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Summary Report of a Specialised Workshop on Nuclear Structure and Decay Data (NSDD) Evaluations

IAEA Headquarters
Vienna, Austria

27-29 April 2015

Prepared by

Alan L. Nichols
Departments of Physics
University of Surrey
Guildford, UK

P. Dimitriou
IAEA Nuclear Data Section
Vienna, Austria

F.G. Kondev
Argonne National Laboratory
Argonne, Illinois, USA

and

E. Ricard-McCutchan
Brookhaven National Laboratory
Brookhaven, Upton, NY, USA

September 2015

IAEA Nuclear Data Section
Vienna International Centre, P.O. Box 100, 1400 Vienna, Austria

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Nuclear Data Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna
Austria

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Abstract

A three-day specialised workshop on Nuclear Structure and Decay Data Evaluations was organised and held at the headquarters of the International Atomic Energy Agency in Vienna, Austria, from 27 to 29 April 2015. This workshop covered a wide range of important topics and issues addressed when evaluating and maintaining the Evaluated Nuclear Structure Data File (ENSDF). The primary aim was to improve evaluators' abilities to identify and understand the most appropriate evaluation processes to adopt in the formulation of individual ENSDF data sets. Participants assessed and reviewed existing policies, procedures and codes, and round-table discussions included the debate and resolution of specific difficulties experienced by ENSDF evaluators (i.e., all workshop participants). The contents of this report constitute a record of this workshop, based on the presentations and subsequent discussions. All presentations are available on IAEA-NDS webpage:
https://www-nds.iaea.org/nsdd/Workshop2015_presentations.html

September 2015

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1. Introduction

The International Atomic Energy Agency sponsored a three-day specialized workshop on nuclear structure and decay data evaluations at the IAEA headquarters from 27 to 29 April 2015. The primary aims were as follows:

- discuss frequently encountered problems in the evaluation of nuclear structure and decay data,
- improve and extend existing knowledge of evaluation policies and theory implementation,
- update of available analysis codes,
- further develop existing evaluation skills.

This specialized workshop was based on a combination of presentations and round-table discussions which evolved around specific examples and "best practices". Participants identified and discussed specific difficulties experienced in their evaluation of nuclear structure and decay data for the Evaluated Nuclear Structure Data File (ENSDF)[1], as a constructive follow-on from a more lengthy series of annual and biennial ICTP-IAEA workshops initiated in 2002 that did not possess the same degree of highly intensive focus on the detail of the evaluation process[2,3,4,5,6]. The most recent of the biennial ICTP-IAEA workshops was held from 24 to 28 March 2014 (see http://indico.ictp.it/event/a13191), and extensive notes are available from the linked ICTP web site which lists the full lecture programme: http://indico.ictp.it/event/a13191/other-view?view=ictptimetable

P. Dimitriou (IAEA Nuclear Data Section) welcomed participants, and emphasised the importance of extensive debate within the workshop. Hopefully, all participants performing nuclear structure and decay data evaluations would benefit from a greater understanding of the redrafted policies and procedures, as described in detail by M. Martin (Oak Ridge National Laboratory, USA) and J.K. Tuli (NNDC, Brookhaven National Laboratory, USA), along with fulsome debate of all issues and problems experienced in their work and tabled at the workshop. The workshop was organised by P. Dimitriou (IAEA Nuclear Data Section), and the technical content coordinated by E. McCutchan (NNDC, Brookhaven National Laboratory, USA) and F.G. Kondev (Argonne National Laboratory, USA). E. McCutchan (NNDC, Brookhaven National Laboratory, USA) and F.G. Kondev (Argonne National Laboratory, USA) also co-chaired the workshop, and A.L. Nichols (University of Surrey, UK) agreed to record and document all relevant discussions. The approved Agenda is attached (Appendix 1), as well as a list of all participants and their affiliations (Appendix 2).

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[1] Evaluated Nuclear Structure Data File (ENSDF), National Nuclear Data Center, Brookhaven National Laboratory, Upton, New York, USA; all reviewed and recommended files available from: http://www.nndc.bnl.gov/ensdf/, and also published in journal form as *Nuclear Data Sheets*, Elsevier Inc., Amsterdam, the Netherlands.

[2] V.G. Pronyaev, A.L. Nichols, Summary Report on "Workshop on Nuclear Structure and Decay Data: Theory and Evaluation", 18-22 November 2002, IAEA report **INDC(NDS)-439**, January 2003, IAEA, Vienna, Austria.
Available online at https://www-nds.iaea.org/publications/indc/indc-nds-0439.pdf

[3] A.L. Nichols, P.K. McLaughlin (editors), Workshop on Nuclear Structure and Decay Data: Theory and Evaluation, Manual, Parts 1 and 2, IAEA report **INDC(NDS)-452**, November 2004, IAEA, Vienna, Austria. Available online at
https://www-nds.iaea.org/publications/indc/indc-nds-0452-part1.pdf
https://www-nds.iaea.org/publications/indc/indc-nds-0452-part2.pdf

[4] A.L. Nichols, P.K. McLaughlin (editors), Workshop on Nuclear Structure and Decay Data: Theory and Evaluation, Addendum - 2005, IAEA report **INDC(NDS)-0473**, July 2005, IAEA, Vienna, Austria. Available online at:
https://www-nds.iaea.org/publications/indc/indc-nds-0473.pdf

[5] A.L. Nichols, P.K. McLaughlin (editors), Workshop on Nuclear Structure and Decay Data: Theory and Evaluation, Addendum - 2006, IAEA report **INDC(NDS)-0496**, June 2006, IAEA, Vienna, Austria. Available online at:
https://www-nds.iaea.org/publications/indc/indc-nds-0496.pdf

[6] A.L. Nichols, P.K. McLaughlin (editors), Workshop on Nuclear Structure and Decay Data: Theory and Evaluation, 2008, IAEA report **INDC(NDS)-0533**, June 2008, IAEA, Vienna, Austria. Available online at:
https://www-nds.iaea.org/publications/indc/indc-nds-0533.pdf

2. ENSDF Policies, Procedures and Codes

Presentations by the participants are available on IAEA-NDS web page https://www-nds.iaea.org/nsdd/Workshop2015_presentations.html. Links to the individual presentations are given in Appendix 3. A brief summary of the work scope and status associated with each presentation is outlined below, along with subsequent discussions. NSR key numbers are shown throughout the text for many of the references (https://www-nds.iaea.org/nsr/). All the actions that were agreed upon are listed in a table that follows the concluding remarks.

2.1. Guidelines for Evaluators, M.J. Martin (Oak Ridge National Laboratory, USA)

Murray Martin has comprehensively revised the definitive *Guidelines for Evaluators*, a document 43 pages in length that addresses, advises and explains in detail a wide range of nuclear data parameters and evaluation procedures of significant value to ENSDF mass chain evaluators. Just over a full day was spent on this particular draft report during which the author undertook a full reading of the whole document interspaced with numerous interruptions. Extensive in-depth questions were posed by all participants during the course of this exercise, and the author responded in kind to all comers. Martin noted all points that impacted on the content of the guidelines, and he will address these issues through clarifying additions and corrections to the text when deemed appropriate. Under these extensively author-based circumstances, his presentation and discussions are not recorded here, and the reader is referred to the final version of the guidelines which will be released at a later date:

> Guidelines for Evaluators, M.J. Martin, Oak Ridge National Laboratory, Oak Ridge, Tennessee, Revised version, April 2015, draft
> http://www.nndc.bnl.gov/nndc/evalcorner/Revised-Guidelines-for-Evaluators.pdf

2.2. Nuclear Data Sheets: Policies and J^{π} Assignments, J.K. Tuli (NNDC, Brookhaven National Laboratory, USA) and Balraj Singh (McMaster University, Hamilton, Canada)

Detailed consideration was given to the General Policies section contained within *Nuclear Data Sheets*, as defined in the two sub-sections entitled "Presentation of Data" and "Theory" (as prompted by Tuli), followed by a re-assessment of arguments for Spin and Parity Assignments (as led by Balraj Singh).

Presentation of Data (Tuli):
General policies were considered individually, and only specific points of note that arose during the discussions are given below. Excitation energies of individual levels connected by γ transitions are determined by least-squares fit to adopted γ energies expressed in laboratory coordinates. Policies for the handling of dominant decay branches, total internal-conversion coefficients, and cross reference flags (XREF) were also reviewed without issue.

Adopted Levels, Gamma data set policies were considered in detail from the point of view of $Q(\beta^-)$, S(n), S(p) and XREF for the nuclide, and relevant nuclear parameters for each adopted level, and γ-ray and E0 transitions. Minor adjustments and corrections were made to the wording to achieve greater clarity.

Policies for Reaction and Decay data sets: J^{π} values in the decay data sets (and reaction data sets with gammas) are taken from the Adopted Levels, Gamma data set, while J^{π} values for other reaction data sets are taken from the Reaction data sets. J^{π} value to the capture state in thermal-neutron capture is assigned assuming s-wave capture. Item 3 defines "intensity" and "probability" as equivalent terms, and will be removed on the basis of being understood and unnecessary. Item 5 defines particle intensities as per 100 particle decays (other than β decay), but delete the requirement to include total particle branching in the drawings and tables. Also delete the need for major references to appear in the drawings (item 9) – such additional refs should be given in the Comments. No modifications were proposed nor contents emphasized in the other existing policy statements identified with the reaction and decay data sets.

Policies for Organization of material: consider levels and γ rays in ^{A}Z from nuclear reactions - reactions are ordered by increasing A, Z of the target, and then by increasing A, Z of the incident nucleus. An optional Level Scheme can be presented if γ rays were observed and placed, and not too complex.

Theory policies (Tuli):
Modest adjustments have been made to the text on Internal Conversion Coefficients − Theoretical electron conversion coefficients are obtained by cubic spline interpolation (BrIcc, 2008Ki07) from tables calculated using the relativistic Dirac-Fock method and the frozen orbital approximation (2002Ba85, 2002Ra45). These tables cover the K, L1, L2, ... R2 shells, E1−E5 and M1−M5 multipolarity, Z = 10 to 126 atomic numbers, and E_γ transition energies from 1 keV above the shell binding energy up to 6000 keV.
Action: new replacement text to be prepared by Kibedi.

Data sources for recommended Angular Distribution and Correlation Coefficients were considered, and various problems were noted concerning the references.
Action: Balraj Singh and Tuli to incorporate most up-to-date references, and consider whether listed references remain appropriate.

Sources of data for penetration parameters and internal-pair formation coefficients were discussed, and agreed as already written in *Nuclear Data Sheets*.

E0 Electronic Factors – **Action**: Kibedi to prepare a suitable replacement paragraph on E0 Electronic Processes.

Consideration of the extremely brief description of Atomic Processes resulted in an **Action**: Kibedi to provide a comprehensive and up-to-date paragraph on atomic processes. Also noted that electron binding energies from Z = 1 to 95 can be found in 1979Se11. All other features of the Theory section were judged to be reasonably formulated, and do not require further clarification.

Spin and Parity assignments (Balraj Singh):
As above, the relevant text to be found within *Nuclear Data Sheets* was assessed and discussed in detail, under the guidance of Balraj Singh.

Ground States: “Spin can be determined by techniques such as atomic-beam resonance, paramagnetic resonance, electron-spin resonance and optical spectroscopy” – statement to be adopted as definitive.

Gamma Transitions:

a) Recommended that Items 3 and 4 be combined as a single statement; **Action**: Balraj Singh.
b) Some of the contents of the table upper limits for (Γ_γ / Γ_W) data created some debate and confusion – comprehensive entries for M1 character implies that this transition was the only type studied so thoroughly. This particular table was established in 1980 on the basis of empirical rules taken from existing experimental data – this database needs to be updated, and a new set of upper limits determined; **implied Action**.

Beta Transitions:
Log*ft* values were tabulated in 1998 (1998Si17), and overall remain valid. Delete unnecessary statements in items 8 and 11 ((log $f't < 7.4$) and (log $f't \geq 7.4$), respectively).

βγ Directional Correlation and βγ Polarization Correlation:
A significant comment made while discussing this set of propositions was that statements 14,

15, 16 and 17 are hardly ever used (if at all) as arguments in ENSDF evaluations. Balraj Singh believed these items should remain in the text, but that a specialist in βγ directional and polarization correlation should be asked to check/confirm their validity; **implied Action**.

Reactions:
Item 23 states that "Coulomb excitation determines J^{π} if the excitation probability agrees with the calculated values of Alder (1960Al23)" – workshop participants registered their concern that they are unsure as to how such an approach can be used to determine J^{π}; **implied Action**.
Item 28: all agreed that this high-spin reaction statement should be moved to the sub-section entitled High-spin states.

Regions of Strong Nuclear Deformation:
Much of this sub-section constitutes a series of descriptive paragraphs, rather than precise guidelines and rules for J^{π} assignments. Efforts should be made to formulate a more succinct sub-section based upon well-defined rules.

Possible new and re-drafted sub-sections:

a) High-spin states and reactions are mentioned at various places in the arguments and rules for J^{π} Assignments. Participants agreed that this material should be pulled together within the existing sub-section dedicated to High-spin states; **implied Action**.
b) Consideration should be given to the preparation and introduction of an appropriate sub-section dedicated to K-isomers (as a consequence of 2015Ko14); **implied Action**.
c) Alpha Decay: statement 38 is correct in that HF values are determined on the basis of even-even decay (HF = 1.0) to be applied to odd-even and odd-odd decay. Validity of this approach needs to be assessed further; **Action** – Verpelli to extract all relevant data through LiveChart as specified by Balraj Singh, followed by possible re-drafting of Alpha Decay sub-section.
d) Sub-section dedicated to Proton Decay was originally written by Sonzogni (NNDC); **Implied Action** on Tuli to ask Sonzogni if he wishes to modify his statement 40 and therefore provide a new version, or leave as written.

Tuli provided a series of brief reminders of the procedures to be adopted in the course of evaluating and assembling the input data to produce an ENSDF data set:

a) Adopted properties – must contain a Q-record; adopt values from 2012Wa38; place systematic uncertainties in comment record; XREF even if only one data set with gammas.
b) Ground state and isomeric levels – if known, decay modes and moments must be defined on continuation records; relevant comments in the comments record; half-life from keynumber is insufficient – include DSID; isomer is a level with $T_{1/2} \geq 1$ ns; take moments from latest Stone compilation (2014StZZ at the present time).
c) Data extraction includes quoting authors' assumptions, measured quantities, deviations, and checking for quoted older values and missed references.
d) Data presentation – order comments; E= is not required in DSID for a reaction; include J^{π} of target for transfer reactions; specify source of data; confirm accuracy of Adopted data set; do not combine different kinds of data sets; gammas ordered by increasing energy; delayed gammas given as IT decay; assess significant digits; consider implications of multiplets; uncertainty of 25 is no longer a rigid rule; provide A_2, A_4 and DCO ratios with definitions; BXL up for levels and down for gammas; do not justify data with the statement "from ENSDF" (which is effectively a meaningless statement). Unresolved discrepancies should be declared, and E_{EC} and E_{β} should only been quantified when they have been measured accurately. The ENSDF evaluator must take full responsibility for all data adopted from XUNDL files.
e) Systematics to be noted:

- log $T_{1/2}$(alpha) vs Log E(alpha) is linear;
- gross beta decay theory of Takahashi reliable to better than a factor of 3;
- certain pairs of configuration lead to isomeric transitions;
- HFs of alpha decay;
- ground state feeding from local systematics;
- macroscopic-microscopic theory of Möller, *et al.*, *Phys. Rev.* **C67** (2003) 055802;
- evaluators should maintain atomic mass systematics for their own regions of responsibility, while taking full account of the atomic mass evaluations of Audi, Wang, *et al.*, *Chin. Phys.* **C36** (2012) 1287-1602 and 1603-2014.

f) Adherence to specified style.

2.3. Various Problems Encountered in Mass Chain Reviews, M.J. Martin (Oak Ridge National Laboratory, USA)

Murray Martin's expertise extends over many years, and he has expended significant amounts of time reviewing mass chain evaluations for ENSDF and subsequent publication in *Nuclear Data Sheets*. Such intensive studies have revealed many common errors and problems experienced by nuclear structure and decay data evaluators as they are faced with anomalies, ill-defined published data and unforeseen procedural difficulties. A significant number of examples were displayed and discussed:

1) Weighted-averaging - handling of significant figures in an uncertainty.
   half-life measurement 1: τ = 1.2 *2* ps which represents $T_{1/2}$ = 0.83 *14* ps,
   half-life measurement 2: $T_{1/2}$ = 0.90 *14* ps.
   Weighted average of these two measurements is 0.865 *99* ps, or 0.86 *10* ps.

   However, the evaluator converted τ to $T_{1/2}$ and rounded off to give 0.8 *1* ps in order to maintain only one single significant figure for the uncertainty, which results in a weighted average of 0.83 *8* ps.
   Comment – by rounding down the $T_{1/2}$ calculated from τ, too much weight has been given to that value, and the uncertainty in the weighted average is too small.

2) Weeding out of unnecessary and superseded NSR keynumbers.
   (i) Data from the same group are reported in more than one publication/source (A, B and C). Source A is the earliest and contains all relevant material. Evaluator should make a clear statement: "From A. Some (or all) of the data are also reported in B and C". Demonstrates that there is no additional material in the later references, and informs the reader that the evaluator is fully aware of the two later sources.
   (ii) When reference C supersedes earlier reports A and B by the same group, state this close relationship as a comment on C, rather than place A and B within "Others" (latter category should only be reserved for independent work).

   ID record should not contain redundant entries. Thus, for example (i) above, only A should be included in the ID record, while only C should appear in example (ii).

3) Weighted-averaging.
   Importance of inter-relationships between quantities in different data sets: a decay scheme has been normalised on the basis of parent spin and parity of 3+, which was later changed to 1+. However, the original normalization was not changed, and the J^{π} assignments that relied on J^{π} of the parent were not modified.

   Consider γ_1-γ_2 cascade from the E_3 level from which the relative ordering has not been established, and for which the evaluator established a tentative intermediate E_1

level (based on AA). At a later date, the relative order was firmly established by BB and reversed to give a level at E_2. The evaluator should delete the E_1 level in the earlier data set, and add level E_2 with a comment of the form "AA proposes a level at E_1 based on the γ_1-γ_2 cascade from level E_3. The reverse order of the cascade has been established in BB to give a level at E_2 rather than E_1".

4) Coulomb excitation data set contained three keynumbers (AA, BB and CC) that were used with respect to BE2 and the first 2+ state.
   (i) BB and CC are from the same group, although the value from CC was quoted with a smaller uncertainty and was placed in "Others" with no explanation. CC was an earlier report of the work quoted by BB, and the evaluator had decided that the later value should be adopted – a comment to the effect resolved this issue, but emphasises the importance of explaining such choices.
   (ii) Value from BB was an absolute measurement, while that from AA was stated to be relative to BE2 = 0.160 from DD for a nuclide in another mass chain but with no uncertainty included. The situation proved to be rather complex, and uncovered a problem in the handling of data from DD in the other mass chain and in reference AA.

5) Obvious misprints in authors' work.
   Example: uncertainties in I_γ were all in the range of 12-15% except for one transition which was given to be 84 *1*. This uncertainty is clearly a misprint and should most probably have been *10* – authors' uncertainty should be replaced, and a comment made to this effect.

6) Error-propagation formulae based on a first-order Taylor series expansion are only valid for reasonably small fractional uncertainties.
   (i) When a quantity is squared, the fractional uncertainty in the product is twice the fractional uncertainty in the original value; thus, $(3.0\ \mathit{1})^2$ becomes 9.0 *6*. However, $(3.0\ 15)^2$ becomes 9 *9* (overlaps with zero), and $(3.0\ \mathit{20})^2$ becomes 9 *12* (overlaps non-physically with negative numbers). The uncertainty range correct to second-order Taylor series expansion is obtained simply by squaring the upper and lower bounds of the value; thus, $(3.0\ \mathit{20})^2$ becomes 9.0 with a value range of 1.0 to 25.0 to give 9.0 *+160-80*.
   (ii) The second-order terms in Taylor series expansions are complex for data division, such that fractional uncertainties greater than approximately 10% result in asymmetric values. When dealing with such quantities, the recommended procedure is to take the reciprocal of the upper and lower bounds of the value; thus, BE2 = 0.25 *5* $\rightarrow$ $[\mathrm{BE2}]^{-1}$ = 4.0 *+10-7*.

   This approach appears to be reasonable, particularly when handling uncertainties with unknown systematic to statistical component ratios.

7) Handling of discrepant gamma energies.
   Consider a particular E_γ flagged with five stars by GTOL that indicates a deviation from the expected value by more than 5σ. If most of the other γ transitions fit comfortably into the level scheme, Martin recommends that the offending transition should not be included in the least-squares fit. This exclusion process can be carried out by placing "?" in column 80 and running GTOL, and then removing "?" from the input file. Possible explanations include a mistake by the author, erroneous assignment of the γ transition to a particular level, or the existence of an unresolved/poorly resolved multiplet. If E_γ(in) is the discrepant value and E_γ(out) is the value given by GTOL when the γ transition is excluded from the run, Martin recommended a rounded-off E_γ(out) value be entered in the energy field with no uncertainty. A comment should also be made of the form "Rounded-off value from

the least-squares adjustment which gives $E_\gamma = E_\gamma$(out). Authors' value is a poor fit, and has not been included in the adjustment".

8) Rounding-off policies.
When should rounding-off begin with respect to uncertainties? An uncertainty of 0.175 would normally be rounded up to 0.18, and not down to 0.17, but there is no set network policy on the matter. Martin rounds up whenever the relevant digit in the uncertainty is 3 or higher: an uncertainty of 0.173 is rounded up to 0.18 (better to overstate than understate an uncertainty).
A common practice in digital analysis is to round up odd digits (i.e., 55 to "6") and not even digits (i.e., 25 to "2") to avoid biasing the answers either up or down. Again there is no network policy, but this is a standard practice elsewhere.

9) Branching in adopted gammas.
Consider a level with only two de-exciting γ transitions. The adopted branching is obtained by simply averaging the ratios from the individual sets of measurements, for which the stronger transition can be assigned a value of $I_\gamma = 100$ with or without an uncertainty. If an uncertainty is assigned to the 100 value, the fractional uncertainty must be subtracted in quadrature from the intensity if the weaker component. However, there is normally no reason to assign an uncertainty to the normalization transition since the important quantity is the ratio itself. Thus, consider three measurements of $I_\gamma(A)/I_\gamma(B)$, namely 0.326 *21*, 0.314 *14* and 0.318 *18* that give a weighted average of 0.318 *10* → $I_\gamma(A)$ = 31.8 *10* can be adopted, with $I_\gamma(B)$ = 100 (if the smallest uncertainty of $I_\gamma(B)$ among the three measurements is 2%, values of 31.8 *8* and 100 *2* could be defined, but the alternative approach is preferred).

10) Asymmetric ICC(exp).
If the multipolarity and δ originate from experimental ICC data, these experimental α value(s) should be entered in the CC field. However, asymmetric α(exp) data are problematic because asymmetric uncertainties cannot be accommodated. Under these circumstances, adopt a symmetrized value, and record the original asymmetric value in a comment; also add an equivalent statement identified with the MR field to declare that δ has been deduced from the experimental asymmetrical α value.

11) Averaging problems.
An average half-life of 484 *35* ms has been determined from two measured values of 478 *44* and 495 *60* ms from the same laboratory. Another half-life measurement of 485 *40* has been reported in a second reference, and combined with the earlier averaged value to give a new average of 484 *26* ms. Rather than adopt the uncertainty of this particular weighted average, the evaluator stated that they preferred the smallest measured uncertainty, and quoted an incorrect value of *35* ms taken from the first averaging exercise. The correct value should have been the smallest value of the three independent measurements, namely *40* ms.

Asymmetric averaging: there are no network guidelines as to how to handle asymmetric uncertainties when determining averages. Consider two half-life measurements of 0.087 *+28-21* and 0.10 *3* ps → adopting the upper uncertainty identified with the first value in the averaging process gives a weighted average of 0.093 *20* ps, whereas adopting the lower uncertainty results in a weighted average of 0.091 *17* ps, that can be combined to give an appropriate value of 0.092 *+21-16* ps. While differences between the upper and lower values are normally small (as in the above), quoting both the upper and lower values might be more useful if this difference is large. Balraj Singh, *et al.* and Kibedi have been involved in the development of codes to undertake weighted average calculations involving input with asymmetric uncertainties. **Implied Action**: A guideline procedure is required to address the averaging of asymmetric uncertainties under such conditions.

12) J^{π} arguments.
All arguments used to establish J^{π} for an adopted level should be traceable to the source data set. As a corollary to this approach, do not place justifications for the L or MULT assignment with the J^{π} argument – leave such details in the source data set.

Sometimes useful to give a J^{π} argument even when no J^{π} is assigned. For example, if a level is known to decay to a 2+ level, then J^{π} may lie in the range of 0 to 4. And perhaps best to use a flagged footnote for such an argument, which is more likely to attract the reader's attention than a comment.

13) Misprints, typing errors, and recalibrations.
Whenever a value is corrected by the evaluator, this corrected value should be placed in the relevant field, and the original value defined only in a comment – do not place the original value in the field, and rely on the comment to convey the corrected value to the reader.

14) Resolution of discrepancies.
Attempts should be made to resolve observed discrepancies between the contents of inter-related data sets.

15) Cf-252 half-life.
Twelve known measurements of the half-life of Cf-252 have been assembled and evaluated separately to give five differing recommendations: 1965Me02, 1969De23, 1973Mi05, 1974Sh15, 1974Sp02 (Spiegel), 1976Mo30, Alberts (1980) private communication, Spiegel (1980) private communication, 1982La25, 1984SmZV, 1985Ax02 and 1992Sh33. These studies demonstrate the subjective nature of the evaluation process, based on the perceived validity of the various measurement techniques and resulting data rejection.

Recommended values are listed as follows from five separate evaluations, followed by processing with the AVETOOLS code:
   a) weighted average of 2.6496 *18* y from all data except value of 1974Sp02 (withdrawn by author);
   b) weighted average of 2.6501 *14* y from all data except values of 1974Sp02 (withdrawn by author) and 1969De23 (ruled to be an outlier on the basis of Chauvenet's criterion);
   c) weighted average of 2.6470 *12* y from all data except values of 1974Sp02 (withdrawn by author) and Spiegel (1980), and 1969De23 and 1973Mi05 (both defined as outliers);
   d) weighted average of 2.6470 *26* y from all data except 1974Sp02 (withdrawn by author), and overall uncertainty of 0.1% applied to account for systematic as well as statistical uncertainties;
   e) weighted average of 2.6502 *26* or 2.650 *3* y from all data except 1969De23 (outlier), 1974Sh15 (superseded by 1992Sh33) and 1974Sp02 (withdrawn by author), and overall uncertainty of 0.1% assigned.

Balraj Singh stated that he does not accept the way the most commonly used DDEP-based averaging procedure handles the Chauvenet's criterion to identify outliers – does not take datum uncertainty into account. Weighting codes are available in which the uncertainties are considered when assessing data sets for possible outliers.

16) β energies and intensities.
Unless a β-endpoint energy is of good enough quality to be included in the mass

adjustment, such data should only be mentioned in comments. Required E_β are calculated automatically from the assigned Q-value and the level energies. If poorly measured endpoint energies are entered into the energy field for decay when the Q-value and daughter level energies are accurately known, ordering inconsistencies may arise between the endpoint energies in the table and the drawing of the decay scheme.

IB field values deduced from the I(γ+ce) imbalances should always be those determined by the evaluator. Note that the evaluator may have some different gamma MULT assignments from those of the authors, and the gamma intensities may be averages from several sources. Since the I_β values arise directly from I_γ and α data (or TI(γ+ce) data), all that is needed is a comment about $I(\beta^-)$ or $I(\beta^+ + \varepsilon)$ stating "From an intensity balance at each level". An exception would be when I_β for one or more branches were used to normalise the decay scheme intensities, and the intensities for these particular branches should be entered in the IB field.

2.4. Consistency in Spin and Parity Assignments, Balraj Singh (McMaster University, Hamilton, Canada)

Balraj Singh introduced and reminded workshop participants of a summary report on J^π and multipolarity assignments derived from heavy-ion compound nuclear experiments, as prepared by Singh and Waddington, and issued originally in June 2001. The multipolarity of γ transitions and relative spins and parities can be determined through the measurement of angular distributions, angular correlations and linear polarization of γ rays, and the study of internal conversion coefficients. Each approach was briefly described and reviewed:

1) **Angular distributions** of γ rays are denoted by W(θ), and constitute the measurement of the intensity as a function of angle θ with respect to the direction of the beam or nuclear spin axis. A_2 and A_4 coefficients depend on ΔJ, the mixing ratio (δ) and the degree of alignment (usually determined by measuring W(θ) for a number of known ΔJ = 2 transitions, although many authors adopt a value of σ/J = 0.3). Angular distribution measurements alone may be used to deduce ΔJ, but not Δπ. Typical values for A_2 and A_4, and their assignments are tabulated below:

ΔJ	**multipolarity**	**sign of A_2**	**sign of A_4**	**typical values**	
				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

2) Measurements of **angular correlations** (DCO, Directional Correlations of γ rays from Oriented states of nuclei) involve the determination of the coincidence intensities for two γ rays, one of known and the other of unknown multipolarity. These γ rays are detected at angles θ_1 and θ_2 with respect to the beam direction, and 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 measured at angle θ_1 and γ_U at angle θ_2. DCO ratios are defined as:

$$R = I(\theta_1\theta_2\gamma_K\gamma_U) / I(\theta_1\theta_2\gamma_U\gamma_K)$$

These ratios are insensitive to spin for high-spin states, but sensitive to relative spins and multipolarities. Values tabulated below are typical for an array with detectors at 37° and 79° for which an alignment of σ/J = 0.3 has been assumed:

ΔJ_γ^{gate}, multipolarity	$\Delta J\gamma$	multipolarity	typical R(DCO)
2, quadrupole	2	quadrupole	1.0
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	1.0
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	1.0
1, dipole	0	dipole	~ 1/0.56

3) **Linear polarization of γ rays** can be determined by means of a Compton polarimeter used to measure the relative intensities of radiation scattered in planes perpendicular and parallel to the reaction plane as defined by the beam direction and incident γ ray. If possible to differentiate between electric and magnetic radiations, the γ-ray polarization can be combined with correlation data to determine Δπ (Jin Soon Kim, *et al*., *Phys. Rev*. **C12** (1975) 499-506).

4) **Internal conversion coefficients or subshell ratios** can be determined from electron spectra or γ-ray intensity balances. Electron data give K-, L- …. internal conversion coefficients or subshell ratios, whereas intensity balance arguments generate total internal conversion coefficients.

Additional observations and advice included the following summary statements:

a) If $T_{1/2}$ for a level is known or a limit can be assumed, RUL may serve to eliminate the M2 option for ΔJ = 2 quadrupole transition (RUL, Recommended Upper Limits for Weisskopf estimates).
b) Spins of states populated in high-spin reactions increase with increasing excitation energy – such reactions tend to populate yrast or near yrast states.
c) Consider a well-deformed nucleus. When a regular sequence of ΔJ = 2 stretched quadrupole transitions is observed as a cascade with high spins, such a sequence may be assigned to a common band with E2 multipolarity for all the transitions in the cascade. A weaker argument holds for less deformed nuclei when a common structure of levels is connected by a regular sequence of ΔJ = 2 stretched transitions. Also, ΔJ = 1, 0 inter-band transitions with significant admixtures are considered to be M1 + E2 type, while pure dipole (δ(Q/D) = 0) transitions are often E1 (small deformation magnetic-rotational M1 bands are exceptions to this rule). [used to formulate rule 37 in *Nuclear Data Sheets* for spin and parity assignments]
d) Presence of strongly coupled bands allows assignment of relative spins and parities of band members.
e) When a regular sequence of ΔJ = 1 stretched dipole transitions is observed at high spins as a cascade in near-spherical nuclei, the sequence may be assigned to a common band with M1 polarity for all the transitions in the cascade. However, cascades of E1, ΔJ = 1 transitions occur in rare cases when nuclides exhibit alternating-parity bands or reflection asymmetry.
f) If there are no angular distribution/correlation data, a regular sequence of transitions in a cascade may be assigned to a common structure or band if (i) low-lying levels of this structure have well established spin and parity assignments; and (ii) there is sound evidence that the band has not changed internal structure as a consequence of band crossing or other perturbations.

g) Consider strongly coupled, deformation-aligned bands. Comparison of the experimentally deduced g_K, as derived from the δ(E2/M1) mixing ratio and assumed g_R and Q_0, with the value calculated on the basis of a proposed quasi-particle configuration may result in the assignment of parity to a band.
h) Comparison of experimental and calculated Routhians and particle assignments (from the cranked shell model) for suggested quasi-particle configurations may provide information about the parity of a rotational band.

There are known to be various errors and inconsistencies associated with the nomenclature for J^π and MULT as adopted in the data records of ENSDF by mass chain evaluators. While there are strong and weak rules that apply directly to J^π assignments as described within the *Nuclear Data Sheets* policy document, there is no such guidance for MULT which is seen to be implied within the existing J^π rules. Under these circumstances, Balraj Singh posed a series of questions identified with (i) whether the existing rules need to be revised, (ii) existing omission of rules for certain reactions, (iii) introduction of additional rules to cover new physics phenomena, (iv) benefits of uniform application of rules in ENSDF evaluations, and (v) standardization of wording for J^π and MULT arguments in Adopted data sets.

J^π and MULT arguments in Adopted and individual decay/reaction data sets:
J^π values in decay data sets, and reaction data sets with gammas, are simply taken from the associated Adopted Levels, Gammas data sets, whereas J^π values in all the other reaction data sets are obtained from the original source of the reaction data. There is no policy statement concerning δ and MULT in the reaction data sets. Suggested that J^π in the reaction data set be the same as in the published paper, and MULT assignments should be based on the existing rules; and J^π values in the Adopted data set should be listed in comments of the reaction data set if they differ.

J^π assignments for ground states and long-lived isomers from measured magnetic-dipole moments:
Until approximately 1998, agreement of measured magnetic moment with the theoretical Schmidt limits value for a certain configuration was a strong rule for J^π assignments. Although downgraded to a weak rule for almost 20 years (#11), some ENSDF evaluators still use this argument as a strong rule. There is a need to re-assess how to handle and treat large-scale shell model calculations in the current literature.

J^π for g.s. and long-lived isomers from systematic trends (NUBASE and others):
Evaluators have adopted different and, by definition, inconsistent approaches – quoted from NUBASE or other sources in data records; listed as tentative (i.e., placed in parentheses) in data records; only listed in comments. There is a need to agree on a common approach.

J^π assignments for isobaric analog states/resonances, and for parent states:
Although specified as weak rule #4 (see *Nuclear Data Sheets*), there are many instances when a strong argument can be cited (e.g., Dossat, *et al*., *Nucl. Phys*. **A792** (2007) 18-86, with 32% β^+ feeding by Fe-48 to the 3037-keV level of Mn-48). Very strong peaks have also been observed in particle-transfer studies that negate against such a weak rule. There are known inconsistencies that embrace arguments within the ENSDF-based data for two-particle transfer reactions, charge-exchange reactions, inelastic scattering studies, and NRF (γ,γ') experiments. Various aids include the assessment of nuclear structure within mirror nuclides (e.g., Doherty, *et al*., *Phys. Rev. Lett*. **108** (2012) 262502), and R-matrix analyses (Chen, *et al*., *Phys. Rev*. **C85** (2012) 015805).

New arguments and rules merit consideration as our understanding of the physics of the nucleus grows:

(n,γ) reactions and DICEBOX computer code (e.g., 2013Fi01);

B(M1)(↓) deduced from measured level lifetime, and compared with B(M1)(↑) from NRF measurements to deduce J^{π} = 1/2– (able to reject 3/2– (2013St05)) → Rb-87: first time that the spin of an excited nuclear state has been determined by measuring the reduced transition strength for both excitation and de-excitation.

We need to share and discuss evidence for potentially new assignment rules from newly emerging physics.

Consideration of further problems and arguments for J^{π} assignments:

a) Even-even nuclei: J^{π} = 2+ and MULT = E2 should be strong arguments for the first excited state populated in Coulomb excitation (only exception would appear to be 3– in Pb-208).
b) First 2+ in even-even nuclei: E2 gamma to 0+ argument is preferred to L(d,d′) = 2.
c) When no MULT or level lifetime is available, MULT has been assumed to be E1, M1 or E2; however, for high-energy γ rays, E3, M2, etc. should also be considered.
d) Log*ft* arguments: many evaluators adopted such arguments when decay schemes are obviously incomplete. Thus, for large Q-values, evaluators should consider the Pandemonium effect; authors define "apparent beta feedings" and "apparent log*ft* values" although this form of data should not be used to assign J^{π} values. Evaluators should ensure that TAGS spectra are available to give some indication of the beta feedings over the Q-value range – consider 2003Al25 in which 295 levels were reported up to 5.9 MeV, along with 1064 γ rays.
e) Presentation of data and J^{π} assignments appear in many different forms in ENSDF without sufficient consideration of J^{π} rules to be found in *Nuclear Data Sheets*.
f) Measurements with large arrays of detectors: good multi-fold γ-γ coincidence or particle γ-γ coincidence data, γ(θ), γ-γ(θ) DCO data, lifetime data, polarization and conversion data, and reliable model calculations of band structures.

J^{π} and MULT assignments for high-spin data:

Balraj Singh stated that experimenter emphasis seems to be most commonly placed on defining band structures, sequences and other such features, rather than the precise determination of energies, intensities, multipolarity, etc. When γ cascades are observed, they are most commonly considered to be a sequence of E2 or M1 + E2 transitions for which γ(θ), γ-γ(θ) DCO data would appear to support such a proposal rather than the ENSDF evaluator determine unique multipolarities independently. Significant confusion can also ensue in the resulting Jπ assignments by evaluators: all given without parentheses; all in parentheses; and some with and others without parentheses.

MULT assignments of E2, M1, M1 + E2 or E1 have been made without any supporting data. And contrary to this situation, DCO or angular distribution and asymmetry data have been documented, while only a general statement was made about MULT, and no assignments appear against the individual γ rays. MULT has been defined on the basis of ΔJ^{π} derived from band structure when no supporting data exist. Many ENSDF files follow the original authors' proposals and presentation, without any evidence of objective or subjective judgements and evaluation.

2.5. Decay Scheme Normalizations, E. McCutchan (NNDC, Brookhaven National Laboratory, USA)

Prior to discussing various anomalies and errors observed in ENSDF that involve the conversion of relative emission and transition probabilities into absolute values, McCutchan drew attention towards two highly relevant papers by Browne (1986Br21) and Tuli with respect to γ-ray intensity data (both papers can be found in *Procedures Manual for the Evaluated Nuclear Structure Data File*, October 1987, Editor: M.R. Bhat, BNL informal report BNL-NCS-40503, National Nuclear Data Center, Brookhaven National Laboratory, Upton, New York, USA). Further information of this type can also be found in the various proceedings of the IAEA-ICTP Workshop on Nuclear Structure and Decay Data:

Workshop	**Venue, Data**	**Report**
IAEA Workshop on Nuclear Structure and Decay Data	IAEA, 18-22 November 2002	INDC(NDS)-439
IAEA-ICTP Workshop on Nuclear Structure and Decay Data: Theory and Evaluation	ICTP, 17-28 November 2003	INDC(NDS)-452, Part 1 INDC(NDS)-452, Part 2
IAEA-ICTP Workshop on Nuclear Structure and Decay Data: Theory and Evaluation	ICTP, 4-15 April 2005	INDC(NDS)-0473, Addendum
IAEA-ICTP Workshop on Nuclear Structure and Decay Data: Theory and Evaluation	ICTP, 20 February-3 March 2006	INDC(NDS)-0496, Addendum
IAEA-ICTP Workshop on Nuclear Structure and Decay Data: Theory and Evaluation	ICTP, 28 April-9 May 2008	INDC(NDS)-0533
IAEA-ICTP Workshop on Nuclear Structure and Decay Data: Theory and Evaluation	ICTP, 11-15 October 2010	ICTP web site
IAEA-ICTP Workshop on Nuclear Structure and Decay Data: Theory and Evaluation	ICTP, 6-17 August 2012	ICTP web site
IAEA-ICTP Workshop on Nuclear Structure and Decay Data: Theory and Evaluation	ICTP, 24-28 March 2014	ICTP web site

The various relevant parameters are defined as follows:

NR – converts relative photon intensity to photons per 100 decays of a particular decay branch;

NT – converts relative transition intensity to transitions per 100 decays of particular decay branch;

BR – converts intensity per 100 decays through the particular decay branch to intensity per 100 decays of the parent;

NB – converts relative beta and EC intensities to intensities per 100 decays through this decay branch;

NP – converts per 100 delayed transition intensities to per 100 decays of the precursor,

and these parameters can all be placed on the single card image of the Normalization Record in the ENSDF data file. McCutchan judged the documentation to be good for the normalization of decay schemes, but felt equivalent material is lacking and needs to be assembled to explain and demonstrate the use of NR, BR, etc. Furthermore, the policy statement for particle transition intensities is particularly impenetrable.

Significant advances in spectral measurements have occurred over recent years, with the advent of various complex forms of 4π detector array and the ability to undertake comprehensive β-decay studies on an event-by-event basis (e.g., 2012Li02). Even under these circumstances, the reported nuclear data need to be assessed and reviewed with care, as demonstrated in the case of β^--decay of Fe-66 and population-depopulation of the 175- and 510-keV nuclear levels of Co-66.

ENSDF decay data for radionuclides that undergo both β^- and β^--n decay has also proved to be problematic: within the same data set, I_γ normalization was assigned a value of 0.284(10), along with a branching ratio for β^--n decay (Pn BR) of 0.628(25), to give an absolute intensity of 28.4(10)% per 100 decays for the main γ ray (tabulated relative intensity of 100%), while the footnote to this table furnished a value of 0.178(10) for the absolute intensity per 100 decays. The value of 0.178(10) comes from 0.284 x 0.628; however, if intensity is required per 100 decays of a particular decay branch the normalization (NR) is 0.284/0.628 = 0.425. The main problem arises in defining NP (multiplier for converting per 100 delayed-transition intensities to per 100 decays of precursor), as demonstrated in a radionuclide that undergoes β^-, β^-n, and β^-2n decay. Significant discussion ensued, including the rather startling statements that NP was incorrectly defined in the ENSDF manual, has created significant confusion and difficulty in delayed-particle evaluations, and would need to be corrected and fully clarified (**agreed Action**: Tuli, B. Singh, Basunia, McCutchan – prepare correct definition and procedure to adopt when applying NP to normalise delayed-transition intensities). Addressing the question "what is the policy for delayed-particles" and intensity data in particular, as posed by McCutchan, Nichols believed that such data in nuclear applications libraries need to be expressed absolutely in terms of the decay of the precursor (initial radionuclide in such a decay process, which is the grandparent (after β^- and β^-n decay) and great-grandparent (after β^- and β^-2n decay)), and not per 100 delayed-particle decays.

Similar observations were made when considering the measurement and evaluation of β-delayed proton emissions. Proton-rich nuclei in the mass region from 36 to 56 have been experimentally studied in a detailed and systematic manner by Dossat, *et al*. (2007Do17) – twenty-six εp-decaying radionuclides from Ca-36 to Zn-56. However, there is observed to be no consistent treatment of these decay data for each individual radionuclide when they have been evaluated for ENSDF. The decay-data entries for Fe-47 in ENSDF were considered: absolute proton-emission probabilities were specified in terms of NP = 1.0 and BR = 0.884, while the normalization factors for absolute γ-ray emission probabilities were NR = 1.0 and BR = 0.884. However, the absolute proton-decay emission probabilities of Fe-49 were identified with NP = 0.567 and BR = 0.567, and the absolute γ-ray emission probabilities were NR = 1.0 and BR = 0.567. The equivalent normalization factors adopted in ENSDF for the proton and γ-ray decay of Cr-45 are even more disconcerting: NP = BR = NR = 1. The resulting discussion led back to the problems identified with the erroneous definition and misunderstanding of the NP factor in ENSDF (see above). McCutchan also reminded workshop participants of the usefulness of suitably measured and quantified annihilation radiation in determining the normalization factor for the γ-ray emission probabilities.

Normalization of IT decay data is normally a relative straight forward process since the decay has to fully populate the ground state. Frequently, population and depopulation of particular levels may be used to derive NR by a number of different ways, and the most appropriate value can be subjectively selected. A separate issue involves, for example, ground state Hf-180 which is stable, but also possesses a significant 1141.5-keV nuclear level of Hf-180m that undergoes substantial IT along with a small β^- decay branch (half-life of 5.5 h); ENSDF policy is to quote a ground-state to ground-state Q-value for this β-decay mode, although both FMTCHK and Webtrend do not welcome such an energy assignment.

2.6. Useful New Computer Codes: Assumptions Made, and How to Use Them, T. Kibedi (Australian National University (ANU), Canberra, Australia)

Kibedi described the operational characteristics of the BrIcc code to calculate theoretical internal conversion and internal-pair formation coefficients (α) for assigned gamma transitions (2008Ki07), and BrIccMixing for the determination of multipole mixing ratios (δ) from measured conversion electron data:

$$\delta^2(\mathrm{E2/M1}) = \frac{I_\gamma(E2)}{I_\gamma(M1)}$$

$$\text{and } \alpha_K(\mathrm{M1 + E2}) = \frac{\alpha_K(M1) + \alpha_K(E2)\, x\, \delta^2}{1 + \delta^2}$$

for which transitions of (M1 + E2 + E0) type are a special case for which the above do not apply.

All BrIcc and BrIccMixing files should be placed in the same directory folder to be included in the specified operational path. The BrIccHome variable should point to this folder, and the "Set" command should be implemented to verify these settings. Calculations of the theoretical Dirac-Fock internal conversion coefficients are based upon the frozen orbital approximation, which continues to be recommended on the basis of a wide range of well-defined experimental studies. Mixing ratio input can be simply and quickly changed in order to study their impact on the ICC data. BrIcc has undergone regular correction, modification and improvement almost on an annual basis since March 2008 (latest version is dated 16 December 2014), and basic help and guidance can be obtained by requesting through "bricc?" and "briccmixing?".

(a). BrIcc:
Concern has been expressed over the potential for BrIcc to generate non-physically large uncertainties in recommended ICC values that overlap with zero, for example, 34(5)-keV E4 gamma transition in the IT decay of Po-211m to give α_{total} and uncertainty of $(3.9 \pm 7.7) \times 10^{+6}$ which compare with $(6.5 \pm 5.0) \times 10^{+6}$ in ENSDF. Kibedi presented a range of BrIcc values in the following manner:

35 + 5 keV = 40-keV γ ray $\rightarrow$ α_{total} of $1.53 \times 10^{+6}$,
34 keV 34-keV γ ray $\rightarrow$ α_{total} of $3.87 \times 10^{+6}$,
35 – 5 keV = 30-keV γ ray $\rightarrow$ α_{total} of $1.16 \times 10^{+7}$,

yet listed as $(3.9 \pm 7.7) \times 10^{+6}$. Under these circumstances, there is a need to assess and edit "Cards.new" before running "bricc 211Po_IT.ens merge":

$$\text{ICC} = [1.16\text{E}{+7} + 1.53\text{E}{+6}] / 2 = 6.57\text{E}{+6},$$
$$\Delta\text{ICC} = [1.16\text{E}{+7} - 1.53\text{E}{+6}] / 2 = 5.04\text{E}{+6},$$

to give α_{total} and uncertainty of $(6.6 \pm 5.0) \times 10^{+6}$.

BrIcc analysis of the 1132.8(6)-keV (M1 + E2) transition in the β^- decay of Ne-25 to Na-25 generates α_{total} of $(9.97 \pm 0.16) \times 10^{-6}$ which includes α_{IPF} of $(1.60 \pm 0.05) \times 10^{-6}$. A full set of ICC data along with individual uncertainties is produced by the BrIcc code, whereas α_{total} in earlier ENSDF files was effectively blank (no values entered when $\alpha_{total} < 10^{-4}$).

(b). BrIccMixing:
The BrIccMixing code can be used to determine the absolute multipole mixing ratio of a gamma transition (also available on MyEnsdf). Both BrIcc and GnuPlot need to be installed in the same directory folder. Measured data with symmetric uncertainties are inputted in free format in the form of (a) absolute internal conversion coefficients, (b) ratios of internal conversion coefficients or intensities, and (c) absolute mixing ratios. Example input data sets and output were shown for the 40.58-keV (M1 + E2) gamma transition of Mo-99(β^-)Tc-99, and 24.89-keV (M1 + E2) gamma transition of Co-58m.

Methods adopted to measure particular parameters leading to the determination of ICCs had been tabulated by Kibedi, and numerous α_K data for the 661.66-keV M4 gamma transition of Cs-137(β^-)Ba-137 were discussed from the point of view of confidence and relative reliability.

3. Evaluation Issues - ENSDF Evaluators

Presentations by the participants are available on IAEA-NDS web page https://www-nds.iaea.org/nsdd/Workshop2015_presentations.html. Links to these individual presentations are available in Appendix 3. A brief summary of the work scope and status associated with each presentation is outlined below, along with subsequent discussions. NSR key numbers are shown throughout the text for many of the references (https://www-nds.iaea.org/nsr/).

3.1. Superprecise Data, E. McCutchan (NNDC, Brookhaven National Laboratory, USA)

McCutchan introduced an example of anomalies experienced while assembling and assessing journal publications concerned with measurements of the γ-ray decay data of ^{83}Se. Two of the most significant studies provide substantial evidence for a reasonably well-defined decay scheme with approximaetly 20 β^- and 90 γ transitions (1973Fe08, 1974Kr27), and quote estimated uncertainties of $\Delta E_\gamma \sim 0.2$ keV (and worse) and $\Delta I_\gamma \sim 5\%$ (and worse). However, a recent equivalent experimental study quotes uncertainties as low as $\Delta E_\gamma = 0.01$ keV and $\Delta I_\gamma \sim 1\%$ (2015Kr02).

Processing the data sets through GTOL results in some extremely high χ^2 values for 22 of the γ rays. McCutchan also pointed out that both sets of data included reasonable descriptions of their energy and efficiency calibration procedures in good detail. Thus, the question was posed as to how, if at all, these two disparate sets of uncertainties can be reconciled?

- weighted-averages are inappropriate in such circumstances,
- adopt the most recent Krane data (2015Kr02)?
- arbitrarily increase the Krane uncertainties?
- merge in the Adopted values of ENSDF?

After some debate, the agreed suggestion was to retain the Krane numbers in the listed data. However, the uncertainties should subsequently be adjusted to more realistic values in order to be listed as such in the Adopted data set.

3.2. Discrepant Data: Subjectivity vs Statistical Treatment, F.G. Kondev (Argonne National Laboratory (ANL), USA)

Kondev defined the evaluation process as the means of providing the best value for a particular physics quantity that sometimes arises from a single measurement, but more often from a series of different measurements. When these different measurements are not discrepant, the weighted-mean of such a data set is a reasonable choice, providing that the uncertainties are effectively equivalent. Every effort should be made to resolve the ambiguities when the data set exhibits discrepancies.

^{233}Pa decay data are important in quantifying the transmutation cross sections of ^{237}Np through the ^{237}Np(n,γ) and ^{237}Np(n,f) reactions, and are of significant relevance in the Th/U fuel cycle and ^{232}Th(n,γ) cross section. While extensive efforts have been made to resolve the differences between the various measurements and evaluations of ^{233}Pa decay data, the decay scheme has remained discrepant. Significant questions need to be asked when evaluating such a radionuclide, and the nett result may be a strong request for further experimental measurements. Most experimental studies have involved mixed sources of ^{237}Np and ^{233}Pa in equilibrium for which the 29.4-keV (E1) γ-ray emission of the parent ^{237}Np overlaps with the highly-converted 28.6-keV (M1+E2) γ-ray emission of the daughter ^{233}Pa. Inconsistencies in the measured emission probability of the 28.6-keV γ ray were noted during the course of an IAEA-CRP on “Updated Decay Data Library for Actinides” (2005-2011), and mass-separated sources of ^{237}Np were successfully prepared at ANL for study in an underground laboratory equipped with a range of LEPS and Ge detectors. However, these particular measurements remained inconclusive, and therefore a further chemical separation was initiated to extract the ^{233}Pa from ^{237}Np for even higher-purity studies with 3-cm^3 LEPS and 25% Ge detectors. Under these circumstances, the 28.6-keV γ line of ^{233}Pa was clearly resolved to give a measured absolute P_γ of 0.076(3)%, and a weighted-mean of 0.075(3)% when combined with the equivalent values of 1973Va33 and 1990Ko41 (which were both obtained from ^{232}Th(n,γ)^{233}Th(β^-)^{233}Pa(β^-) sources that contained no interference from the 29.4-keV γ ray of ^{237}Np). More extensive studies of the β^- decay of ^{233}Pa by Kondev, *et al*. can be found in 2010Ko27 and 2011Ko32.

Kondev also provide his own additional guidelines to aid in ENSDF evaluations and the handling of discrepant data:

1. procedures adopted to measure nuclear data parameters should be assessed in detail – source preparation, type of detector(s), method adopted (direct or indirect), interferences (isomer and impurity emissions), etc.,
2. determine the best data subjectively before averaging them,
3. document in detail all subjective judgements – explain your final data selection,
4. stay connected with and involved in relevant measurement programmes.

Always be critical of the experimental measurements you are trying to assess, and make sure that you have assembled and considered all of the available data. And two final warnings: (a) a good evaluation is not simply a case of averaging numbers, and (b) sometimes the most accurately quoted value in the literature is not the best.

3.3. Nuclear Structure Information from Cross-Section Measurements, A. Negret (Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Romania)

Neutron inelastic cross-section measurements are performed at EC-JRC-IRMM by the GELINA 100-keV to 20-MeV neutron source and 200-m TOF technique. An array of 12 HPGe detectors with an overall efficiency of 100% are used to monitor the inelastic reactions and their cross sections by direct quantification of gamma-ray energies and intensities to give gamma production cross sections (excitation functions), total inelastic cross sections and nuclear level cross sections. Observed gamma rays can be assigned to the decay scheme on the basis of their depopulation and population of specific nuclear levels; gamma rays that populate the same level possess production cross sections of the same shape, and their ratios as a function of the neutron energy are branching ratios.

Measurements of the ^{56}Fe(n,n')^{56}Fe reaction have been performed, and nuclear level cross sections were determined for all low-lying levels except the 3076.2-keV level of ^{56}Fe (spin and parity of (3^-)). Both of the depopulating 991.5- and 2229-keV gamma emissions from this level are of particularly low absolute intensity, as shown in the spectral analysis data. Several levels in similar experimental studies of the ^{206}Pb(n,n')^{206}Pb reaction were shown to have more than one depopulating gamma-ray emission for which quantifiable relative intensities can be determined. As observed above, Negret noted that cross-section data can contain information of value to ENSDF evaluators, such as level and gamma transition sequences, and branching ratios Furthermore, gamma-ray emission energies could also be determined, but are regularly ignored as a consequence of the emphasis placed on the generation of precise reaction data. Efforts should be made to ensure that such data are properly recorded, and are therefore available to ENSDF mass-chain evaluators.

3.4. Renormalization of Absolute Alpha-particle Energies, D. Abriola (TANDAR Laboratory, Argentina)

Discrete alpha-particle energies adopted within ENSDF are predominantly based on the spectroscopic studies by means of a magnetic spectrometer at BIPM and subsequent assessments and adjustments undertaken by Rytz, *At. Data Nucl. Data Tables* **47** (1991) 205 (1991Ry01), as illustrated by the α-decay entry for ^{148}Gd (see also Akovali, Review of Alpha-Decay Data for Doubly-Even Nuclei, *Nucl. Data Sheets* **84** (1998) 1 (1998Ak04)) and adopted in mass-chain evaluations. Recommended energies were determined from known measurements and formulae developed and documented in 1961Ry02 and 1971Gr17. The renormalization analyses of Rytz have been repeated with updated 2015 fundamental constants. As represented by the α emission of ^{148}Gd, most resulting changes in the α-particle energies were found to be negligible ($\Delta \approx 1$ eV, e.g., 3182.680(24) → 3182.682 keV).

During the course of subsequent discussions, Kondev stated that measurements of the main α-group energies of ^{249}Cf at Argonne National Laboratory by means of α-particle spectroscopy were somewhat lower by ≈ 2 keV than the recommended Rytz data (1991Ry01); see Ahmad, *et al*., *Phys. Rev*. **C91** (2015) 044310. These studies were motivated by the recent Penning-trap measurements of Eibach, *et al*., *Phys. Rev*. **C89** (2014) 064318, in which a somewhat higher energy difference of 7.9(25) keV was observed for ^{249}Cf. Something would appear to be systematically wrong with the recommended α-particle energies within this particular decay chain as far as comparison with the spectral α-energy evaluations of Rytz are concerned.

3.5. Inter-relation of ENSDF with Excitation Functions and Isomeric Cross-section Ratios, C. Nesaraja (Oak Ridge National Laboratory, USA)

Nesaraja stressed the importance of accurate excitation functions and isomeric cross-section ratios for neutron-induced reactions from threshold to ~ 20 MeV in fission reactor operations, accelerator-driven systems and fusion research, medical radioisotope production, quantification of radiation damage, and security and safeguards. For example, Ni possesses large neutron-induced, proton-emission cross sections that lead to the production of ^{56,57,58,60}Co. STAPRE calculations of the contributions to the total, ground state and first excited state from the ^{59}Co(n,2n)^{58}Co^{m,g} reaction have been compared with experimental data, and show the following trends:

- calculated cross sections to produce the ground state are overestimated,
- calculated cross sections to produce the isomeric state are underestimated,
- calculated total cross sections are in good agreement with the experimental data.

Similar observations have been made for the ^{58}Fe(p,n)^{58}Co^{m,g} reaction, although the available experimental data for the total cross section are so limited as to prevent a comparison with calculation. This type of behaviour has also been observed to a lesser extent for the ^{58}Ni(n,p)^{58}Co^{m,g} reaction:

- calculated cross sections to produce both the ground and isomeric states are underestimated,
- calculated total cross sections are in good agreement with the experimental data.

The problem has been identified with the nuclear structure data adopted from ENSDF – adoption of a mixing ratio (δ) of –0.33 for the (M1 + E2) 28.30-keV gamma transition populating the 24.95-keV isomeric state of ^{58}Co^{m}. This value originates from Bertschat, *et al*. *Nucl. Phys*. **A151** (1970) 193 (1970Be33) as determined from the measured ratio of the precession amplitudes in ^{57}Fe(d,n)^{58}Co^{m,g} studies, for which two alternative δ values were estimated of –0.33(6) and –2.3(4) by the authors. Other studies could have aided in resolving this conflict (1995Bu26, 1999Av04, 2000Gu36, 2004So01), but were not used in the ENSDF evaluation. When the alternative value for δ of –2.3(4) was adopted in the STAPRE calculations, much better agreement was obtained between measurements and calculation for (a) all of the various ^{59}Co(n,2n)^{58}Co^{m,g} cross sections, (b) ^{58}Ni(n,p)^{58}Co^{m,g} cross section to the isomeric state, and (c) ^{58}Fe (p,n)^{58}Co^{m,g} cross sections to the ground and isomeric states.

A most noteworthy feature of the above studies to a mass-chain evaluator is that variations in excitation functions of this magnitude can occur as a consequence of adopting a particular nuclear structure parameter (δ mixing ratio in this particular case). Efforts to resolve and achieve good agreement are of significant value in resolving a situation in which two alternatives have been derived, and clearly point towards the correct value.

3.6. When Most Recent Data Differ from Earlier Data: Example of ^{187}Hg, M.S. Basunia (Lawrence Berkeley National Laboratory, USA)

Difficulties have been experienced over many years in identifying the individual J^{π} and half-lives of ground state and isomeric state pairs. However, significant advances in mass and spectroscopic measurements have furnished the ability to resolve such problems to the satisfaction of ENSDF evaluators. Consider ^{187}Hg ground and isomeric states, and a 1998 study by Rupnik, *et al.*, *Phys. Rev*. **C58** (1998) 771 (1998Ru04):

	1991Fi02 **NDS 62 (1991) 159**	**1998Ru04**	**2003 and 2012** **NUBASE**	**2009Ba12** **NDS 110 (2009) 999**
Ground state				
J^π	13/2 +	3/2 –	3/2 (–)	3/2 (–)
half-life	2.4 (3) min	2.4 min	1.9 (3) min	2.4 (3) min
Isomeric state				
J^π	3/2 –	13/2 +	13/2 +	13/2 (+)
half-life	1.9 (3) min	2.2 min	2.4 (3) min	1.9 (3) min

The decay rates of the 5035- and 4870-keV alpha groups were measured by Hansen, *et al*. (1970Ha18) to determine half-lives of 1.9(3) and 2.4(3) min, respectively. As shown in the table above, the identities of the ground and isomeric states of ^{187}Hg have proved to be problematic. Greater emphasis should be placed on the listings in NUBASE if atomic mass data determined by means of mass spectrometry on ions captured in Penning traps, which underlines the need to modify such data within 2009Ba12.

^{187}Pb and ^{187}Pb^{m} was another example to be considered, following on from the measurements of Andreyev, *et al.*, *Phys. Rev*. **C66** (2002) 014313 (2002An19). While J^π assignments have been proposed of $13/2^+$ for the ground state and $(3/2^-)$ for the isomeric state, these values have been swopped in NUBASE and an energy of 19(10) keV quantified for the isomeric state. ^{129}Pr/^{129}Pr^{m} and ^{191}Pb/^{191}Pb^{m} were also discussed on the basis of the quoted excitation energy of the isomeric state in NUBASE. Basunia stated that there were 28 such inversions of ground and isomer pairs when J^π data within ENSDF and NUBASE are compared, and noted that these important anomalies should be addressed by the appropriate mass-chain evaluator in order to conform with 2012 NUBASE. He requested the assembly of a table of such ground-isomer states that defines the particular difficulties in ENSDF, and the proposed J^π assignments in NUBASE and their arguments.

3.7. Problems and Questions, S. Singh Dhindsa (Maharishi Markandeshwar University, Mullana, India)

An IAEA-sponsored initiative is underway to improve the ENSDF analysis codes - see IAEA report INDC(NDS)-0665, September 2014; also available on:

https://www-nds.iaea.org/publications/indc/indc-nds-0665.pdf

As part of these studies, Sukhjeet Singh and Balraj Singh have developed the RadD program to deduce the r_0 radius parameter for odd-odd and odd-A nuclei, based on the adoption of compiled and recommended radii of even-even nuclei as input parameters (1998Ak04). This radius parameter is subsequently used in the calculation of alpha hindrance factors. Comments had already been sought from nuclear structure and decay data evaluators in order to improve the RadD program. Kondev had previously responded to this work, and stated that a Makefile should be provided for Unix-based computer systems. Singh stated that a Makefile had been prepared for RadD, although only applicable to this program with one or two output commands. Also, as requested, both data input files, ELE.in and the 1998Ak04 data file, have been incorporated into the data structure subroutine of the RadD source code.

Further thought has been given how best to enter user-friendly instructions to define the decaying parent and daughter radionuclides – agreement was reached that the user enters daughter information in free format and the program undertakes calculations in order to refer to and output elemental symbols, atomic numbers and mass numbers for both the parent and daughter(s). Interpolation methods were also briefly discussed to determine the acceptability of adopting an appropriate technique for the deduction of missing data.

The ALPHAD program reads ENSDF-format files for the calculation of alpha-decay data (theoretical half-lives, hindrance factors (HFs), and r_0 data). The existing policy for the calculation of HF by means of the spin-independent equations of 1947Pr17 was noted, along with the derivation of odd-A and odd-odd radius parameters from adjacent even-even nuclei (1998Ak04). However, radius parameters for odd-even, even-odd, odd-odd and even-even have been fully tabulated, and could be introduced into the existing program for automatic inspection and selection of the most appropriate values. The newly developed RadD subroutines and/or the newly produced r_0 tables will be incorporated in the ALPHAD code by Sukhjeet Singh in collaboration with Balraj Singh.

Compilations of magnetic rotational bands after 20 December 2006 were presented on a nuclide-by-nuclide basis ranging from ^{58}Fe to ^{204}At. There are a total of 28 new magnetic rotational bands in 21 new systems post-20 December 2006, along with 178 magnetic rotational bands in 76 nuclides prior to this date. Finally, a brief discussion ensued as to availability and validity of secondary references:

- NNDC should aim to provide mass-chain evaluators with copies of all secondary references directly, or from another source;
- evaluators should be able to submit copies of all secondary reports for a particular mass chain to the NNDC for archiving in order to assist future evaluators.

Tuli stated that one aspect of NSR custodianship at NNDC was the aim to accumulate electronic copies of all keynumbered publications, reports and private communications, and the addition of previously omitted references. Obviously, the proposed provision of all secondary references would be most welcome.

3.8. Evaluation of (n,γ) Data, R.B. Firestone (Lawrence Berkeley National Laboratory, USA)

Neutron-induced reaction data have regularly been evaluated to produce recommended (n,xγ) data sets of value in mass-chain evaluations. Gamma-ray intensities are normalized to generate P_γ data and reduced photon strengths, based on a set of five primary references:

1. Zs. Revay, G.L. Molnar, Standardisation of the prompt gamma activation analysis method, *Radiochim. Acta* **91** (2003) 361–369.
2. *Database of Prompt Gamma Rays from Slow Neutron Capture for Elemental Analysis*, IAEA report STI/PUB/1263, International Atomic Energy Agency, Vienna, 2007, ISBN 92–0–101306–X. http://www-pub.iaea.org/MTCD/publications/PDF/Pub1263_web.pdf
3. Zs. Revay, *et al.*, *Handbook of Prompt Gamma Activation Analysis,* ed. G.L. Molnar, Kluwer Academic Publishers, Dortrecht, 2004.
4. F. de Corte, A. Simonits, Recommended nuclear data for use in the k_0 standardization of neutron activation analysis, *At. Data Nucl. Data Tables* **85** (2003) 47–67.
5. S.F. Mughabghab, *Atlas of Neutron Resonances*, Elsevier, 2006.

Consider $P_\gamma = \sigma_\gamma/\sigma_0$ with σ_γ taken from Refs. 1-4, and σ_0 from either Ref. 5 or evaluation. Firestone described specific features of such an extensive set of (n_{th},γ) data. The comments should include a summary of previous σ_0 measurements compiled from EXFOR and NSR, along with recommended σ_0 value of Mughabghab. Various other features were discussed, including the assignment of multipolarities for the primary γ rays, and the effective spin and parity of the capture state placed in the J^π field (with discussion of the relative spin and parity contributions in the comments) and based on σ_γ from *Atlas of Neutron Resonances*.

The Rydberg-Ritz Combination Principle was proposed in 1908 to explain the relationship of the spectral lines for all atoms, and has been effectively used in reverse to find new (n,γ) levels. However, spectral complexities mitigate against the validity of this approach - levels found by means of energy sums should not be adopted unless their existence can be confirmed by other reaction measurements, and/or at least 3 to 4 interconnecting transitions can be found with reasonably well-matched energies. Level intensity balances play an important role in the search for large discrepancies that can be addressed by proposing interconnecting transitions, modified ICCs, or defining multipole γ-ray placements (as discussed in the comments, and reported in second-level records). Consideration of the statistical population/depopulation of (n,γ) levels can be made to provide a semi-quantitative assessment:

- (n,γ) populates all low-lying levels with comparable intensities to nearby levels of the same spin when $J^\pi = J^\pi \pm 1$; levels not populated do not exist, or possess significantly different spins;
- (n,γ) populates low-lying levels with significantly lower intensities when $J^\pi = J^\pi \pm 2, 3$;
- (n,γ) populates low-lying levels with very weak intensities, if at all, when $J^\pi = J^\pi \pm 4, 5$.

Observed trends in the feeding intensity can also be used to constrain and predict J^π values.

Firestone noted that adopted activation decay data can be extended to include (n,γ) production cross sections, and both individual γ-ray cross sections and normalization to the k_0 value[7] from Refs. 2 and 4. Activation γ-ray cross sections have been observed in EGAF measurements, and are reported by de Corte and Simonits. Furthermore, some precise 4πβγ measurements have been shown to be inaccurate.

Photon strengths observed in experimental studies of average resonance capture (ARC) have been used to distinguish M1 from E1 transitions, assuming s-wave capture (L.M. Bollinger, G.E. Thomas, *Phys. Rev*. **C2** (1970) 1951). Intensities can be corrected, and intensity normalization quantified from experiment or calculation. An extensive (n,n'γ) database is available in the Baghdad *Atlas of Gamma-ray Spectra from the Inelastic Scattering of Reactor Fast Neutrons* (1978De41), and this detailed process of discrete-emission analysis has been undertaken to derive comprehensive listings of nuclear levels – previously adopted levels not seen in these (n,n'γ) studies are judged to be highly questionable. Resonance capture (n,γ) data need to be evaluated in a similar manner to (n_{th},γ) data, normalized as undertaken for ARC, and reduced transition probabilities calculated, with resonance parameters taken from *Atlas of Neutron Resonances*. – any updating should be the responsibility of the reaction evaluation community.

Firestone concluded by describing the work to be conducted by the Bay Area Nuclear Group (BANG), and subsequent data sets to be provided to the IAEA-NDS for dissemination:

1. thermal P_γ, σ_γ, σ_0, S_n and activation data will be provided for future updates of the IAEA-EGAF database https://www-nds.iaea.org/pgaa/
2. beginning with the Baghdad Atlas, (n,n'γ) P_γ, σ_γ data will be provided to the IAEA-NDS as EGAFNN, a subset of EGAF;
3. ARC and resonance (n,γ) P_γ data will be evaluated and provided to the IAEA-NDS as EGAFRES, a subset of EGAF;
4. complete Adopted Levels, Gamma evaluations will be performed on (n,γ) and (n,n'γ) nuclides, and submitted for inclusion into ENSDF;
5. ENSDF evaluations will be modified to conform to the needs of the RIPL file in collaboration with the IAEA-NDS.

All attendees interested in collaborating in such work were encouraged by Firestone to join this (n,xγ) evaluation effort.

[7] k_0 factor comprises all relevant physical constants for gamma rays emitted by a radionuclide which is used for quantification in Neutron Activation Analysis.

3.9. Observation of Technical Issues, and the EVP Editor, E. McCutchan (NNDC, Brookhaven National Laboratory, USA)
McCutchan shared some of her experiences in reviewing mass chain evaluations for ENSDF, based partially on her developing understanding of "Guidelines for Evaluators" by Murray Martin. She provided the following examples:

1. incorrect spin and parity assignments and missing flags involved in the grouping of level bands;
2. erroneous keynumbers identified with mis-typing, and subsequent detected by visual scanning of reference titles;
3. inconsistent normalization factors within a specific set of recommended decay scheme data (found particularly in footnotes to tables);
4. unassigned and ill-defined footnotes to tables.

The EVP Editor developed by Sonzogni (NNDC) possesses many useful checking features that can greatly assist evaluators and reviewers in their detection and correction of errors in the data compiled for ENSDF.

The "Check for missing Level/Gammas" option scans all levels and gammas in the individual datasets, and confirms they have a correspondence in the Adopted Levels and Gammas based on XREF. A list of levels and gammas which are missing in the Adopted dataset is generated, and Levels with incorrect XREFs are also indicated. The "Adopted Summary" feature generates a GUI where, for each level, information in the Adopted and individual datasets is summarized on a level-by-level basis. All relevant information is included: level energy, $T_{1/2}$, J^{π} for levels and gamma-ray energy, intensity (converted into branching ratios), multipolarity and mixing ratio for gammas. GUI is interactive and allows the user to select the data they wish to include in the Adopted values and calculate weighted averages of the selected values.

3.10. Problems Faced by New Evaluators, S. Erturk (Niğde University, Turkey)
Erturk noted that his concerns about updating the General Guidelines for ENSDF evaluations had been most significantly addressed by the recent work of Murray Martin (as described in Section 2.1, above). Problems had been experienced in the installation and running of various ENSDF software packages, and there was a requirement for more user-friendly versions to work on OS, Windows, Linux and Macs – Tuli pointed out that the necessary software was available to operate directly through the NNDC and IAEA-NDS Web sites (e.g., MyEnsdf) in order to circumvent localised operational difficulties. An acceptable form of standardization of the various processing programs would also be extremely beneficial – thus, uncertainty calculations should be undertaken by evaluators using the same agreed code, and standard language should be used throughout all ENSDF files. References cited in ENSDF should be readily accessible by the evaluators through an appropriate permissible account - other routes involving the Web can be cumbersome and time consuming.

The existing ENSDF mentoring scheme needs to be re-defined, with clear deadlines for each step within the process and agreed essential visits between both parties. NSDD workshops were viewed as extremely important in the understanding and testing of all the software packages, and should be extended further to ensure overall success in attracting and training mass-chain evaluators worldwide. Erturk queried whether the IAEA would be able to influence or provide the financial support for new evaluators. Both Dimitriou and Nichols stated that the IAEA-NDS should only be viewed as a temporary source of rather modest funding at a maximum of up to 4,000 Euro per annum, and is best described as a form of starter seed-funding while the evaluator and his/her institute pursue a more stable form of funding via either national or geographical-area support.

4. Workshop Content - Overall Impressions

Highly-specialized nuclear physics expertise is required for ENSDF mass chain evaluations of the desired quality and completeness. Eleven evaluators who had become involved in such work over the previous approximately ten years came together with other specific specialists to create a suitable workshop environment for constructive debate. All participants focused their attention initially on clarifying numerous aspects of the *Guidelines for Evaluators*, as re-drafted by Murray Martin (Oak Ridge National Laboratory, USA). Other facets of the work were assessed and discussed, including arguments for spin-parity assignments, resolution of decay scheme inconsistencies, and on-going developments in relevant computer codes to assist in the analysis and evaluation of nuclear structure and decay data. These presentations intermingled with open discussion were followed by wide-ranging debates that focused on difficulties and other issues experienced by participants.

All attendees were given the opportunity to discuss relevant topics and problems of their choice that may have arisen during the course of their own evaluation efforts. Challenging problem areas were discussed, and possible solutions to address such anomalies and difficulties were simultaneously aired and assessed on the basis of "best practices" to be found in the existing ENSDF manual and draft guidelines as well as other suggestions. Possible topics for debate were submitted prior to the meeting to ensure the existence of a reasonable ordered agenda to follow on from detailed presentations of the re-drafted *Guidelines for Evaluators* and the *Nuclear Data Sheets General Policies* for ENSDF. Under such circumstances, active and constructive verbal feedback is essential for the success of this type of workshop.

Discussions with the relatively newly appointed mass chain evaluators indicated that all had benefitted immensely from the methodical reading and in-depth discussions of the contents of the re-drafted guidelines, along with the recommended evaluation policies, procedures and rules. Problems experienced over the years by nuclear structure and decay data evaluators were also presented and discussed – participants at such future specialized workshops need to understand the nature of what is required: any individual lessons learned can and should be constructively and fully shared with other mass chain evaluators in such an ideal forum.

A majority of the participants believed that this form of specialized NSDD workshop would benefit from the inclusion of the following forms of focused session:

i) dedicated hands-on exercises to demonstrate 'best practices',
ii) treatment of exceptional cases,
iii) how to run and use the various analysis and utility codes.

Such exercises, presentations and discussions would be particularly instructive and effective towards improving and refreshing the skills of participating evaluators. This practical approach to refresher training should be considered in any future form of this workshop.

5. Concluding Remarks

The contents of this report constitute a summary of the presentations and discussions that ensued during the course of a three-day specialised workshop on Nuclear Structure and Decay Data Evaluations, organised and held at the headquarters of the International Atomic Energy Agency in Vienna, Austria, from 27 to 29 April 2015. This workshop covered a wide range of topics and issues that need to be addressed when evaluating and maintaining the Evaluated Nuclear Structure Data File (ENSDF). A significant aim was to improve evaluators' abilities to identify and understand the most appropriate evaluation processes to adopt in the formulation of individual ENSDF data sets.

The detailed consideration of a revised version of *Guidelines for Evaluators* is of particular note, which will appear in final form before the end of 2015 on the web sites of the IAEA Nuclear Data Section and NNDC:

https://www-nds.iaea.org/nsdd/

http://www.nndc.bnl.gov/ – Structure and Decay.

while *Evaluated Nuclear Structure Data File: A Manual for Preparation of Data Sets*, BNL-NCS-51655-01, can be viewed on:

http://www.nndc.bnl.gov/nndcscr/documents/ensdf/ensdf-manual.pdf

Existing policies, procedures and codes were also considered, and round-table discussions included the debate and resolution of specific difficulties experienced by ENSDF evaluators. Both the quality of nuclear data evaluations and the consistency of the recommended ENSDF data files are highly dependent on improving and maintaining the knowledge and skills base of the evaluators and mentors through sharing processes which occurred in this dedicated workshop.

ACTIONS: agreed and implied

Location in text	Action	
Sub-section 2.2	Prepare replacement text on Internal Conversion Coefficients – *Nuclear Data Sheets*, Theory.	Kibedi
Sub-section 2.2	Incorporate most up-to-date references for Angular Distribution and Correlation Coefficients, and consider whether listed references remain appropriate – *Nuclear Data Sheets*, Theory.	Tuli, Balraj Singh
Sub-section 2.2	Prepare replacement text on E0 Electronic Factors – *Nuclear Data Sheets*, Theory.	Kibedi
Sub-section 2.2	Prepare a replacement text on Atomic Processes – *Nuclear Data Sheets*, Theory.	Kibedi
Sub-section 2.2	Re-draft statements #3 and #4 to combine as a single item – *Nuclear Data Sheets*, J^{π} Assignments, Gamma Transitions.	Balraj Singh
Sub-section 2.2	Undertake literature search to check and update the table of upper limits of (Γ_{γ} / Γ_{W}) values – *Nuclear Data Sheets*, J^{π} Assignments, Gamma Transitions.	Unassigned
Sub-section 2.2	Ask specialist in βγ directional and βγ polarization correlations to check the validity of statements #14, #15, #16, #17 – *Nuclear Data Sheets*, J^{π} Assignments, βγ Directional Correlation and βγ Polarization Correlation.	Unassigned
Sub-section 2.2	Demonstrate how Alder data (1960Al23) can be used to determine J^{π} – *Nuclear Data Sheets*, J^{π} Assignments, Reactions (statement #23).	Kondev
Sub-section 2.2	Bring together rules/arguments identified with high-spin states/reactions within the existing sub-section – *Nuclear Data Sheets*, J^{π} Assignments, High-spin states.	Balraj Singh, Tuli
Sub-section 2.2	Consider preparation of appropriate sub-section within J^{π} Assignments dedicated to K-isomers – *Nuclear Data Sheets*.	Kondev, Kibedi
Sub-section 2.2	Extract all relevant HF data by means of LiveChart codes; and assess HF data and consider whether re-draft of Alpha decay sub-section is required - *Nuclear Data Sheets*, J^{π} Assignments, Alpha Decay (statement #38, etc.).	Verpelli and Balraj Singh
Sub-section 2.2	Ask Sonzogni if he wishes to modify original statement 40 for proton decay, or leave as written - *Nuclear Data Sheets*, J^{π} Assignments, Proton Decay (statement #40).	Tuli and Sonzogni
Sub-section 2.3	*Guidelines to Evaluators*: procedure required to address the averaging of asymmetric uncertainties.	Unassigned
Sub-section 2.5	Prepare correct definition and procedure to adopt when applying NP factor to normalise delayed-transition intensities (*Evaluated Nuclear Structure Data File: A Manual for the Preparation of Data Sets*).	Tuli, B. Singh, Basunia, McCutchan
All encompassing actions:		
Change/correct *Guidelines to Evaluators* – for subsequent issue.		Martin
Update/correct General Policies and J^{π} Assignments in *Nuclear Data Sheets*.		Tuli

Annex 1

IAEA

IAEA Specialized Workshop on Nuclear Structure and Decay Data Evaluations

IAEA Headquarters, Vienna, Austria
27-29 April 2015
Meeting Room C0343

Adopted Agenda

1a. Monday, April 27, 2015: 9.00 – 12.00, including 20 min break

- M. Martin (ORNL) – 180 min: "Guidelines for Evaluators"

1b. Monday, April 27, 2015: 13.30– 18.00, including 30 min break

- M. Martin (ORNL) – 60 min: "Guidelines for Evaluators"
- J. Tuli (BNL) – 180 min: "Nuclear Data Sheets General Policies"

2a. Tuesday, April 28, 2015: 9.00 – 12.00, including 20 min break

- M. Martin (ORNL) – 180 min: "Technical issues observed in recent evaluations"

2b. Tuesday, April 28, 2015: 13.30 – 18.00, including 30 min break

- B. Singh (McMaster U) – 90 min: "Consistency in spin and parity assignments"
- E. McCutchan (BNL) – 90 min: "Decay schemes normalization"
- T. Kibedi (ANU) – 60 min: "Some useful new computer codes: assumptions made and how to use them" (e.g. BrICCmixing)

3a. Wednesday, April 29, 2015: 9.00 – 12.00 - examples presented by the participants, including 30 min break

- E. McCutchan (BNL) – 30 min: "How to deal with super-precise data and data without uncertainties"?
- F.G. Kondev (ANL) – 30 min: "How to deal with discrepant data: subjectivity vs statistical treatment?"
- A. Negret (NIPNE) – 30 min: "Nuclear structure information from cross section measurements"
- D. Abriola (TANDAR) – 15 min: "Comment on the renormalization of absolute alpha-particle energies"
- C. Nesaraja (ORNL) – 30 min: "Inter-relation of ENSDF work with excitation functions and isomeric cross section ratios"
- S. Basunia (LBNL) – 30 min: "When latest data differ from earlier ones: An example of ^{187}Hg"

3b. Wednesday, April 29, 2015: 13.30 – 18.00 - examples presented by the participants, including 30 min break

- E. McCutchan (BNL) – 30 min: “What to look for when running ensdf analysis codes, including EVP”?
- S.S. Dhindsa (MMU) – 30 min: “ General problems of evaluators and some new questions
- R.B. Firestone (LBNL) – 30 min: “Evaluation of (n,γ) data”
- S. Erturk (NU) – 15 min: "Some problems for new Evaluators"
- Discussion and Concluding Remarks

IAEA

Specialized Workshop on Nuclear Structure and Decay Data Evaluations

27 – 29 April 2015
International Atomic Energy Agency,
Vienna, Austria

List of participants

ARGENTINA

Daniel Hugo ABRIOLA
Laboratory Tandar
Comision Nacional de Energia Atomica
Av. General Paz 1499
1650 San Martin
Provincia De Buenos Aires
Tel. + 54 11 6772 7007
e-mail: abriola@tandar.cnea.gov.ar

AUSTRALIA

Tibor KIBEDI
Department of Nuclear Physics
Australian National University
Canberra, ACT 0200
Tel. + 61 2-6125-2093
e-mail: Tibor.Kibedi@anu.edu.au

BULGARIA

Stefan LALKOVSKI
Faculty of Physics
University of Sofia
D. Tsankov Str. 10
1164 Sofia
Tel. + 359 2 6256 834
E-mail: stl@phys.uni-sofia.bg

CANADA

Balraj SINGH
Department of Physics and Astronomy,
McMaster University
1280 Main Street West
Hamilton, Ontario L8S 4M1
Tel. + 1 905 525 9140 23345
e-mail: ndgroup@mcmaster.ca

HUNGARY

Janos TIMAR
Institute for Nuclear Research
Hungarian Academy of Sciences
Bem ter 18/c, PO Box 51
4001 Debrecen
Tel. + 3652 509 200
e-mail: timar@namafia.atomki.hu
timar@atomki.mta.hu

INDIA

Sukhjeet Singh DHINDSA
Department of Physics
Maharishi Markandeshwar University,
Mullana, Ambala-Haryana
133 207
Tel. + 91 08059930767
e-mail: sukhjeet.dhindsa@gmail.com

ROMANIA
Alexandru NEGRET
"Horia Hulubei" Nat. Inst. of Physics and Nuclear Engineering (IFIN-HH)
PO Box MG-6
077125 Bucharest-Magurele
Tel. + 40 724 195 397
e-mail: negret@ifin.nipne.ro
alnegret@tandem.nipne.ro

TURKEY
Sefa ERTURK
Nigde University
Science Faculty
Department of Physics
51200 Nigde
Tel. + 90388 2254223
e-mail: sefaerturk@gmail.com
sefa@nigde.edu.tr

UNITED KINGDOM
Alan L. NICHOLS
38 Mattock Way
Abingdon, OX14 2PQ
Tel.+ 44 1235524077
E-mail: alanl.nichols@btinternet.com

UNITED STATES OF AMERICA
Aaron HURST
Lawrence Berkeley National Laboratory
1 Cyclotron Road, Berkeley
CA 94720
Tel. + 1 510 486 5718
e-mail: amhurst@lbl.gov

Caroline NESARAJA
Oak Ridge National Laboratory
PO Box 2008
Oak Ridge, TN 37831
Tel. +1 865 576 7038
E-mail: nesarajacd@ornl.gov

UNITED STATES OF AMERICA
Elizabeth RICARD-McCUTCHAN
National Nuclear Data Center,
Brookhaven National Laboratory
PO Box 5000
Upton, NY 11973-5000
Tel. + 631 344 5096
e-mail: mccutchan@bnl.gov

Murray J. MARTIN
Oak Ridge National Laboratory
PO Box 2008
Oak Ridge, TN 37831
Tel. + 1 865 4822969
e-mail: martinmj@bellsouth.net

Richard B. FIRESTONE
Lawrence Berkeley National Laboratory
University of California, Berkeley
CA 94720
Tel. + 1 510 486 7646
e-mail: rbf@lbl.gov

Shamsuzzoha BASUNIA
Lawrence Berkeley National Laboratory
1 Cyclotron Road, Berkeley
CA 94720
Tel. + 1 510 486 7648
e-mail: sbasunia@lbl.gov

Filip G. KONDEV
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439
Tel. + 1 630 252 4484
e-mail: kondev@anl.gov

UNITED STATES OF AMERICA
Jagdish TULI
National Nuclear Data Center
Brookhaven National Laboratory
PO Box 5000
Upton, New York 11973-5000
Tel. + 1 631 344 5080
e-mail: tuli@bnl.gov

IAEA
Paraskevi DIMITRIOU
IAEA Nuclear Data Section
Vienna International Centre
PO Box 100
1400 Vienna
Tel. + 43 1 2600 21708
e-mail: P.Dimitriou@iaea.org

JORDAN
Khalifeh Abu Saleem
Commissioner for Nuclear Research
Jordan Atomic Energy Commission
PO Box: 70 Amman (11934)
Tel. +962 652 30978 Ext.: 107
e-mail:
Khalifeh.AbuSaleem@JAEC.GOV.JO

Marco VERPELLI
IAEA Nuclear Data Section
Vienna International Centre
PO Box 100
1400 Vienna
Tel. + 43 1 2600 21723
e-mail: M.Verpelli@iaea.org

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Specialized Workshop on Nuclear Structure and Decay Data Evaluations

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Annex 4

Group Photo

Nuclear Data Section
International Atomic Energy Agency
P.O. Box 100
A-1400 Vienna
Austria

e-mail: *NDS.Contact-Point@iaea.org*
fax: (43-1) 26007
telephone: (43-1) 2600-21725
Web: http://www-nds.iaea.org