}\times(1+\alpha)$ appearing in the denominator of the formula for the reduced transition probability, if calculated together, may exhibit a smaller range of values than the factors $E\gamma^{2L+1}$ and $(1+\alpha)$ calculated separately. The correlation in the E and α terms should be taken into account in calculating uncertainties for the reduced transition probabilities.

6. Reduced transition probabilities are not needed for mixed multipolarities where δ is not known; however, if an evaluator chooses to give them, they should be given as limits.

3.6 Electric monopole strength

RULER should be run to generate the absolute electric monopole strength, $\rho^2(E0)$. This quantity will appear in the output on a continuation record. See Section 1.11, E0 transitions for a description of the input data needed for the $\rho^2(E0)$ calculation. See also Appendix D.

> Note: Since $\rho^2(E0)$ generally lies in the range 10^{-1} to 10^{-3}, the output values from RULER are by convention quoted in units of $10^3 \times \rho^2(E0)$.

4.   Analysis and Utility Programs

haven National Nuclear Data Center (NNDC) maintains and distributes various programs in support of the International Atomic Energy Agency sponsored Nuclear Structure and Decay Data Network (NSDD). A list of these programs, with a brief description can be found on the main ENSDF page, at the bottom under Resources, A list of these programs is also available at the IAEA website, "https://www-nds.iaea.org/nsdd" in the right-hand column. If the programs are kept on your computer, be sure to update them whenever a new versions are issued, to ensure that the newest versions are being used.

> Note: Errors found in analysis/utility programs should be reported to NNDC.

2. Be sure to check the output of all programs to be sure that the values produced are reasonable. This is especially important in cases where limits are involved, or where input values to a program overlap zero.

3. It is mandatory that FMTCHK be run and that all fatal errors be corrected before submitting the mass chain to NNDC.

4. For datasets with gammas, it is recommended that the excitation energies be obtained from the least-squares adjustment program, GTOL. Keep in mind that if the input energies are given without uncertainties, GTOL will add an uncertainty of 1 keV to each transition. See discussion in Section 1.4. Uncertainties, Comment 2.

5.   Some Mathematical Relationships

1.   Recoil correction for gamma transitions
$$E\gamma(recoil)(keV) = 5.3677 \times 10^{-7} \times E\gamma(keV)^2 \times A^{-1}$$

2.   Relationship between half-life and total width
$$T\tfrac{1}{2}(s) \times \Gamma(eV) = 4.5623 \times 10^{-16} \text{ eV-s}$$

3.   Relationship between BE2W and BE2)↑
$$BE2W = 1.6835 \times 10^5 \times A^{-4/3} \times (2J_i+1)(2J_f+1)^{-1} \times BE2)\uparrow$$

4.   Relationship between BEλ and the Eλ matrix element
$$BE\lambda(J_i{\to}J_f)=(2J_i+1)^{-1} \times |{<}J_i\|ME\lambda\|J_f{>}|^2,$$
where <MEλ > is the Eλ matrix element and J_i is the spin of the initial state

5.   Relationship between BEλ(down) and BEλ(up)
$$BE\lambda(J_f{\to}J_i)=(2J_i+1)(2J_f+1)^{-1} \times BE\lambda(J_i{\to}J_f)$$

6.   Relationship between Eα and Qα*
$$Q\alpha = (M{-}m_\alpha) - [(M{-}m_\alpha)^2 - 2ME\alpha]^{\frac{1}{2}} + 0.0786$$
where M is the mass of the alpha-decaying parent, m_α is the mass of the doubly ionized alpha particle, and 0.0786 keV is the binding energy of two electrons in He.

*2017Wa10. From the 2017AME, 2017Wa10, page 030002-38.

6.   Checklist for submitting Mass Chains

Libby McCutchan, National Nuclear Data Center, Brookhaven National Laboratory

1.   Run FMTCHK and correct all errors

2.   Run PANDORA and correct any issues

3.   Ensure that all relevant references from NZR have been included

4.   Ensure that ^{J} values in the Adopted Levels are given with justification

5.   Ensure that T½ values in the Adopted Levels are traceable

6.   Ensure that E, Iγ, Mult and MR in the Adopted Gammas are traceable

7.   Check that G.S. and isomer properties in Adopted Levels match exactly those corresponding properties in the parent records

8.   Ensure that all isomers are flagged with M (or M1, M2...) in columns 78-79

9.   Check band drawings for incorrectly flagged levels or missing flags

10.   Ensure that the ^{J}, Mult, and MR values in Decay Datasets are identical to those in the Adopted Levels

11.   Confirm that the latest version of BrIcc has been run on all datasets requiring ICC values

12.   Ensure that the procedure for the normalization for Decay Datasets is clearly indicated

13.   Confirm that all Decay Datasets have been updated with the latest Q values and logft or HF codes run with updated Q values

14.   Check that XUNDL datasets have not been exactly copied into the evaluation. (XUNDL) datasets should be merged with existing datasets, not adopted as is)

15.   Check the reference titles for keynumbers that don't belong to the evaluation

16.   Ensure that citations for any temporary keynumber assignments are included

Appendices

The following appendices are referred to or augment material in the Guidelines but may not be otherwise readily available. In addition to the documents given here, there are other relevant articles in the B.L. report B.L.-NCS-40503. This report can be found in the Evaluators corner. There is a link on the left menu which says "ENSDF Procedures". It can also be found on the main ENSDF page, at the bottom under Resources. Click on "Procedures Manual". A direct link is "https://www.nndc.bnl.gov/nndc/evalcorner/ENSDF-Procedures.pdf".

A. Calculation of Radius Parameters for α decay of Odd-A and Odd-Odd Nuclides
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See 2020Si16* for an evaluated set of radius parameters (r_0) for even-even nuclides, an update of the evaluation1998Ak04, and a discussion of the program ALPHAD_RadD. This program calculates r_0 values for the ODD-A and ODD-ODD nuclides using the values for the even-even nuclides. As discussed in 2020Si16*, the nuclear radius parameter for the alpha decay of an even-even nuclide is determined by defining the calculated transition probability for an alpha decay from the ground state of the parent to the ground state of the daughter to be equal to the experimental transition rate, that is, the hindrance factor for this branch is defined as 1.0 (HF=1.0). The radius parameter calculated by ALPHAD_RadD is given by $R=r_0 A^{1/3}$, where A is that of the daughter

*2020Si16 show graphs of r_0 as a function of N for the even-Z nuclides. It is assumed that the parameters for the odd-Z nuclides lie midway between those for the adjacent Z-1 and Z+1 nuclides. Thus, for example, the r_0 parameters for the Z=85 Astatine nuclides trace out a curve midway between the curves for the Z=84 Polonium and Z=86 Radon nuclides.

Similarly It is assumed that for the even-Z, odd-N case, the parameters for the odd-N isotopes lie midway between the values for the Z, N-1 and Z, N+1 even-even nuclides.

Note that in what follows, all averages are unweighted. A weighted average is not appropriate. Keep in mind that one is not trying to get a best value for two measurements of the same quantity, but rather a value midway between parameters for adjacent nuclides.

1. Odd-Z, Even-N Nuclides

The r_0 parameter for an odd-Z, even-N nuclide is obtained as an unweighted average of the values for the nuclides with Z-1, N and Z+1, N. The uncertainty is obtained as an unweighted average of the upper (or lower) limits of these adjacent nuclide values.

2.   Even-Z, Odd-N Nuclides

The r_0 parameter for an even-Z, odd-N nuclide is obtained as an unweighted average of the values for the nuclides with Z, N-1 and Z, N+1. The uncertainty is obtained as an unweighted average of the upper (or lower) limits of these adjacent nuclide values.

3.   Odd-Z, Odd-N Nuclides

For an odd-odd nuclide, Z, N, one needs r_0 parameters for the four nuclides with Z±1, N±1. In step one, r_0 values for Z, N-1 and for Z, N+1 are obtained as described in 1. above. The value for Z, N is then obtained as an average of the two values from step one. Alternatively, one can average the values for the Z-1, N and Z+1, N nuclides, each of which is obtained as described in 2. above. The two approaches give the same value of r_0.

Example: The following example illustrates the above procedures for the alpha decay of the odd-Z Francium nuclides with Z=87 and N=118, 119, and 120, decaying to the daughter Astatine nuclides with Z=85 and N=116, 117, and 118, respectively. One gets the Astatine daughter radius parameters from the four adjacent even-even nuclides with Z=84, 86 and N=116, 118. From 2020Si16 these values are

$$r_0(^{200}Po) = 1.5026 \; 13$$
$$r_0(^{202}Po) = 1.4917 \; 27$$
$$r_0(^{202}Rn) = 1.5290 \quad 42$$
$$r_0(^{204}Rn) = 1.5029 \; 36$$

These four points form the four corners of a grid, as given by the values in bold in the following table. Z and N here correspond to the daughter.

	N=116	N=117	N=118
Z=84	^{200}Po r_0 =1.5026 *13*	^{201}Po r_0=1.4972 *20*	^{202}Po r_0=1.4917 *27*
Z=85	^{201}At r_0=1.5158 *28*	^{202}At r_0=1.5066 *30*	^{203}At r_0=1.4973 *32*
Z=86	^{202}Rn r_0=1. 5290 *42*	^{203}Rn r_0=1.5160 *39*	^{204}Rn r_0=1.5029 *36*

The value for ^{201}Po is obtained by taking an unweighted average of the parameters for ^{200}Po and ^{202}Po, and that for ^{201}At comes from an unweighted average of the values for ^{200}Po and ^{202}Rn, and so on. The uncertainties come from an unweighted average of the corresponding maximum (or minimum) values. Thus, for ^{201}At, the average of 1.5026 and 1.5290 gives 1.5158, and the average of the upper limits, 1.5039 and 1.5332, gives 1.5186 which corresponds to an uncertainty of +28 on the value 1.5158. The lower limits of course give the same uncertainty.

The value for the odd-odd ^{202}At can be obtained by averaging the values for ^{201}Po and ^{203}Rn, or the values for ^{201}At and ^{203}At. The two approaches give the same value of 1.5066 *30*.

The program ALPHAD_RadD referred to above performs this calculation and generates the required r_0 parameters.

It is strongly recommended to evaluators working in mass regions with alpha decay that they plot the r_0 parameters for the nuclides in and around their mass regions. These plots can be of use in estimating parameters when critical even-even data are missing. For example, suppose that in the above example the r_0 parameter for ^{202}Po was not known experimentally. It might still be possible to obtain a reasonable estimate of the value by extrapolation from the known lower-N Po values. Similarly, one might be able to estimate a value for ^{202}At or ^{203}At by extrapolation from values for lower-N At nuclides. Even an approximate value might be sufficient to establish a particular alpha branch as being favored. Of course such extrapolations are worth doing only if the r_0 plots are fairly regular, and the regularity, or lack thereof, is something that is useful to know in one's mass region.

B.   *Sign Conventions for Mixing Ratios in Electromagnetic Transitions from Angular Correlations and Angular Distributions
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August, 1987

*Revised with minor changes in the text, and a correction to the LHS of the present equation (8), original equation (13).

August, 2016

Since the multipole components in a gamma transition of mixed character mix coherently, an angular distribution or angular correlation measurement can determine the phases, that is, the relative signs of these components. The following discussion is restricted to the case where two components with multipole orders L and L' =L+1 compete. Since the relative phase of these two components is invariant with respect to any arbitrary phase convention for the wave functions or the transition operators, it is a physically significant quantity.

The two most widely used phase conventions are those proposed by Steffen [1] and by Rose and Brink [2] but there are many more that have appeared in the literature. Table I gives a summary of the relation between the phase conventions used by these authors relative to that of Steffen, whose convention is adopted in the following material.

General Formalism

Consider the following two-gamma cascade connecting levels with spins J_1, J_2, and J_3 with each transition consisting of just two multipole components, L and L' = L+1.

$$J_1 \overline{}$$

$$\downarrow \gamma_1 \quad L_1, L_1'$$

$$J_2 \overline{}$$

$$\downarrow \gamma_2 \quad L_2, L_2'$$

$$J_3 \overline{}$$
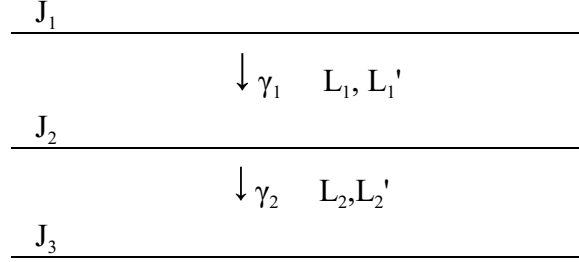
Expressions for the directional correlation of γ_1 and γ_2 can be reduced to the form

$$W(\theta) = \Sigma B_k(\gamma_1) A_k(\gamma_2) P_k(\cos\theta) \tag{1}$$

with the sum including only even k.

where the B_k are orientation parameters and the A_k are directional distribution coefficients. The parameters B_k are characteristic of the (axially symmetric) orientation of the intermediate state, J_2 in our example, while the coefficients A_k characterize the directional distribution of γ_2 with respect to the orientation axis of J_2. The following discussion describes the case where the intermediate state is oriented by the observation of the incoming radiation γ_1 from the state J_1.

Note: It is pointed out in reference [20] that the restriction to even k in (1) holds in cases where the states involved have pure parity and the radiations are parity conserving, e.g. electromagnetic radiation, conversion electrons, and alpha particles. $A_k = 0$ for odd k for such cases. If the circular polarization of the gammas is observed, if the nuclear states have parity admixtures, if β's are observed, then, if the intermediate state is polarized and not just aligned, odd-k terms can contribute.

For a given transition, γ, we denote the relative amplitude of the multipole orders L' + 1 and L by $\delta(\gamma)$ as defined in (4) and (5) below. The sign of δ is dependent on several factors:
   a) The form in which eq. (1) is expanded
   b) The choice of matrix elements, emission or absorption
   c) The form of the Wigner-Eckhart theorem used to define the reduced matrix elements
   d) The form of the electromagnetic multipole transition operators

For the extraction of δ from the analysis of an angular correlation or angular distribution experiment only a) is relevant. The B_k and A_k can be expanded in terms of tabulated constants which depend only on the L's and J's and that expansion fixes the sign of δ. If, however, an attempt is made to calculate the mixing

ratios on the basis of some model and to compare them with values deduced from experiment, then b), c), and d) must be taken into account.

Following the work of Steffen [1], for the case of an unpolarized, unaligned initial state J_1, the B_k and A_k can be expressed as

$$B_k(\gamma_1) =$$
$$\frac{F_k(L_1 L_1 J_1 J_2) + 2\delta(\gamma_1)(-1)^{L-L'+k} F_k(L_1 L_1' J_1 J_2) + \delta^2(\gamma_1) F_k(L_1' L_1' J_1 J_2)}{1+\delta^2(\gamma_1)} \tag{2}$$

$$A_k(\gamma_2) =$$
$$\frac{F_k(L_2 L_2 J_3 J_2) + 2\delta(\gamma_2) F_k(L_2 L_2' J_3 J_2) + \delta^2(\gamma_2) F_k(L_2' L_2' J_3 J_2)}{1+\delta^2(\gamma_2)} \tag{3}$$

where

$$\delta(\gamma_1) = <J_2\|\pi_1' L_1'\|J_1> / <J_2\|\pi_1 L_1\|J_1> \tag{4}$$

$$\delta(\gamma_2) = <J_3\|\pi_2' L_2'\|J_2> / <J_3\|\pi_2 L_2\|J_2> \tag{5}$$

The coefficients F_k are defined and tabulated by Frauenfelder and Steffen [3]. They are also tabulated in references [4, 5, 6]. Steffen uses emission matrix elements and the initial state always appears on the right. Equations (1), (2), and (3) define a unique sign for the mixing ratios. Note that the coefficients F_k are defined such that

$$F_0(LL'J_2J_3) = \delta_{LL'}$$

where $\delta_{LL'}$ is the Kronecker delta, and thus

$$B_0(\gamma) = A_0(\gamma) = 1$$

As an example, for the cascade $J_1=4$, $J_2=2$, $J_3=0$, the tables in reference [3] give

$$F_2(2242) = -0.1707, \ F_2(2202) = -0.5976$$

The definition of operators and reduced matrix elements used by Rose and Brink [2] are such that

$$\delta_{Rose-Brink} = (-1)^{L-L'} \delta_{Steffen}$$

Note that Rose and Brink use absorption matrix elements and the initial state always appears on the left. As a consequence, in the work of these authors the coefficients F_k are replaced by coefficients R_k, tabulated in [2] and defined so that

$$R_k(LL'J_iJ_f) = (-1)^{L-L'+k} F_k(LL'J_fJ_i)$$

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but otherwise the forms of equations (2) and (3) remain unchanged. Both Rose - Brink and Steffen give a thorough discussion of the factors a) through d) mentioned above, so that calculations of δ can be carried through consistently in either formalism.

Another phase convention that one still encounters occasionally, although mainly in older papers, is that of Biedenharn and Rose [4]. These authors adopt the convention of always writing the intermediated state, J_2 in our example, on the right. This convention leads to an additional phase factor of $(-1)^{L-L'+k}$ in the second term of equation (2), thus

$$\delta_{Biedenharn-Rose}(\gamma_1) = -\delta_{Steffen}(\gamma_1)$$

Note that in the Biedenharn and Rose formalism, the sign of the mixing ratio depends on whether a given transition appears first or second in a cascade.

Table I gives a summary of the phase conventions one might find in the literature. They are all given here relative to the convention of Steffen, where the sign of the mixing ratio for both the first and second transition is arbitrarily set to be "+". Note that in the formalism of references [9], [10], and [16] the sign depends on whether or not the transition involves a parity change.

Special Cases
Some special cases the evaluators might come across are described in the following sections.

1.   Intermediate Unobserved Radiation

Consider the cascade $J_1\,(\gamma_1)\,J_2\,(\gamma_2)\,J_3\,(\gamma_3)\,J_4$ where the directional distribution of γ_3 is measured relative to the direction of γ_1 and radiation γ_2 is unobserved.

$$
\begin{array}{l}
J_1 \rule{6cm}{0.4pt}\\
\qquad\qquad \downarrow \gamma_1 \quad L_1, L_1'\\
J_2 \rule{6cm}{0.4pt}\\
\qquad\qquad \downarrow \gamma_2 \quad L_2, L_2'\\
J_3 \rule{6cm}{0.4pt}\\
\qquad\qquad \downarrow \gamma_3 \quad L_3, L_3'\\
J_4 \rule{6cm}{0.4pt}
\end{array}
$$
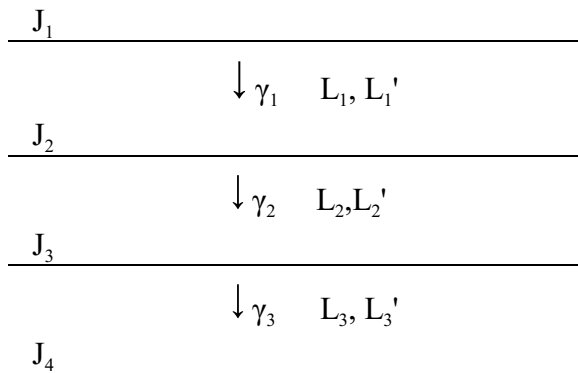
This case can be treated using equation (1) with the addition of a multiplicative de-orientation factor $U_k(LJ_2J_3)$ defined by

$$U_k(L_2J_2J_3) =$$

$$\frac{(-1)^{J_2+J_3}[(2J_2+1)(2J_3+1)]^{1/2}\left[(-1)^{L_2}\left\{\begin{matrix}J_2J_2k\\J_3J_3L_2\end{matrix}\right\}+(-1)^{L_2'}\varDelta^2(\gamma_2)\left\{\begin{matrix}J_2J_2k\\J_3J_3L_2'\end{matrix}\right\}\right]}{1+\varDelta^2(\gamma_2)}$$ (6)

$$=\frac{U_k(L_2J_2J_3)+\varDelta^2(\gamma_2)U_k(L_2'J_2J_3)}{1+\varDelta^2(\gamma_2)}$$

where

$$\varDelta^2(\gamma_2)=\frac{1+\alpha(L_2'\pi')}{1+\alpha(L_2\pi)}\delta^2(\gamma_2)$$

$\alpha(L')$ and $\alpha(L)$ being the total conversion coefficients for the L_2+1 and L_2 components, respectively of γ_2, and $\delta(\gamma_2)$ is defined by equation (5). The { } are 6-J symbols.

The $U_k(LJJ')$ are called de-orientation coefficients since they take account of the decrease in alignment resulting from the unobserved transition. They are tabulated in [2], [16], and [17]. Equation (6) is from Anicin et al. [21]. Explicit expressions given in all other sources with which I am familiar are incorrect in that they contain δ^2 in place of $\varDelta^2$. Note that $\varDelta$ is parity dependent through the factor $(1+\alpha(L_2'\pi'))/(1+\alpha(L_2\pi))$. For $\alpha \ll 1$ this factor reduces to unity, and $\varDelta \rightarrow \delta$, but for large α this factor can distinguish, for example, M1+E2 from E1+M2.

Note that equation (6) contains no interference term since the radiation it represents is not observed. Note also that $U_0(JJ)=1$

The angular distribution for the general case of n radiations with the correlation between the first and last transition being measured is given, by extension, by

$$W(\theta) = \sum_{k=even} B_k(\gamma_1)U_k(\gamma_2)...U_k(\gamma_{n-1})A_k(\gamma_n)P_k(\cos\theta)$$ (7)

2.   Correlations involving Internal Conversion electrons

If internal conversion electrons, rather than gammas, are observed for either of the transitions in the cascade described by equation (1), then the factors F_k appearing in equations (2) and (3) should be replaced by the factors $b_k(ce_i\Lambda\Lambda')F_k$, where the $b_k(ce_i\Lambda\Lambda')$ are particle parameters for conversion in the i shell for $\Lambda, \Lambda' = $ M1, E2, or E1, M2, etc., tabulated in [22], and the mixing ratio δ should be replaced by

$$\delta(ce_i) = \left[\frac{\alpha_i(L'\pi')}{\alpha_i(L\pi)} \right]^{1/2} \delta(\gamma)$$

For a $(\gamma)(ce_i)(\theta)$ experiment where the second transition is M1+E2, for example, equation (3) becomes

$$A_k(ce_i)[1 + \delta^2(ce_i)] =$$
$$F_k(11J_3J_2)b_K(ce_iM1, M1) + 2\delta(ce_i)F_k(12J_3J_2)b_k(ce_iM1, E2) + \qquad (8)$$
$$\delta^2(ce_i)F_k(22J_3J_2)b_k(ce_iE2, E2)$$

where the $1+\delta^2$ term has been transposed to the LHS.

3.   Resonance Fluorescence

The angular distribution in a (γ,γ') experiment, where the exciting and deexciting transitions are the same, follows from equations (1), (2), and (3) with the further observation that the reduced matrix elements defined in equations (4) and (5) have, for this case, the property that

$$\delta(\gamma_1) = -\delta(\gamma_2)$$

For the sequence $J_3(L_2L_2+1)J_2(L_2L_2+1)J_3$ one then has

$$W(\theta) = \sum_{k-even} A_k^{\ 2}(\gamma_2)P_k(\cos\theta) \qquad (9)$$

with $A_k(\gamma_2)$ given by equation (3) and $\delta(\gamma_2)$ given by equation (5). The more general case of (γ,γ') is treated like $\gamma\gamma(\theta)$ with the ground state as the initial state, J_1.

4.   Coulomb Excitation

The angular distribution of gammas in a Coulomb excitation experiment takes the form of equation (1) with

$$B_k(\gamma_1) = b_k(\S)F_k(22J_1J_2) \qquad (10)$$

where J_1 is the target spin, J_2 the spin of the Coulomb-excited state, J_3 is the spin of the final level following the gamma emission, and $b_k(\S)$ is a particle parameter which depends on the excitation process through the parameter $\S$. These particle parameters are tabulated in [5].

5.   Alpha Decay

The form for the $\alpha\gamma(\theta)$ correlation is similar to that described above for $ce\gamma(\theta)$. The factors F_k in the expression for B_k are multiplied by the particle parameters for alpha decay, b_k, defined by

$$b_k(LL'') = b_k(L''L) = \cos(\eta_L - \eta_{L'}) \frac{2[L(L+1)L''(L''+1)]^{1/2}}{L(L+1) + L''(L''+1) - k(k+1)} \qquad (11)$$

where $L'' = L+2$, L+4 etc., and $\delta(\gamma)$ is replaced by

$$\delta(\alpha) = \langle J_2 \| H_{L'}(\alpha) \| J_1 \rangle / \langle J_2 \| H_L(\alpha) \| J_1 \rangle$$

For alpha decay in which a single L value dominates, B_k takes the same form as equation (10), namely

$$B_k(\alpha) = b_k(LL)F_k(LLJ_1J_2)$$

For mixed-L transitions, since L+L'' = even, the phase factor in the second term of equation (2) becomes +1, and equations (2) and (3) have exactly the same form. The phase angle appearing in equation (11) contains the Coulomb phase shifts and depends on the target nuclide and the alpha particle energy. It enters only in the mixed L, L'' term of equations (2). See references [3] and [23]* for a definition of this phase term.

* Note that in equation (123) of [23], the cross term should be multiplied by a factor of 2.

The difference in phase angles for L and L'' are usually small (see reference [24] and references contained therein) so that the cos term is close to +1 or -1. We adopt $\cos(\eta_L - \eta_{L''}) = +1$ which, along with the forms of equations (12) and (13) below, defines the phase of $\delta(\alpha)$.

For the case where only the two lowest L values contribute significantly, equation (2) becomes

$$B_k(\alpha)[1 + \delta^2(\alpha)] =$$

$$b_k(LL)F_k(LLJ_1J_2) + 2\delta(\alpha)b_k(LL'')F_k(LL''J_1J_2) + \delta^2 b_k(L''L'')F_k(L''L''J_1J_2)$$

(12)

where the $(1+\delta^2)$ term has been transposed to the LHS of the equation. For the case of L=0, the particle parameter cannot be defined in terms of the functions F_k for the gammas. For L=0+2, using equation (7.10) of Steffen [1b], or equation (107) of [1c], equation (12) for k=2 becomes

$$B_2(\alpha) = \frac{2\delta_{J_1J_2}\delta(\alpha)\cos(\eta_2 - \eta_0) + \delta^2(\alpha)b_2(22)F_2(22J_2J_1)}{\delta_{J_1J_2} + \delta^2(\alpha)}$$

(13)

where $\delta_{J_1J_2}$ is the Kronecker delta. For a pure L=0 alpha transition, the angular distribution is isotropic.

6.   Other Cases

When the intermediate state, J_2 in Fig. 1, is oriented by low-temperature techniques or by nuclear reactions etc., the angular distribution can be described by equation (7), with the B_k now treated as alignment parameters which may be determined experimentally, estimated empirically, or calculated on the basis of a specific model [17]. See for example references [1], [2], and the tabulations and references quoted in references [17] and [18].

7. The following table gives the signs of δ relative to that of Steffen et al., the most commonly used convention for decay schemes.

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Sign of δ normalized to convention of Steffen		Reference
γ₁	γ₂	
+ (normalization)	+ (normalization)	Steffen [1], [14], [15]
+	+	Frauenfelder-Steffen [3]
+	+	Poletti-Start [13]
+	+	Taylor et al. [8]
+	+	Yamazaki [17]
+	+	Ferguson [19]
-	+	Biedenharn-Rose [4]
-	+	Ferguson-Rutledge (1957) [7]
Pure E2 assumed	+	Alder et al. [5]
+ (Δπ=yes) - (Δπ=no)	+ (Δπ=yes) - (Δπ=no)	Litherland-Ferguson [10] Poletti-Warburton [16] Ferguson-Rutledge (1962) [9]
-	-	Rose-Brink [2]
-	-	Smith [11]
-	-	Harris et al. [12]
-	-	Watson-Harris [18]

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C. Reduced Gamma-Ray Matrix Elements, Transition Probabilities, and Weisskopf Single-Particle Estimates*
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September, 1982

*Revised with minor changes in the text, and with some δ factors included explicitly.

August, 2016

The formulas given below for Weisskopf estimates BλW are the basis for the calculations in the program RULER.

For an electromagnetic transition of energy E, the relationships among the reduced matrix elements, $B(\sigma L)$, and the partial gamma-ray half-lives, $T_{1/2}^{\gamma}$, are

$$T_{1/2}^{\gamma}(EL)xB(EL)\downarrow = \frac{(\ln 2)L[(2L+1)!!]^2(h/2\pi)}{8\pi(L+1)e^2b^L}\left(\frac{hc/2\pi}{E_{\gamma}}\right)^{2L+1} \tag{1}$$

and

$$T_{1/2}^{\gamma}(ML)xB(ML)\downarrow = \frac{(\ln 2)L[(2L+1)!!]^2 h/2\pi}{8\pi(L+1)\mu_N^2 b^{L-1}}\left(\frac{hc/2\pi}{E_{\gamma}}\right)^{2L+1} \tag{2}$$

The Weisskopf single-particle estimates for the $B(\sigma L)$ are

$$B(s.p.)(EL)\downarrow = \frac{1}{4\pi b^L}\left(\frac{3}{3+L}\right)^2 R^{2L} \tag{3}$$

$$B(s.p.)(ML)\downarrow = \frac{10}{\pi b^{L-1}}\left(\frac{3}{3+L}\right)^2 R^{2L-2} \tag{4}$$

so that

$$T_{1/2}^{\gamma}(s.p.)(EL) = \frac{(\ln 2)L[(2L+1)!!]^2 h/2\pi}{2(L+1)e^2 R^{2L}}\left(\frac{3+L}{3}\right)^2\left(\frac{hc/2\pi}{E\gamma}\right)^{2L+1} \tag{5}$$

and

$$T_{1/2}^{\gamma}(s.p.)(ML) = \frac{(\ln 2)L[(2L+1)!!]^2 h/2\pi}{80(L+1)\mu_N^2 R^{2L-2}}\left(\frac{3+L}{3}\right)^2\left(\frac{hc/2\pi}{E\gamma}\right)^{2L+1} \tag{6}$$

The relationship between a measured $B(\sigma L)\uparrow$ to a level with spin J_f and half-life $T_{1/2}(J_f)$ from a level with spin J_i connected by a transition γ_k with mixing ratio δ_k is given by Eq. (1) or (2) with

$$T_{1/2}(J_f) = T_{1/2}^{\gamma_k}(EL)\varepsilon(\gamma_k)\frac{\delta_k^2}{1+\delta_k^2} = T_{1/2}^{\gamma_k}(ML)\varepsilon(\gamma_k)\frac{1}{1+\delta_k^2}$$

and

$$B(\sigma L)\uparrow = \frac{(2J_f+1)}{(2J_i+1)}B(\sigma L)\downarrow$$

where $\varepsilon(\gamma_k)$ is the fraction of the decays of level J_f that proceed by the observed mode γ_k and is

defined by
$$\varepsilon(\gamma_k) = \frac{\lambda_k^{\gamma}}{\sum_i (1+\alpha_i)\lambda_i^{\gamma}} = \frac{BR(\gamma_k)}{(1+\alpha_k)}$$

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In the above equations, $b = 10^{-24}\,cm^2$, $R = R_0 A^{1/3} x10^{-13}\,cm$, and $B(EL)$ and $B(ML)$ are in units of $e^2 b^L$ and $\mu_N^2 b^{L-1}$, respectively.

Explicit expressions for the above equations are given below for L=1 to 5. E_γ is in keV, $T_{1/2}$ is in seconds, Γ is in eV, and $(W.u.)$ stands for Weisskopf units. The mixing ratio factors are included explicitly for L=1, 2, and 3. It is unlikely that they would be needed for higher multipoles but they could be taken into account if necessary.

The Weisskopf estimates for E1 and M1 transitions are expressed in terms of both $T_{1/2}$ and width, and for E2 transitions in terms of both $T_{1/2}$ and $B(E2)$. See the Guidelines for details as to when and why the alternate expressions should be used.

The constants adopted are as follows:

$$hc/2\pi = 1.9733x10^{-8}\,keV-cm$$
$$h/2\pi = 0.6584x10^{-18}\,keV-s$$
$$e^2 = 1.43998x10^{-10}\,keV-cm$$
$$\mu_N^2 = 1.59234x10^{-38}\,keV-cm^3$$
$$R_0 = 1.2$$

E1 Transitions

$$T_{1/2}^{\gamma}(E1)xB(E1) \downarrow = \frac{4.360x10^{-9}}{E_{\gamma}^3}$$

$$B(s.p.)(E1) \downarrow = 6.446x10^{-4} A^{2/3} (e^2 x10^{-24} cm^2)$$

$$T_{1/2}^{\gamma}(s.p.)(E1) = \frac{6.764x10^{-6}}{E_{\gamma}^3 A^{2/3}}$$

$$B(E1)(W.u.) = \frac{6.764x10^{-6} BR}{E_{\gamma}^3 A^{2/3} T_{1/2}(1+\alpha)}\left(\frac{1}{1+\delta^2}\right) = \frac{1.4827x10^{10} BR}{E_{\gamma}^3 A^{2/3}(1+\alpha)}\left(\frac{1}{1+\delta^2}\right)\Gamma$$

$$T_{1/2}(J_f)xB(E1) \uparrow = \frac{4.360x10^{-9} BR}{E_{\gamma}^3(1+\alpha)}\left(\frac{2J_f+1}{2J_i+1}\right)\left(\frac{1}{1+\delta^2}\right)$$

E2Transitions

$$T_{1/2}^{\gamma}(E2)xBE2 \downarrow = \frac{56.59}{E_{\gamma}^5}$$

$$B(s.p.)(E2) \downarrow = 5.940x10^{-6} A^{4/3} (e^2 x10^{-48} cm^4)$$

$$T_{1/2}^{\gamma}(s.p.)(E2) = \frac{9.527x10^6}{E_{\gamma}^5 A^{4/3}}$$

$$B(E2)(W.u.) = \frac{9.527x10^6 BR}{E_{\gamma}^5 A^{4/3} T_{1/2}(1+\alpha)}\left(\frac{\delta^2}{1+\delta^2}\right)^* = \frac{1.6835x10^5}{A^{4/3}}\left(\frac{2J_i+1)}{2J_f+1}\right)B(E2)\uparrow$$

$$T_{1/2}(J_f)xB(E2) \uparrow = \frac{56.59 BR}{E_{\gamma}^5(1+\alpha)}\left(\frac{\delta^2}{1+\delta^2}\right)^*\left(\frac{2J_f+1)}{2J_i+1}\right)$$

* Where $\delta = \left|\frac{E2}{M1}\right|$. For $\delta = \left|\frac{M3}{E2}\right|$, this factor should be replaced by $\frac{1}{1+\delta^2}$

E3 Transitions

$$T_{1/2}^{\gamma}(E3) \, x \, B(E3) \downarrow = \frac{1.215 x 10^{12}}{E_{\gamma}^{7}}$$

$$B(s.p.)(E3) \downarrow = 5.940 x 10^{-8} A^2 \, (e^2 x 10^{-72} cm^6)$$

$$T_{1/2}^{\gamma}(s.p.)(E3) = \frac{2.045 x 10^{19}}{E_{\gamma}^{7} A^2}$$

$$B(E3)(W.u.) = \frac{2.045 x 10^{19} \, BR}{E_{\gamma}^{7} A^2 T_{1/2}(1+\alpha)} \left(\frac{1}{1+\delta^2} \right)^{*}$$

$$T_{1/2}(J_f) \, x \, B(E3) \uparrow = \frac{1.215 x 10^{12} \, BR}{E_{\gamma}^{7}(1+\alpha)} \left(\frac{1}{1+\delta^2} \right)^{*} \left(\frac{2J_f+1}{2J_i+1} \right)$$

$* $ Where $\delta = \left| \dfrac{M4}{E3} \right|$. For $\delta = \left| \dfrac{E3}{M2} \right|$, this factor should be replaced by $\dfrac{\delta^2}{1+\delta^2}$.

E4 Transitions

$$T_{1/2}^{\gamma}(E4) \, x \, B(E4) \downarrow = \frac{4.087 x 10^{22}}{E_{\gamma}^{9}}$$

$$B(s.p.)(E4) \downarrow = 6.285 x 10^{-10} A^{8/3} \, (e^2 x 10^{-96} cm^8$$

$$T_{1/2}^{\gamma}(s.p.)(E4) = \frac{6.503 x 10^{31}}{E_{\gamma}^{9} A^{8/3}}$$

$$B(E4)(W.u.) = \frac{6.503 x 10^{31} \, BR}{E_{\gamma}^{9} A^{8/3} T_{1/2}(1+\alpha)}$$

$$T_{1/2}(J_f) \, x \, B(E4) \uparrow = \frac{4.087 x 10^{22} \, BR}{E_{\gamma}^{9}(1+\alpha)} \left(\frac{2J_f+1}{2J_i+1} \right)$$

E5 Transitions

$$T_{1/2}^{\gamma}(E5)xB(E5)\downarrow=\frac{2.006x10^{33}}{E_{\gamma}^{11}}$$

$$B(s.p.)(E5)\downarrow=6.929x10^{-12}A^{10/3}\ (e^2x10^{-120}cm^{10})$$

$$T_{1/2}(s.p.)(E5)=\frac{2.895x10^{44}}{E_{\gamma}^{11}A^{10/3}}$$

$$B(E5)(W.u.)=\frac{2.895x10^{44}BR}{E_{\gamma}^{11}A^{10/3}T_{1/2}(1+\alpha)}$$

$$T_{1/2}(J_f)xB(E5)\uparrow=\frac{2.006x10^{33}BR}{E_{\gamma}^{11}(1+\alpha)}\left(\frac{2J_f+1}{2J_i+1}\right)$$

M1 Transitions

$$T_{1/2}^{\gamma}(M1)xB(M1)\downarrow=\frac{3.943x10^{-5}}{E_{\gamma}^{3}}$$

$$B(s.p.)(M1)\downarrow=1.791\ (\mu_N^2)$$

$$T_{1/2}^{\gamma}(s.p.)(M1)=\frac{2.202x10^{-5}}{E_{\gamma}^{3}}$$

$$B(M1)(W.u.)=\frac{2.202x10^{-5}BR}{E_{\gamma}^{3}T_{1/2}(1+\alpha)}\left(\frac{1}{1+\delta^2}\right)=\frac{4.827x10^{10}\Gamma_0}{E_{\gamma}^{3}(1+\alpha)}\left(\frac{1}{1+\delta^2}\right)$$

$$T_{1/2}(J_f)xB(M1)\uparrow=\frac{3.943x10^{-5}BR}{E_{\gamma}^{3}(1+\alpha)}\left(\frac{1}{1+\delta^2}\right)\left(\frac{2J_f+1)}{2J_i+1}\right)$$

M2 Transitions

$$T_{1/2}^{\gamma}(M2)B(M2)\downarrow=\frac{5.117x10^5}{E_{\gamma}^5}$$

$$B(s.p.)(M2)\downarrow=1.650x10^{-2}A^{2/3}\ (\mu_N^2 x10^{-24}cm^2)$$

$$T_{1/2}^{\gamma}(s.p.)(M2)=\frac{3.102x10^7}{E_{\gamma}^5 A^{2/3}}$$

$$B(M2)(W.u.)=\frac{3.102x10^7\ BR}{E_{\gamma}^5 A^{2/3}T_{1/2}(1+\alpha)}\left(\frac{\delta^2}{1+\delta^2}\right)^*$$

$$T_{1/2}(J_f)xB(M2)\uparrow=\frac{5.117x10^5\ BR}{E_{\gamma}^5(1+\alpha)}\left(\frac{\delta^2}{1+\delta^2}\right)^*\left(\frac{2J_f+1)}{2J_i+1}\right)$$

$*$ Where $\delta=\left|\dfrac{M2}{E1}\right|$. For $\delta=\left|\dfrac{E3}{M2}\right|$, this factor should be replaced by $\dfrac{1}{1+\delta^2}$

M3 Transitions

$$T_{1/2}^{\gamma}(M3)xB(M3)\downarrow=\frac{1.099x10^{16}}{E_{\gamma}^7}$$

$$B(s.p.)(M3)\downarrow=1.650x10^{-4}A^{4/3}\ (\mu_N^2 x10^{-48}cm^4$$

$$T_{1/2}^{\gamma}(s.p.)(M3)=\frac{6.659x10^{19}}{E_{\gamma}^7 A^{4/3}}$$

$$B(M3)(W.u.)=\frac{6.659x10^{19}\ BR}{E_{\gamma}^7 A^{4/3}T_{1/2}(1+\alpha)}\left(\frac{\delta^2}{1+\delta^2}\right)^*$$

$$T_{1/2}(J_f)xB(M3)\uparrow=\frac{1.099x10^{16}\ BR}{E_{\gamma}^7(1+\alpha)}\left(\frac{\delta^2}{1+\delta^2}\right)^*\left(\frac{2J_f+1}{2J_i+1}\right)$$

$*$ Where $\delta=\left|\dfrac{M3}{E2}\right|$. For $\delta=\left|\dfrac{E4}{M3}\right|$, this factor should be replaced by $\dfrac{1}{1+\delta^2}$

M4 Transitions

$$T_{1/2}^{\gamma}(M4)xB(M4)\downarrow=\frac{3.696x10^{26}}{E_{\gamma}^{9}}$$

$$B(s.p.)(M4)\downarrow=1.746x10^{-6}A^{2}\left(\mu_{N}^{2}x10^{-72}cm^{6}\right)$$

$$T_{1/2}^{\gamma}(s.p.)(M4)=\frac{2.117x10^{32}}{E_{\gamma}^{9}A^{2}}$$

$$B(M4)(W.u.)=\frac{2.117x10^{32}BR}{E_{\gamma}^{9}A^{2}T_{1/2}(1+\alpha)}$$

$$T_{1/2}(J_{f})B(M4)\uparrow=\frac{3.696x10^{26}BR}{E_{\gamma}^{9}(1+\alpha)}\left(\frac{2J_{f}+1}{2J_{i}+1}\right)$$

M5 Transitions

$$T_{1/2}^{\gamma}(M5)xB(M5)\downarrow=\frac{1.814x10^{37}}{E_{\gamma}^{11}}$$

$$B(s.p.)(M5)\downarrow=1.925x10^{-8}A^{8/3}\left(\mu_{N}^{2}x10^{-96}cm^{8}\right)$$

$$T_{1/2}^{\gamma}(s.p.)(M5)=\frac{9.426x10^{44}}{E_{\gamma}^{11}A^{8/3}}$$

$$B(M5)(W.u.)=\frac{9.426x10^{44}BR}{E_{\gamma}^{11}A^{8/3}T_{1/2}(1+\alpha)}$$

$$T_{1/2}(J_{f})xB(M5)\uparrow=\frac{1.814x10^{37}BR}{E_{\gamma}^{11}(1+\alpha)}\left(\frac{2J_{f}+1}{2J_{i}+1}\right)$$

D. Monopole Transition Strength
Excerpted by M. J. Martin from Ref [1]
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2016

The E0 transition probability is defined by

$$W(E0) = \frac{\ln 2}{T_{1/2}(E0)} = W_{ic}(E0) + W_{\pi}(E0)$$

where $T_{1/2}(E0)$ is the partial half-life of the initial state for E0 decay and W_{ic} and W_{π} are the transition probabilities for internal-conversion electron and electron-positron pair emission, respectively. They are defined by

$$W_{ic}(E0) + W_{\pi}(E0) = \rho^2(E0) \times \left[\Omega_{ic}(E0) + \Omega_{\pi}(E0) \right]$$

where Ω_{ic} and Ω_{π} are electronic factors independent of nuclear properties. The nuclear structure information is contained in the quantity $\rho(E0)$, defined by

$$\rho(E0) = \frac{\langle f | M(E0) | i \rangle}{eR^2}$$

where R is the nuclear radius and M(E0) is the monopole matrix element, $\sum_k e_k r_k^2$. Since there is often an ambiguity in determining the sign of $\rho(E0)$, it is customary to use the square, $\rho^2(E0)$. The reduced E0 transition probability, B(E0), is given by the square of the E0 matrix element,

$$B(E0) = \rho^2(E0)e^2R^4$$

where e is the electric charge.

In Ref [2], in a discussion of E0 transitions between 2+ states, the quantity

$$q_K^2(E0) = \frac{I_K(E0)}{I_K(E2)}$$

where $I_k(E0)$ and $I_k(E2)$ are the K-shell intensities of the E0 and E2 components, respectively, of the 2+ to 2+ transition.

A dimensionless ratio of the E0 and E2 transition probabilities was defined in Ref [3] as

$$X(E0/E2) = \frac{B(E0)}{B(E2)} = \frac{\rho^2(E0)e^2R^4}{B(E2)}$$

As given in Ref [1], X(E0/E2) can be determined experimentally from the relation

$$X(E0/E2) = 2.54 \times 10^{-6} \times q_K^2(E0/E2) \times \frac{\alpha_K(E2)}{\Omega_K(E0)} \times E_{\gamma}^5$$

where E is the E2 γ-ray energy in keV.

The experimental monopole strength can be obtained directly if the partial half-life of the E0 transition, $T_{1/2}(E0)$, is known.

$$\rho^2(E0) = \frac{\ln 2}{T_{1/2}(E0)}[\Omega_K(E0) + \Omega_{L1}(E0) + ... + \Omega_\pi(E0)]^{-1}$$

or alternatively from

$$\rho^2(E0) = q_K^2(E0/E2) \times \frac{\alpha_K(E2)}{\Omega_K(E0)} \times W_\gamma(E2)$$

if the E2 transition rate, $W_\gamma(E2)$, is known.

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E.   Alpha-Decay Hindrance Factors
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(June 1987)

1.   The Concept of a Hindrance Factor

The probability for α decay depends primarily on two factors:

(a) the difference in the nuclear structure configurations between the parent and the daughter nuclear states

b) the energy of the α particle.

Note: The dependence on energy is very strong. For example, for ground-state to ground-state decays of even-even isotopes, changing the energy from $E\alpha = 4$ MeV to $E\alpha = 8$ MeV reduces the partial α half-life, by 20 orders of magnitude.

Our main interest in the Nuclear Data Network is in the effects of nuclear structure on α decay (J^π and configuration assignments); therefore, it is useful to define the concept of α_{HF} which is related to the experimental α intensity Iα, but with the energy dependence (as well as the weaker Z and A dependence) removed. This is quite similar to the procedures adopted for β decay (the use of log ft's) and γ decay (the use of Weisskopf units for reduced transition probabilities).

In even-even nuclei, the strongest α transitions are the g.s. to g.s. transitions (0^+ to 0^+). They range from 65% to over 99% of total α decay. By definition, HF = 1 for these α branches. All other α HF's are

calculated relative to the 0^+ to 0^+ HF's. For example, in the mass region A>214, the HF's for 0^+ even-even parents to the 2^+ first excited daughter states vary smoothly as a function of A from 0.9 to 4.0. See Ref [3].

In odd-A and odd-odd nuclei, the HF is defined relative to the HF's for g.s. to g.s. transitions in the neighboring even-even nuclei .See section 3.

2.   The Use of α_{HF} in Nuclear Data Evaluations

The α HF's exhibit remarkable regularities [2,3]. These systematic features are the basis for their usefulness in evaluations (again in close analogy to the use of log ft's and reduced transition probabilities as well as of spectroscopic factors). The main uses are for J^π and configuration assignments and estimation of unknown α-decay branches

a) J^π assignments. The Summary of Bases for Spin and Parity Assignments in NDS contains two strong rules, #33 and #34, based on α decay for J^π assignments; however, more arguments could be suggested based on the systematic trends discussed in Refs [2,3]

It is clear from Ref [2] that in the deformed actinide region, all rotational bands have very characteristic α_{HF}'s. For favored bands i.e., the same configuration in parent and daughter levels (It is assumed that the band are not strongly mixed.), the α_{HF}'s may be calculated easily using the rotational model. The agreement with experiments is usually within a factor of 3 (for L = 2 transitions the agreement is usually better than 50%). Considering the $\approx$4 orders of magnitude spread in measured α_{HF}'s, this agreement as well as the systematic trends in non-favored transitions (effects of L-transfer, spin flip, Nilsson configuration changes, Coriolis coupling) are very useful for J^π and configuration assignments. Clearly, our J^π rules #31 and #32 for rotational bands should be updated since α_{HF}'s are no less useful than level energies in establishing assignment of a level to a rotational band.

The systematic trends in the closed-shell lead region are no less impressive. Ref [3] . For example, α_{HF}'s from parent $3p_{1/2}$ to daughters $3p_{1/2}$, $3p_{3/2}$ and $2f_{5/2}$ are the same to within $\approx$20% for Po, Rn, and Ra isotopes. Similar agreement is apparent: in the $2f_{5/2}$parents decays to ^{201,203,205}Po; in the$2g_{9/2}$ parents decays to ^{209}Pb, ^{209}Po, ^{211}Rn, ^{213}Ra; and in the $1h_{9/2}$ parents decays to ^{207,209}Tl, ^{207,209,211,213}Bi, and ^{215}At.

The consistency is not as good, but still impressive in the odd-odd nuclei: the decay of $(\pi 1h_{9/2})(v2g_{9/2})1^-$ and $(\pi 1h_{9/2})(v2g_{9/2})9^-$ parents. Clearly, our J^π assignment weak argument #4 can be strengthened when supporting α_{HF} information is available.

b)   Estimation of unknown α decay branches. The same systematic trends of α decay that were pointed out in Refs [2,3] can also be used to estimate unknown α branches. One type of application is to estimate an intensity of a single α branch which was not measured but may be of importance to the mass chain evaluation. For example, we estimated the ^{209}Po α branch to the 5/2$^-$ g.s. of ^{205}Pb at 20%. Experimentally it was not possible yet to resolve this branch from

the favored 80% α to the 1/2⁻ state. This estimate is relevant to the calculation of Qα of ^{209}Po as well as to the degree of usefulness of ^{209}Po as an α energy standard. Another example is the estimate of Iα to 2⁺ states in a number of heavy elements based on interpolation of the very smooth variation of α_{HF}'s in this region. This estimate is essential for the correct calculation of the radius parameter used to calculate α_{HF}'s for the whole region See Section 3.

The second type of application is the estimate of %α, i.e., the total α decay branching of ground states or isomers in cases where this branching is not known experimentally. The key to these estimates is the systematics of favored α transitions, which are usually by far the most intense and determine to a large extent the total α-decay branching. (The exceptions are cases where the favored level in the daughter is very high in energy.)

In the case of even-even ground-state α decays, the smooth systematic trends of the radius parameter (section 3) determine the intensity of the main 0⁺ to 0⁺ α branch. The second strongest transition usually is the 0⁺ to first-excited 2⁺ state; this branch can be estimated quite reliably from the systematic trend of 2⁺ HF's. Often the above 2 branches account for over 99% of the total a decay.

For odd-A and odd-odd nuclei, the estimates of %α can be quite reliable provided that the level energy of the favored configuration in the daughter is known. In odd-A nuclei, such estimates may be reliable to ±20% when Qα is well known. In odd-odd nuclei (where less good data are available), the reliability may be ±50%. For example, in the mass region A = 191 through 213 for all 50 cases of odd-A favored α's, HF's vary from 1.1 to 1.6 for J≠1/2 and from 1.4 to 2.2 for J=1/2. For odd-odd nuclides the favored α_{HF}'s vary from 1.5 to 2.5 (except for 5⁺ states which are probably of mixed configuration). In transition regions (where the deformation changes rapidly), there are significant differences between the parent and the "favored" daughter configurations; as a result, the "favored" α_{HF}'s are larger.

Uncertainties in Qα of 200-400 key correspond to an order of magnitude uncertainty in a calculated $T_{1/2}(\alpha)$. Even in cases of such large uncertainties, the estimate of %α may still be useful. For example, the estimate %α << 1 syst may indicate that %ε ≈ 100; thus, log ft's could be calculated. Table 5 of Ref [3] lists the %α and Qα values for 186 < A < 223; "syst" indicates the values derived from systematics of α_{HF} and of Qα, respectively. For a graphical representation of Qα values see, for example, Ref [4]. In a few cases, $T_{1/2}$ could be estimated for ground states and isomers. Table 6 of Ref [3] lists the individual α_{HF} values, including the ones derived from the systematic trends, and the Iα values deduced from the α_{HF} values. In cases of strong configuration mixing, the estimates are less reliable; however, for strong α branches, the sensitivity of α_{HF} (and therefore of Iα) to configuration mixing is much smaller than the corresponding sensitivity of log ft values, of reduced transition probabilities, and in many cases of magnetic moments.

3.   Calculation of αHF*

The calculation of $\alpha_{HF's}$ in NDS is based on the spin-independent equations of Preston, Ref [5], and is essentially the same as the calculations done for the sixth, seventh and eighth editions of the Table of Isotopes, Ref [6] (1967, 1978, and 1996).

*See also Appendix A for details on obtaining the r_0 parameters, and 2020Si16 for an evaluation of these parameter for even-even nuclides.

a) For even-even nuclei, the α_{HF}'s of excited states are inversely proportional to $I\alpha$ and are normalized to the value HF = 1 for the 0^+ to 0^+ g.s. to g.s. transition. The computer program removes the energy dependence (which is calculated from the input $Q\alpha$ and E(level) in the daughter). The uncertainties in the parent $T_{\frac{1}{2}}$, α branching, and $Q\alpha$ cancel out, because of the method of normalization. If the level energies are accurate (say, $\Delta E \leq 5$ keV), the uncertainty in HF will be the same as the fractional uncertainty in $I\alpha$.

In addition to α_{HF}, the computer program calculates the parameter, r_0, (roughly equivalent to the nuclear radius) from $Q\alpha$, $T_{\frac{1}{2}}(\alpha)$, and $I\alpha$ to the g.s. (Z and A also enter in). It is useful for evaluators to keep track of the r_0 systematics in the region of their responsibility. In my experience (in the lead and actinide regions) the ro values for each element lie on fairly smooth curves, the exception being sharp breaks at the closed shells N = 126 and N = 152.

b) For odd-A and odd-odd nuclei, the α_{HF}'s are also inversely proportional to $I\alpha$, but the normalization is to the neighboring nuclei. See Appendix A. The r_0 parameter has to be included in the input to the computer program. See 2020Si16* for a discussion of the program ALPHAD_RadD which calculatyes these automatically. Usually for odd-A isotopes, the r_0 will be the average of the two nearest even-even neighbors, and for odd-odd isotopes the average of the four nearest even-even neighbors. See Appendix A. The uncertainties in the α_{HF}'s are usually much larger than in the case of even-even nuclei for the following reasons: There is the additional uncertainty in the r_0 parameter; the uncertainties in $Q\alpha$ and $T_{\frac{1}{2}}$ (parent) as well as in the α-branching of the parent, do not cancel out. Typical uncertainties are, for example, 3 keV in $Q\alpha$ of 5 MeV resulting in $\approx 4\%$ uncertainty in α_{HF}, Δr_0 of 0.01 resulting in $\approx 20\%$ uncertainty in α_{HF}, and of course linear dependence on uncertainties in $I\alpha$ and $T_{\frac{1}{2}}(\alpha)$.

* 2020Si16. S. Singh, S. Kumar, B. Singh, A. K. Jain, Nucl. Data Sheets 167, 1 (2020)

In contrast to most calculations of log ft's, we do not have to worry here about unplaced transitions. In fact, α_{HF}'s can be calculated from $E\alpha$, $I\alpha$ and Z without any knowledge of the decay scheme. However, the interpretation of the results of α_{HF} calculations demands considerable experience and detailed knowledge of nuclear structure.

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F. J^{π} and Multipolarity Assignments in (HI,xnypzαγ) Reactions

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In heavy-ion compound nuclear experiments (HI,xnypzαγ), the multipolarities of the γ transitions and the relative spins and parities of the levels are generally determined through the measurement of angular distributions, angular correlations, linear polarizations, and through measurements of internal conversion coefficients.

Angular distributions

1. The angular distributions of γ-rays, $W(\theta)$, is a measurement of the intensity as a function of the angle θ with respect to the beam direction or to the nuclear spin axis.

$$W(\theta)=\sum_{k=even} A_k P_k (\cos \theta)$$

2. The values of the coefficients A_k depend on ΔJ, the mixing ratio δ(L+1)/L, and the degree of alignment. In most cases only A_2 and A_4 need to be considered. For high-spin states the distributions are largely independent of spin.

3 The degree of alignment, σ/J, is usually determined through a measurement of $W(\theta)$ for a number of known ΔJ =2 transitions. In actual practice many authors use σ/J = 0.3 for the degree of alignment. Here σ is the half-width of the Gaussian describing the magnetic sub-state population. The attenuation caused by the degree of alignment affects only the magnitudes of A_2 and A_4. Level lifetimes are assumed to be small so that alignment is maintained.

4. Angular distribution measurements alone may be used to deduce ΔJ and/or the multipole order (L) (multipolarity), but not Δπ.

5. Typical values of A_2 and A_4 are given in the table below ($\sigma/J = 0.3$ assumed). The angle θ is measured relative to the beam direction. If θ were with respect to the spin axis, then the sign of A_2 is generally reversed.

Table of Angular Distributions

ΔJ	Multipole Order	Sign of A_k*		Typical Values	
		A_2	A_4	A_2	A_4
2	Quadrupole	+	-	+0.3	-0.1
1	Dipole	-		-0.2	0.0
1	Quadrupole	-	+	-0.1	+0.2
1	Dipole + Quadrupole	+ or -	+	+0.5 to -0.8	0.0 to +0.2
0	Dipole	+		+0.35	0.0
0	Quadrupole	-	-	-0.25	-0.25
0	Dipole + Quadrupole	+ or -	-	+0.35 to -0.25	0.0 to -0.25

*   Note that A_4 is positive for all δ values for $\Delta J=1$, Dipole +Quadrupole, and negative for $\Delta J=0$, Dipole + Quadrupole.

Angular Correlations, e.g. DCO, Directional Correlations of γ-rays from Oriented States of Nuclei

6. DCO measurements involve the determination of the coincidence intensities for two γ-rays, γ_K of known multipole order (L) and γ_U of unknown multipole order. The γ-rays are detected at two angles, θ_1 and θ_2, with respect to the beam direction. The coincidence intensities are determined as two - dimensional areas, $I(\theta_1 \theta_2 \gamma_K \gamma_U)$ and $I(\theta_1 \theta_2 \gamma_U \gamma_K)$, where in the former case γ_K is detected at angle θ_1 and γ_U at angle θ_2.

The DCO ratios are then defined as

$$R=I(\theta_1\theta_2\gamma_k\gamma_u)/I(\theta_1\theta_2\gamma_u\gamma_k)$$

7. As with angular distributions, these ratios are insensitive to spin for high spin states but are sensitive to relative spins and γ multipole orders.

8. The angles θ_1 and θ_2 are generally determined by the geometry of the array. The values of R given below are typical for an array with detectors at 37° and 79°. An alignment of $\sigma/J=0.3$ has been assumed.

Table of Typical DCO Ratios

ΔJ_γ^{gate}, Multipole order	ΔJ_γ	Multipole order	Typical R(DCO)
2, Quadrupole	2	Quadrupole	1
2, Quadrupole	1	Dipole	0.56 (θ_1=37°, θ_2=79°)
2, Quadrupole	1	Dipole + Quadrupole	0.2 to 1.3 (θ_1=37°, θ_2=79°)
2, Quadrupole	0	Dipole	1
2, Quadrupole	0	Dipole + Quadrupole	0.6 to 1.0 (θ_1=37°, θ_2=79°)
1, Dipole	2	Quadrupole	1/0.56 (θ_1=37°, θ_2=79°)
1, Dipole	1	Dipole	1
1, Dipole	0	Dipole	~1/0.56

Linear polarization of γ-rays

9. A Compton polarimeter apparatus allows the measurement of relative intensities of radiation scattered in planes perpendicular to and parallel to the reaction plane (plane defined by the beam direction and incident gamma ray).

10. Determination of γ-ray polarization may differentiate between electric and magnetic radiations and thus, when combined with correlation data, allow determination of $\Delta\pi$. See Kim et al. [7]

Internal conversion coefficient data

11. Internal conversion coefficients or subshell ratios may be obtained from electron spectra or from γ-ray intensity balances.

12. The interpretation of internal conversion coefficient data is as given in NDS under rules for spin and parity assignments. Note that electron data usually give K-, L-, etc., conversion coefficients or sub-shell ratios whereas intensity balance arguments give total conversion coefficients

Other considerations

13. If T½ (level) is known or a limit can be assumed (based on coincidence resolving time, for example), RUL (recommended upper limits for Weisskopf estimates) may serve to eliminate the M2 option for a $\Delta J = 2$ quadrupole transition.

14. Generally for the states populated in high-spin reactions, spins increase with increasing excitation energy. This is a result of the fact that these reactions tend to populate yrast or near yrast states.

15. For a well-deformed nucleus, when a regular sequence of $\Delta J=2$ (stretched quadrupole) transitions is observed at high spins as a cascade, then the sequence may be assigned to a common band with E2 multipolarity for all the transitions in the cascade. A similar but somewhat weaker argument holds for less deformed nuclei where a common structure of levels is connected by a regular sequence of $\Delta J=2$ (stretched transitions) as a cascade. For interband transitions, $\Delta J = 1$ or 0 transitions with significant admixtures are considered to be of MI + E2 type. If the transition is pure dipole ($\delta(Q/D)=0$), it is quite often El. The small deformation magnetic rotational (M1) bands present exceptions to this rule.

16. The presence of strongly coupled (deformation alignment) bands allows assignment of relative spins and parities of the band members. The presence of a measurable quadrupole admixture in the $\Delta J = 1$ cascading transitions is required to prove that all the states have the same parity. This is because nuclei with octupole deformation may have two rotational $\Delta J = 2$ sequences of opposite parity connected by cascading El transitions.

17. For near-spherical nuclei, when a regular sequence of $\Delta J = 1$ (stretched dipole) transitions is observed at high spins as a cascade, then the sequence may be assigned to a common band with M1 multipolarity for all the transitions in the cascade. (Cascades of $\Delta J = 1$, El transitions occur in rare cases of nuclides which show alternating-parity bands or reflection asymmetry.)

18. In the absence of angular distribution/correlation data, a regular sequence of transitions in a cascade may be assigned to a common structure or a band if:

    1) The low-lying levels of this structure have well established spin parity   assignments.

    2) There is good evidence that, at higher energies and spins, the band has not changed in its internal structure due to band crossings or other perturbations.

19. In strongly coupled bands, (deformation aligned) a comparison of an experimentally deduced value of g_K (from mixing ratio $\delta(E2/M1)$ and assumed g_R and Q_0) with that calculated on the basis of a proposed quasi-particle configuration may lead to the assignment of parity to a band.

20. A comparison of experimental and calculated Routhians and particle alignments (from cranked shell-model calculations) for suggested quasi-particle configurations may give information about the parity of a rotational band.

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G. Procedures/guidelines for ENSDF half-life evaluations (ground states and long-lived isomers)

ACTION 44, Kuwait, January 2013, IAEA report INDC(NDS)-0635:

A.L. Nichols (University of Surrey, UK), B. Singh (McMaster University, Canada)

April 2, 2011: edited December 10, 2013 by B.Singh, Feb. 20, 2014 by A.L.Nichols; March 18, 2015 by B. Singh; April 16, 2015 by A. L.Nichols and B. Singh; April 29, 2015 by A. L. Nichols and B. Singh

(1)   Identify and accumulate ALL published measurements of the half-life of the specified nuclear level(s)

(2)   Ensure that all of the above identified half-life data and origins (NSR key-numbers) are listed systematically (in reverse chronological order) in the *Comments* area, or as a footnote in the Adopted Levels, Gammas data set.

(3)   Consider any other features of each specific measurement for either rejection or increased preference, based on your own experience and subjective judgements. Examples include the following:

- acceptance or rejection of *grey* references (publications that have not been fully peer reviewed: laboratory reports; conference proceedings; sometimes the journal issue of a set of conference papers, etc.),

- measurement technique (compared with others, the technique is judged/known to be more appropriate for the half-life being addressed),

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

- known reliability or improvements in a particular measurement technique (improvements might make the date of the measurements important),

- regular and lengthy measurement programme of specific half-lives for important applications (normally a policy instigated by national standards laboratories, but also observed to be undertaken by others) can result in rejecting all but the most recently reported value; complications can also arise when the laboratory changes equipment/technique,

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

and various other imponderables.

An important issue of procedure is faced by any evaluator commissioned to derive a recommended half-life with an uncertainty (for example) at the 1σ level from a set of data varying widely with measurement techniques, data handling procedures by the measurers, and problems with the detail (or lack thereof) provided in a publication. Unrealistically low uncertainties are known to be reported in the field of half-life measurements (particularly obvious when systematic uncertainties are ignored by the experimenters), such that various subjective decisions may need to be taken by the evaluator:

A.reject measurements that do not quantify the uncertainty budget at all;

B.reject or be cautious of measurements with uncertainties that are judged to be totally unrealistic and/or incorrect;

C.reject or be cautious of half-life studies that suffer from insufficient measurement time when determining activity decay as a function of time in order to quantify the slope of such a plot, and which do not provide details of counting losses;

D.increase the uncertainty in a particular measurement on the basis of known limitations in the measurement technique, hopefully described adequately in the paper;

E.increase specific uncertainties during the course of the process of weighted-mean calculation, and subsequently recycle until the weighting of any particular half-life measurement does not exceed a prescribed level (one common practice is "no more than 50% weighting").

All actions of above type which involve some form of subjective judgement require full explanation of what was done and why, and should be included in the *Comments* area.

(4)   Identify outliers (see definition in the following paragraph), document and discard, based on the criteria adopted in least-squares analysis codes. Numerous averaging techniques have been proposed and developed (see VISUAL AVERAGING LIBRARY or AVETOOLS on NNDC webpage).

Examples include:

weighted mean (WM);

limitation of the relative statistical weight (LRSW or LWM); 1992Ra08, (M. U. Raiput, T. D. McMahon, Nucl. Instrum. Methods Phy. Res. A312, 289 (1992)). .Reference 3 in this paper mentions W. L. Zijp, ECN-179, Petten, The Netherlands (1985) for the concept of the LWM method.

normalised residuals (NR); (M. F. James, R. W. Mills, D. R. Weaver, The use of the normalized residual in averaging experimental data and in treating outliers. Nucl. Instrum. Methods Phy. Res. A313, 277 (1992))

Rajeval Technique (RT) (M. U. Rajput, T. D. MacMahon, Nucl. Instrum. Methods Phy. Res. A312, 289, (1992) ;

BootStrap (BS) (O. Helene, V.R. Vanin, Nucl. Instrum. Methods Phy. Res. A481, 626 (2002)) etc.

These disparate techniques use different methods to handle the uncertainties, identify outliers, and derive the mean value and uncertainty. LRSW, NR and RT use the uncertainties and occasionally inflate them to accommodate discrepant data; all three of these methods should be used simultaneously to identify outliers (i.e. defined as such if at least two of the methods identify a data point as an outlier). BS method ignores uncertainties, and therefore does not identify outliers. 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, and available through NNDC. This code also handles asymmetric uncertainties. Note that AVETOOLS does not handle asymmetric uncertainties.

(5) All acceptable half-life data should be analysed by means of these techniques
- may need to define which method is the most appropriate – WM, LRSW, NRM, RT, BMR, BootStrap, others, and so adhere to consistency in the selection of the recommended half-life value and uncertainty,

- role of reduced 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.

- when a new half-life measurement for a ground state or long-lived isomer comes to the evaluator's attention, the impact of that measurement on the currently recommended ENSDF value should be assessed, and suitable adjustments made in ENSDF, if deemed necessary.

- as an overall guide:
- adopt WM value and uncertainty when measured half-life data are not discrepant;

- adopt value from LRSW or other procedures when measured half-life data exhibit discrepancies;

- the recommended uncertainty should generally be no smaller than the smallest uncertainty to be found in sets of experimental half-life data that are not individually defined in terms of various types of separated component uncertainties (also see below);

- if the statistical and systematic components of the half-life uncertainty have been quantified as separate entities in the various measurements, the recommended overall uncertainty in the half-life should be the sum of the lowest systematic uncertainty to be found in the data set and the weighted mean of the statistical uncertainty, in general, added in quadrature. Both components should be given:

- the final uncertainty should not be lower than 0.01%;

- the adopted analytical route should be clearly described in the *Comments* area (data accepted; data rejected; numerical method adopted/applied).

(6) Literature coverage: some half-life articles are published in non-nuclear physics or non-radioactivity journals, and can consequently be missed by NSR. Examples of such omissions can be found in journals that include Health Physics, Geochronology and Geochemistry, and Planetary and Earth Sciences. The DDEP group generally undertakes a more complete literature search than ENSDF for their selected set of nuclides, but they do not always register and request NSR key-numbers, when they make use of a reference not found in NSR. Examples of previously missing important articles on half-life measurements that were added to NSR about two months ago on request of one of the authors of this report: 1991Ma68 (*Health Physics* 61, 511) for ^{214}Pb, ^{214}Bi; 1989Ma67 (*Health Physics* 57, 121) for ^{218}Po; 2001Po32 (*Radiochemistry* 43, 549) for ^{175}Hf, ^{181}Hf; and also several other references.

(7) Useful article: there is an interesting article by S. Pomme *et al.* from IRMM, Geel, published in *Journal of Radioanalytical and Nuclear Chemistry* 276 (2008) 335-339, which constitutes a useful document for evaluators of half-lives. Pomme and co-workers have also published significant articles on half-life measurements, mostly in *Applied Radiation and Isotopes*. A search of NSR can retrieve a list of some of these papers published during 2011-2014, where methodology and uncertainty budgets are discussed in good detail.

Examples (2010/11):

^{62}Co half-life

Reference	Half-life (min)	Comments
1949Pa01	1.6 (2)	β-decay curves followed over six half-lives; decay curve shown
1960Pr05	1.9 (3)	β-decay curve not shown – only lists half-life
1962Va23	1.5 (1)[*]	β-decay curve followed over four half-lives; no discussion of impurities
1969Wa16	1.50 (4)[#]	γ-γ coincidence and high energy β; decay curves not shown – only lists half-life
1970Jo12	1.4 (2)	1129-keV γ decay followed for more than five half-lives; decay curves shown for several γ rays
	1.54(10)	Recommended value (LRSW – Limitation of Relative Statistical Weights)

[*] Uncertainty increased to ± 0.2 to reduce weighting to below 50%.
[#] Uncertainty increased initially to ± 0.20 to reduce weighting to below 50%.

^{62m}Co half-life

Reference	Half-life (min)	Comments
1949Pa01	13.9 (2)	β-decay curves followed over six half-lives; decay curve shown
1957Ga15	13.91 (5)*	γ decay measured in well-type scintillation detector; minor Cu-64 and Ni-65 impurities present; no decay curves shown – only lists half-life
1960Pr05	13.8 (2)	β-decay curve not shown – only lists half-life
1962Va23	13.9 (2)	β-decay curve followed over about two half-lives; no discussion of impurities
1969Wa16	14.00 (24)	High energy β and γ decay; decay curves not shown - only lists half-life
1969Mo04	13.8 (5)	1163-, 1172-, 2003- and 2103-keV γ decay followed for about six half-lives; decay curves shown for several γ rays
1970Jo12	13.5 (3)	1163- and 1173-keV γ decay followed for more than two half-lives; decay curves shown for several γ rays
	13.86 (9)	Recommended value (LRSW)

*Uncertainty increased to ± 0.20 to reduce weighting to below 50%.

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^{62}Cu half-life

Reference	Half-life (min)	Comments
1954Nu27	10.1 (2)#	^{62}Cu milked from parent ^{62}Zn
1965Eb01	9.76 (2)	Decay of positron annihilation radiation; ^{64}Cu impurity considered constant - no decay curves, only lists measured half-life
1965Li11	9.79 (6)	Decay of positron annihilation radiation corrected for ^{64}Cu activity, and fitting of excitation functions for ^{63}Co(n,2n)^{62}Cu reaction at En=12.6-19.6 MeV – lists half-life derived from these fittings
1969Bo11	9.7 (1)	Decay of positron annihilation radiation and fitting of excitation functions for ^{63}Co(n,2n)^{62}Cu reaction at En=13-18 MeV – lists half-life derived from these fittings
1969Jo07	9.73 (2)	Decay of positron annihilation radiation - no decay curves, only lists measured half-life
1975Ca40	9.80 (2)	γ-ray decay – no decay curves, only lists measured value
1997Zi06	9.68 (4)	4πβ liquid scintillation spectrometry, twelve independent measurements spanning two to four half-lives
	9.673 (26)	4πγ ionization chamber, two independent measurements spanning two to four half-lives
2002Un02	9.673 (8)*	Quote 1997Zi06, see above, but uncertainty is statistical only.
	9.74 (6)	LRSW: weighted average of the above with uncertainty expanded so that range includes the most precise value (9.673 min); data set exhibits significant inconsistencies that mitigate against LSWM approach
1997Zi06	9.68 (4)	4πβ liquid scintillation spectrometry, twelve independent measurements spanning two to four half-lives
	9.673 (26)	4πγ ionization chamber, two independent measurements spanning two to four half-lives
2002Un02	9.673 (8)*	Quote 1997Zi06, see above, but uncertainty is statistical only.
	9.675 (22)	Recommended value: from weighted average of two values in 1997Zi06. Uncertainty should be increased to 0.026.

Rejected as outlier, and not included in the data sets for LRSW analyses.
*Not included in averaging.

Further comments:
2012Fi12 (NIST correction to 2002Un02 half-life data (see also footnote above for [*])) –
adjusted value of 9.672(8) min has no impact on the analysis of the data published
up to and including 2002. 2014Un01 report a half-life of 9.673(8) min, which is identical to
their previous value and therefore has no impact on the analysis of the data published up to and
including 2002.

Half-life of ^{207}Bi: review of ENSDF evaluation, 2010 (A.L. Nichols)

Each relevant paper considered in reasonable detail below. Comments are given in order of year
of publication of each of the highly-relevant papers. Earlier half-life measurements are significantly
less accurately characterised, and have not been assessed in this exercise.

1978Ya04: Yanokura et al., Nucl. Phys. A229 (1978) 92-98
Three different approaches were taken to measure the half-life of ^{207}Bi.

(1).   The absolute disintegration rate of ^{211}At in a purified sample was measured by means of a
liquid scintillation counter, and a large volume of the same solution was used to study the gamma-
ray decay of daughter ^{211}Po and ^{207}Bi with a heavily-shielded Ge(Li) detector, calibrated against
IAEA standard γ-sources of ^{22}Na, ^{54}Mn, ^{57}Co, ^{60}Co, ^{133}Ba and ^{137}Cs. The prominent 569.7-keV
gamma ray was used to calculate the decay rate of ^{207}Bi (emission probability of 99.85% was used
from Parsa and Markowitz, *J. Inorg. Nucl. Chem.* 36 (1974) 1429-1431), with a theoretical total
internal conversion coefficient of 0.0221 adopted for this E2 transition). Thus, the half-life value
for ^{207}Bi was "evaluated" to be 32.2 ± 1.3 years.

(2).   A ^{207}Bi half-life of 31.7 ± 3.7 years was determined from a source prepared for liquid
scintillation counting, but after complete decay of ^{211}At, whereby the large uncertainty was
attributed to the poor detection efficiency when gamma counting this particular liquid sample (?).

(3).   And finally, the half-life of ^{207}Bi was also determined from the EC/α branching ratio, the
emission probability of the 6868-keV α transition from ^{211}Po to the 569.7-keV nuclear level in ^{207}Pb,
the half-life of ^{211}At, and the decay probability of ^{207}Bi feeding the 5769.7-keV nuclear level in
^{207}Pb. A half-life value of 33.4 ± 0.8 years was calculated via this method. The author assigned the
small uncertainty to the counting statistics involving the 569.7-keV gamma ray – this value was
adopted as the definitive recommended half-life through rather nebulous reasoning (simply because
the value was deemed to be the most accurate?).

Systematic uncertainties are ignored in this set of studies, and are difficult to extract from the
contents of the paper. Furthermore, such issues as the data sources for the direct 569.7-keV
gamma-ray study need to be re-assessed (emission probability and ICC(total)) to derive a new half-
life value, rather than simply adopt the original value of 32.2 ± 1.3 years. The half-life derived from
the liquid sample should simply be discarded as seriously inaccurate. Finally, the half-life
calculated from the EC/α branching ratio and other derived nuclear data needs to be re-assessed
(and discarded if deemed inappropriate).

<u>1990Al11: Alburger and Harbottle, *Phys Rev.* C41 (1990) 2320-2324</u>
An end-window gas-flow proportional counter was used to determine the decay of β^- radiation from two samples of ^{44}Ti and one sample of ^{207}Bi. Consideration of the detailed and overall performance of this system can be found in Alburger *et al*. *Earth Planetary Sci. Letts.* 78 (1986) 168-176. Long-term drift in counter voltage was deemed to be of the order of less than 0.5 V (c.f. 25 V to achieve the equivalent of 1σ statistical uncertainty); box pressure would have to vary by 0.15″ compared with monitored changes of better than 0.03″. Changes in temperature of 2°F would result in 1σ standard deviation change in activity ratios, while a variation from 30% to 80% in the relative humidity would also cause a variance of 1σ standard deviation. These latter parameters were only monitored close to the end of the earlier studies on ^{32}Si/^{36}Cl with the following observations: temperature fluctuated from 72.4 to 74.7°F, and average relative humidity varied between 35% to 76% - judged as unfortunate and important variations in any attempt to define SYSTEMATIC uncertainties. Fluctuations of the data points from a smooth exponential decay were observed that are approximately THREE times the statistical uncertainty, and the authors assigned this unusual behaviour to variations in the temperature and relative humidity. Uncertainties were also identified with the operating pressure for the system – judged by the authors as operational under somewhat lower conditions than optimum. Other considerations involved studies of restoration of operational stability (system required a week to re-stabilize of any power shut-down), and change to a new gas supply (no observable effect). One might judge an overall SYSTEMATIC uncertainty of the order of $\pm$ 1.5 for a value of 34.9 years, without consideration of source preparation, radionuclidic purity and stability.

Clearly, the uncertainties quantified in this paper are only the STATISTICAL uncertainties from the relative activity measurements for ^{36}Cl, ^{44}Ti and ^{207}Bi (Figs. 1, 2, 3, 4). A recommended value of 34.9(4) years is derived by the authors for the half-life of ^{207}Bi.

Consideration of a combination of systematic and statistical uncertainties could result in a significant adjustment to 34.9 $\pm$ 2.0 years. However, there are a number of imponderables in this analysis that can be seen to justify the rejection of the half-life value from this particular study by the original 207 mass chain evaluators.

<u>1991Li10: Lin and Harbottle, *J. Radioanal. Nucl. Chem.* 153 (1991) 51-55</u>
Note same common author for 1990 and 1991 publications (Harbottle).

An inadequate paper, with insufficient detail and lack of clear traceability. Used gamma-ray spectroscopy to monitor the disintegration rates of individual gamma rays, and calculated half-life data from a combination of these disintegrations rates, "known" gamma abundances and the detector efficiency curve. Measured gamma-ray abundances are compared with equivalent data from the NBS certification of the ^{207}Bi source, and recommendations to be found in *Nucl. Data Sheets* 43 (1984) 383.

Interestingly, three half-live values are quoted in this paper:

      (1). 31.6 $\pm$ 0.7 years from "only" the major 569-keV gamma line;
      (2). 32.7 $\pm$ 0.7 years from the 569- and 1063-keV gamma lines;
      (3). 32.7 $\pm$ 0.8 years from the 569-, 1063- and 1770-keV gamma lines.

There is an argument to be made for just adopting the half-life value of 31.6 ± 0.7 years, although a reasonable understanding of the recommended uncertainty is required (and is judged to be unrealizable).

1992Un01: Unterweger *et al., Nucl. Instrum. Methods Phys. Res.* A312 (1992) 349-352
2002Un02: Unterweger, *Appl. Radiat. Isot.* 56 (2002) 125-130
Represent a small part of a long-term NBS/NIST exercise to monitor, characterise and revise the decay half-lives of an extensive list of radionuclides maintained and stored within NIST. These studies have been ongoing for approximately five decades, based on measurements by means of $4\pi\gamma$ pressurized ionization chambers and (more recently) high-resolution HPGe detectors.

Both of these papers lack sufficient detail, but refer to detailed descriptions and equipment and techniques to be found in NBS Special Publication 626 (1982) 85 and NBS Special Publication 250-10 (1987). However, specific systematic uncertainties are noted, such as the lower response of the ionization chamber that was believed to arise from instabilities in the old battery pack, and improvements noted after the vibrating reed electrometer and capacitor bank were replaced with a multi-range electrometer. Other unexplained changes also occurred periodically in the response of the ionization chamber to radium references sources prior to 1973.

The 1992 publication contains a recommended half-life for ^{207}Bi of 11523 ± 19 days which is equivalent to 31.55 ± 0.05 years (1 year (mean tropical year) $\equiv 365.2422$ days), which had only been followed for 0.6 half-lives (~ 19 years). Uncertainties are quantified in terms of Statistical Uncertainty (10.0) and Other Uncertainty (16.0), although I am uncertain as to what these numbers really mean.

The 2002 publication contains a recommended half-life for ^{207}Bi of 11523.0 ± 15.0 days which is equivalent to 31.55 ± 0.04 years (1 year $\equiv 365.2422$ days), which had been followed for 0.9 half-lives (~ 28 years). Uncertainties are also quantified in terms of Statistical Uncertainty (9) and Other Uncertainty (12), although I remain uncertain as to what these numbers mean.

Concluding Remarks

I would recommend discarding:
    half-life (2) from Yanokura et al;
    half-life of Alburger and Harbottle;
    half-lives (2) and (3) of Lin and Harbottle;
    ignore 1992 half-life of Unterweger *et al*. (replaced by recommended 2002 value).

Rework and accept half-lives (1) and (3) from Yanokura et al (however, may still discard re-worked half-life (3));
accept half-life (1) of Lin and Harbottle;
accept 2002 half-life of Unterweger, but see also 2014Un01 from Unterweger for a revised value from (11523 ± 15) d in 2002Un02 to (11403 ± 61) d in 2014Un01, due to correction for source movement at NIST over years.

^{207}Bi half-life: 2011Ko04 – F.G. Kondev, S. Lalkovski, NDS 112 (2011) 707-853
Recommended $T_{1/2}$: 31.55 y *4*

$T_{\frac{1}{2}}$: From 2002Un02, using $4\pi\gamma$ pressurized ionization chamber at NIST; statistical uncertainty 0.025 y and systematic uncertainty 0.033 y. No impurities in the sources were observed using HPGe; decay has been followed over a period of $t \approx 28$ y. The value agrees with that of 31.55 y 5 reported by the same group (1992Un01), when decay was followed over a period of $t \approx 19$ y. Value superior to others described below.

Others (not used in the NDS evaluation):
32.7 y *8* (1991Li10) by measuring the activity of a calibrated ^{207}Bi source ($t \approx 17$ y after the source was calibrated) with a HPGe detector; value determined by averaging activities for 569γ, (Iγ = 97.75%), 1063γ (Iγ = 76.0% 14) and 1770γ (Iγ = 6.95% 13); $T_{\frac{1}{2}}$ = 31.6 y *7*, when the activity was deduced using 569γ only. The quoted uncertainty is statistical only. A sizable systematic uncertainty can be expected, given the uncertainties in the nuclear data parameters used in the calibration of the source.

34.9 y *4* (1990Al11) using a gas-flow proportional counter system; the uncertainty is statistical only and quoted at 2σ level; the source was produced by bombarding a Pb target with 22-MeV deuterons following chemical separation; the measurements were followed over a period of $t = 3.4$ y. A break in the singles rates were observed around $t = 1.7$ y after the beginning of the measurements. So the data were analyzed in two separate parts yielding $T_{\frac{1}{2}}$ = 34.88 y 21 from the first 27 points (up to t = 1.7 y) and 35.2 y *9* from the next eight points; the quoted $T_{\frac{1}{2}}$ is higher than the adopted one. The quoted uncertainty is statistical only, although a large systematic uncertainty should be expected owing to sensitivity of the measurements to temperature and humidity changes. It is worth noting that $T_{\frac{1}{2}}$ = 66.6 y *16* was reported by this group (1990Al11) for ^{44}Ti, which is higher than other precise measurements of 58.9 y *3* (2006Ah10) and 60.7 y *13* (1999Wi01).

33.4 y *8* (1978Ya04) deduced indirectly using the decay of a ^{211}At source and knowledge of the ε/α branching ratio of ^{211}At (0.583/0.417), the emission probability of 6568-MeV α to the 569.7-keV level of ^{207}Pb (0.58% 1), the half-life of ^{211}At (7.23 h *2*) and the total emission probability of 569.7γ fed in ^{207}Bi ε decay (99.85%). The quoted uncertainty is statistical only, but a large systematic uncertainty can be expected. The authors also quote a value of 32.2 y 13 using the disintegration rate of ^{211}At in a purified sample measured by the means of a liquid scintillation counter and by adopting the 569.7γ to determine the decay rate of ^{207}Bi. A measurement performed after a complete decay of ^{211}At yielded $T_{\frac{1}{2}}$ = 32.2 y *37*, whereby the large uncertainty was attributed to the poor detection efficiency when gamma counting this particular sample.

38 y *4* (1972Ru10) using a ^{207}Bi source by counting the 569.7-keV gamma ray, using a NaI(Tl) scintillation spectrometer over a period of $t = 0.5$ y.

38 y *3* (1961Ap01) deduced indirectly using the decay of ^{211}At source and knowledge of the α branching ratio of ^{211}At (40.9%), the half-life of ^{211}At (7.214 h *35*) and the total emission probability of 569.7γ that is fed in ^{207}Bi ε decay (assumed 100% gamma-ray emission probability and 2.2% total α).

28 y *3* (1959So12) using the parent-daughter activity of ^{207}Po and ^{207}Bi.

Concluding Remarks

On balance, we sympathise with the rejection of much of the existing half-life data (2010/11), with the emphasis placed solely on the NIST measurements of 2002Un02 to the exclusion of all other studies.

Further comments, February 2014:
Amongst other publications since 2010, 2012Fi12 and 2014Un01 from NIST provides strong evidence that some of their reported half-life measurements over many years are systematically incorrect because of previously undetected physical movements of the source holder within the ionization chamber used to perform the work. The impact on the measured half-life of ^{207}Bi shows a change from (11523 ± 15) d to (11403 ± 61) d. which represents a decrease in the half-life of ≈ 1%. An adjusted half-life value of 31.22 y *17* constitutes a significant correction to the originally recommended half-life and uncertainty of 31.55 y *4* reported by 2002Un02 and adopted in ENSDF – the uncertainty at the 1σ confidence level has increased by a factor of 4.25.

Acknowledgments.

References

Refences for the Guidelines are embedded in the text. Those for each of the appendices are embedded in the text and/or tabulated as provided by the author(s).