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# INDC International Nuclear Data Committee

## IMPROVED DECAY DATA FOR MONITORING APPLICATIONS

**Summary Report of the Technical Meeting**
**24 - 26 March 2021**
**(Virtual Event)**

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Vienna, Austria

July 2021

**IAEA Nuclear Data Section**
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## (Virtual Event)

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National Superconducting Cyclotron Laboratory
Michigan State University
East Lansing, MI, USA

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## ABSTRACT

A Technical Meeting was held to review the progress of the IAEA project on Decay Data for Monitoring Applications. Participants reported on the status of the evaluations of the 27 priority radionuclides and discussed technical aspects of the evaluation process. The evaluation guidelines were revised and the evaluators' work program was updated to ensure the timely delivery of the evaluated decay data library. Summaries of the reports and technical discussions are given in the report.

July 2021

## Contents

# 1. INTRODUCTION

The IAEA is coordinating an international effort to update the decay data for selected fission products that are relevant to environmental monitoring of air and soil samples for traces of nuclear fission events (explosive and non-explosive). The first meeting of the project was held on 6-8 May 2019, at the IAEA Headquarters, and laid the groundwork for the project. Participants of the project included nuclear experts from five member states (MS): Tibor Kibédi (Australia), Balraj Singh (Canada), Monica Galan (Spain), Alan Nichols (UK), Jun Chen (USA), Filip Kondev (USA), Jagdish Tuli (USA), and IAEA staff members Paraskevi (Vivian) Dimitriou (Scientific Secretary of the meeting), and Marco Verpelli. During the course of the project, one of the nuclear data experts withdrew (Monica Galan) and two new participants from Romania, Alexandru Negret and Sorin Pascu, joined the evaluation effort.
Filip Kondev (USA) agreed to act as technical coordinator of the project, while Vivian Dimitriou (IAEA) was charged with the overall management of the project on behalf of the IAEA.

Representatives from the Comprehensive Nuclear Test-Ban Treaty Organisation (CTBTO), Boxue Liu, Romano Plenteda, Robert Werzi, as potential user of these data, attended the first meeting, and presented an overview of their nuclear data needs for radionuclide monitoring. High-quality evaluated decay data are required for the analysis of daily accumulated spectra, as well as for R&D work and performing high-quality Monte-Carlo simulations for identification and quantification of radionuclides. Recommended nuclear and atomic radiation for long-lived radionuclides and selected noble gas Xe isotopes are among their nuclear data needs.

Based on the discussions held at the first meeting, a priority list of 27 radionuclides was created. Evaluation work will cover all the decay properties associated with the $\beta^-$, ec/$\beta^+$ decay and internal gamma transitions of these 27 radionuclides. In addition, atomic radiation data will be derived using the BrIccEmis code developed by T. Kibédi, while β spectra, *logf*t values and average β-decay energies will be calculated using the BetaShape code developed by X. Mougeot at CEA-LHNB. An internal review process to be performed by project participants was also established. The library will be produced in ENSDF format, and will be hosted and disseminated by the IAEANuclear Data Section (NDS). All resulting data will be submitted for publication in a peer-reviewed journal.

The evaluation work and reviews have been discussed at five consecutive meetings: 6-8 May 2019; 12 May 2020; 25-27 August 2020; 16 November 2020; 17 December 2020 (all held virtually due to restrictions in connection with the Covid-19 pandemic). The Minutes of these meetings are attached to this document in Annexes I to V. Annex VI sets out the updated Guidelines for evaluators as formulated by the participants of this project.

The second IAEA (and $6^{th}$ in total) meeting of the project was held virtually, from 24 to 26 March 2021. All 10 participants of the project attended, presented their results and discussed technical issues pertaining to their evaluations: Jun Chen (USA), Tibor Kibédi (Australia), Filip Kondev (USA), Balraj Singh (Canada), Jagdish Tuli (USA), Alan Nichols (UK), Alexandru Negret (Romania) and Sorin Pascu (Romania), as well as IAEA staff member Vivian Dimitriou and Marco Verpelli. Roberto Capote (Deputy Head, Nuclear Data Section) welcomed participants and wished them a productive meeting. Filip Kondev was elected chairperson of the meeting and Jun

Chen rapporteur. The meeting began with brief reports by all participants and continued with technical discussions. Summaries of the reports and technical discussions are given in Section 2 and Section 3, respectively. The meeting agenda and list of participants are provided in Appendices 1 and 2, respectively.

# 2. REPORT SUMMARIES

## 2.1. Jun Chen (MSU):

i) The evaluations of all 3 assigned radionuclides $^{115g}$Cd, $^{115m}$Cd, $^{126}$Sb have been completed and submitted for review; review comments on $^{115g}$Cd have been received, and the revised evaluation will be sent back to the reviewer soon.

ii) Reviews of $^{95}$Zr and $^{141}$Ce have been completed and sent to the evaluators.

iii) Remaining work: expecting review comments on $^{115m}$Cd, $^{126}$Sb; complete review of $^{139}$Ce [Sec. Note: evaluated data file submitted after the meeting.]

## 2.2. Paraskevi (Vivian) Dimitriou (IAEA):

i) Evaluation of $^{139}$Ce was revisited: $T_{1/2}$ was re-evaluated (references of published values were sorted, more information on some measurements was also found (BIPM-04/77); electron capture fraction $P_K$ and fluorescence yield $\omega_K$ were re-assessed based on recent publications.

ii) Comments were provided by Kondev on the final evaluation (after review) of $^{106}$Ru.

iii) Evaluation of $^{106}$Rh: this radionuclide has been added to the priority list - decays more rapidly than parent $^{106}$Ru, and has a complex IT-decay scheme in contrast to its parent which does not emit any gammas (see also final item in discussion section). Singh offered to work on this evaluation together with Dimitriou.

iv) Remaining work: evaluation of $^{132}$Te, $^{133g,m}$Xe; joint evaluation of $^{106}$Rh; review of $^{126}$Sb [Sec. Note: review of $^{95}$Nb was submitted on 11 May 2021, after the meeting].

## 2.3. Tibor Kibédi (ANU):

i) Evaluation of $^{137}$Cs $T_{1/2}$: 11 measured values were selected for assessment out of a total of 72 measurements. Kibédi finally selected 5 values for averaging based on the following criteria: well-documented measurements, with appropriate uncertainties. An inter-comparison of the selection of $T_{1/2}$ and averaged value obtained by Kibédi, Singh and from DDEP was presented; Singh suggested the questionable (most precise) value from 1990Ma15 should not be considered since the systematic uncertainty might not have been taken into account (not discussed in the paper). He recommended increasing the uncertainty by a factor of 2 to 3 if the measurement was to be considered and agreed to send his most recent presentation of his half-life evaluation to Kibédi.

ii) Kibédi agreed to document in the comments section of the ENSDF file the arguments for rejecting several of the half-life measurements.

iii) Singh suggested to use “day” instead of “year” as half-life unit to maintain precision.

iv) The inter-comparison of Kibédi’s $T_{1/2}$ evaluation and a recent new DDEP re-evaluation was a useful exercise – however, participants of this project should not consider it a requirement that their new evaluations agreed with either the DDEP or ENSDF evaluations. Singh expressed an opinion that ENSDF and DDEP evaluators should collaborate on the evaluations of nuclides of common interest, and arrive at a consensus on the recommended data for important decay properties such as the half-lives to avoid creating confusion to users of such data.

v) The BrIccEmis code will be used to calculate atomic decay data for all the $\beta^-$ and ec/$\beta^+$ decay data sets in this project. Kibédi and his students are working to improve the performance of the code. Uncertainties from the nuclear decay data will be propagated as agreed at the previous meeting. The online bibliography on Auger electron references is far from complete, so Kibédi called for evaluators to send him references on Auger electron data that they may have in their private collections.

vi) Remaining tasks: complete evaluation of $^{137}$Cs, $^{136}$Cs, $^{131}$I; undertake reviews of $^{127}$Sb, $^{105}$Rh and $^{143}$Ce.

### 2.4. Alexandru Negret / Sorin Pascu (IFIN-HH):

i) Evaluation of $^{133}$I was submitted on 31 March 2021 (after the meeting) and is currently with the reviewer.

ii) Evaluation of $^{140}$La is in progress.

Noted that $^{133}$Xe as daughter of $^{133}$I will also be evaluated, and therefore Dimitriou and Negret will be in contact to exchange data.

### 2.5. Alan Nichols (University of Surrey):

i) Evaluation of $^{127}$Sb was completed in June 2020 and awaits review (Kibédi).

ii) Revised evaluation of $^{144}$Ce along with reply to the reviewer's preliminary comments sent back to the reviewer on 23 May 2021 (after the meeting).

iii) Extensive review of $^{131m}$Te was sent to the evaluator on 26 October 2020.

iv) Remaining tasks: evaluation of $^{99}$Mo/$^{99}$Tc; review of $^{137}$Cs (once file becomes available).

Following Kondev's question, it was agreed that the latest version of AME (AME2020) published in March 2021 would be implemented in all the evaluations, including those that have already been submitted for review (implementation during review process).

### 2.6. Balraj Singh (McMaster University):

i) Evaluation of $^{147}$Nd: still waiting for publication of a LLNL paper on a new measurement.

ii) Evaluation of $^{135}$Xe has been completed: reviewer assigned at the meeting (Kondev).

iii) Two other assigned evaluations have been completed ($^{105}$Rh, $^{143}$Ce), and are currently with the reviewers.

iv) $^{131m}$Te evaluation is in post-review (reviewer's comments have been received).

v) Review of $^{106}$Ru was submitted to evaluator; further comments have been received (see Section 2.2.).

vi) Review of $^{97}$Zr was completed. After revision by the evaluator, the file is currently with the reviewer for final review of changes; however, Singh is thinking of updating $^{97}$Zr for the ENSDF database but is waiting for approval from the ENSDF manager.

vii) Preliminary review of $^{144}$Ce was sent to the evaluator; a revised file with reply from the evaluator has been received for further comments (after the meeting).

### 2.7. Jagdish Tuli (LBNL):

i) All assigned evaluations have been completed and submitted for review ($^{95,97}$Zr, $^{95}$Nb).

ii) Post-review file of $^{95}$Zr was sent back to the reviewer, along with responses to review comments. The final file has been uploaded onto the shared OneDrive folder (after the meeting).

iii) Review comments on $^{115g}$Cd were sent to evaluator.

iv) Tuli gave a short background account of the units of day and year for half-life - tropical year is adopted in ENSDF and Wallet Card (1 year defined as days).

v) Remaining tasks: revise $^{97}$Zr and $^{95}$Nb which are both in post-review stage; complete review of $^{115m}$Cd (revised $^{95}$Nb was sent to the reviewer after the meeting).

### 2.8. Filip Kondev (ANL):

i) Evaluation of $^{141}$Ce has been completed and reviewed - currently under revision.

ii) Evaluation of $^{140}$Ba and review of $^{133}$I are ongoing.

## 3. TECHNICAL DISCUSSIONS

Roberto Capote re-iterated the importance of producing a review paper describing the evaluation methodology used to produce the adopted decay data sets and presenting all the new evaluated data.

It was agreed that technical comments on each evaluation are useful, and should be included within the ENSDF files. Furthermore, their content will be of value when assembling the proposed review paper.

### 3.1. LOGFT and BetaShape codes

It was confirmed that the fractions of EC CK, CL, … to the K, L, …,shells provided by the LOGFT code into the ENSDF file are the same relative probabilities for EC to the respective atomic shells, $P_K$, $P_L$,…., provided as output by the BetaShape code.

The BetaShape code has improved capabilities in comparison to the LOGFT code: shape factors are considered (includes database of about 130 experimental shape factors for distinct $\beta^-$ and $\beta^+$ emissions). Therefore, BetaShape provides more accurate average $\beta^-$decay energies than LOGFT and extends to very low energies by extrapolation (unlike LOGFT). Additionally, BetaShape provides ratios of fractions of EC to the sub-shells, which are needed to run BrIccEmis, while LOGFT does not. Therefore, Kibédi recommends using BetaShape instead of LOGFT in ENSDF evaluations. BrIccEmis can also calculate sub-shell ratios, but based on a different atomic model. He also mentioned that differences between $P_K$, $P_L$, …, values given by LOGFT and those of Schönfeld (1998Sc28) are due to the different atomic models implemented in the LOGFT code and the Schönfeld paper.

There was a suggestion to benchmark BetaShape output for EC/$\beta^+$ decay since this part of the code has not been extensively tested against LOGFT. However, Singh pointed out that LOGFT had never been benchmarked either, and that an exhaustive comparison of the output of the two codes that was performed for all the β-decay data sets in ENSDF showed overall small differences in the *logft* values. Based on those results, one should not expect large differences for EC/$\beta^+$ decay either, although these cases still need to be considered and assessed.

As was agreed at previous meetings, evaluators will send their final evaluated decay data sets to Verpelli, who would then run them through BetaShape and send the results back to the evaluators for further adjustments.

### 3.2. Combining systematic with statistical uncertainties

Capote clarified that a systematic uncertainty is like an offset that can be considered as a bias to be corrected, otherwise the data point should be discarded. On the other hand, the systematic uncertainty is assumed to be random (not one-way), and for one-dimensional quantities such as half-lives ($T_{1/2}$), can be summed with the statistical uncertainty in quadrature. However, in certain cases, the statistical and systematic uncertainties can usefully be expressed and given separately.

Kondev pointed out that there are many cases in which quantification of the systematic uncertainty in an experiment is a serious challenge.

Singh mentioned that one-way uncertainties (an offset or bias) are often encountered in measurements of the energies of the emitted gammas and should not be combined in quadrature. Nevertheless, Tuli added that if the energy calibration is off in the reported measurements, the uncertainties of the gamma energies can be added in quadrature, unless all gamma-ray energies deviate by similar amounts (bias). Capote remarked that while difficult to add the energy shift to the uncertainty of a measurement, these uncertainties can be generally added in quadrature.

The conclusion was to add statistical and systematic uncertainties in quadrature (as already practiced in the current set of ENSDF evaluations).

### 3.3. $T_{1/2}$ of excited levels (ns range)

Singh raised the question of including evaluated half-lives of the excited levels in the decay data sets. According to the current guidelines, the half-life of the excited level should be evaluated and included in the file only if it is a long-lived state with $T_{1/2}$ comparable to the ground state. In that case, both ground state and excited state should be treated in equilibrium and this should be mentioned in the comments section. Singh suggested that for completeness the short half-lives in the ns or ps scale should also be evaluated and included in the decay data set. It was argued that if the short $T_{1/2}$ is given in Adopted Levels in ENSDF, it should be adopted in the present evaluation since a complete re-evaluation would require extra effort. Another view was that it should not be simply copied from ENSDF and referenced as such, since ENSDF is a dynamic database and changes with time.
Finally, evaluators agreed to an amendment (bold) of the Guidelines as follows:

**Daughter:**
**Level:**
**E [in keV]**: From a least-squares fit to Eγ (use ***GTOL*** program).
**Jπ [JPI]:** From Adopted Levels of the ENSDF evaluation; a reference to the corresponding NDS publication should be given. If different from ENSDF, the value must be explained.
**T1/2:** From Adopted Levels of the ENSDF evaluation, a reference to the corresponding NDS publication should be given. If different from ENSDF, the value must be explained.
**The half-life data for excited levels in the daughter nucleus must be given if known along with proper documentation. If the half-life is comparable to or longer than that of the parent state, one needs to consider the equilibrium condition, and therefore must be evaluated.**

### 3.4. Averaging discrepant data

Dimitriou raised the question of which averaging method to use in the case of discrepant data: should one use an averaging method such as Mandel-Paule, Expected Values Method, Bootstrap, Limitation of Statistical Weights that take into account the uncertainties, even when the data are discrepant and the uncertainties cannot be trusted, or would the unweighted average be more suitable?

According to Singh, uncertainties may not be the only untrustworthy feature of the data, but also the mean values. Therefore, the traditional unweighted average method, which considers only the mean values and not their uncertainties, is problematic. An alternative approach would be to take the average of the minimum and maximum values of the data points (based on the values and uncertainties) to determine the lower and upper limits of the mean value, respectively. The Mandel-Paule method for treating discrepant data is used regularly by NIST, and is considered to be reliable.

Kondev suggested that first, one should identify and discard problematic data points, before proceeding to take the average, whether weighted or the limitation of statistical weight. If resolution of ambiguities in the data is not possible, the unweighted average is a good solution (i.e., individual uncertainties are not trustworthy). He also suggested increasing the uncertainty of very precise values by 3-5$\sigma$, instead of discarding them. Ultimately, it is a judgement the evaluator has to make, and constitutes a subjective call.

### 3.5. Parent decay chains

After further detailed discussions on the relevance of the decay data of certain daughter nuclides in a parent-daughter decay chain, the following additional (daughter) nuclei which have shorter half-lives than their parent nuclides, will be added to the priority list either immediately or at a later time after the top priority (priority 1) radionuclide evaluations that are included in the assignments master file have been completed:

i) $^{106}$Rh: already assigned jointly to Dimitriou and Singh
ii) $^{132}$I: to be deferred to a later stage (priority 2)
iii) $^{144}$Pr: to be deferred to a later stage (priority 2)

As a general statement regarding this project, Nichols acknowledged the welcome usefulness of the X4-NSR pdf database. The X4-NSR database is maintained by V. Zerkin (IAEA) and J. Totans (NNDC/BNL), and is available to all NSDD evaluators.

## 4. CONCLUDING REMARKS

The 2$^{nd}$ IAEA meeting (virtual) of the data development project on Decay Data for Monitoring Applications was held from 24 to 26 March 2021. Participants reported their results and discussed technical aspects of the evaluation work. The priority list of radionuclides was updated to include the daughter nuclide(s) that contribute to parent-daughter decay chains and the guidelines were amended to incorporate the half-lives of short-lived excited states.
The next IAEA follow-up meeting will be held in autumn 2021.

## Appendix 1: Adopted Agenda

IAEA Technical Meeting on Decay Data for Monitoring Applications
24 – 26 March 2021
IAEA Headquarters, Vienna, Austria
(Virtual Event)

**Wednesday, March 24th**
*13:00 – 16:00 CET*

- Welcome address: Roberto Capote, Nuclear Data Section, Deputy Section Head
- Election of chairman and rapporteur, adoption of agenda, administrative matters

- Reporting
    - Kondev (Technical Coordinator: status of project)
    - Chen
    - Dimitriou
    - Kibedi
    - Negret/Pascu
    - Nichols
    - Singh
    - Tuli

*Break as needed*

**Thursday, March 25th**
*13:00 – 16:00 CET*

- Reporting (cont'd)

- Roundtable Discussion
  Topics:
  1. Logft, average beta energy, other beta/EC decay properties: LOGFT or BetaShape?
  2. Differences between BNL LOGFT PK, PL,…, and Schonfeld (1998Sc28) values
  3. Combining systematic with statistical errors
  4. Reporting errors in NSR entries
  5. Including Comments in ENSDF files

*Break as needed*

**Friday, March 26th**
*13:00 – 16:00 CET*

- Roundtable Discussion (cont'd)
  6. Averaging discrepant data
  7. T1/2 of excited levels
  8. BetaShape calculations - work flowchart
  9. Parent decay chains

Closing of the meeting *Break as needed*

## Appendix 2: Participants' List

**IAEA Technical Meeting on Improved Decay Data for Monitoring Applications**

24-26 March 2021
Virtual Event

# PARTICIPANTS

| Country | Name | Surname | Affiliation | Email |
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| | | | | |

## Annex I: 1st Meeting on Decay Data for Monitoring Applications, 6-8 May 2019

**Meeting Minutes**

Participants:
T. Kibédi – Dept. of Nuclear Physics, ANU, Canberra, Australia
B. Singh – Dept. of Physics and Astronomy, McMaster University, Hamilton, Ontario, Canada
M. Galan - Madrid, Spain
F.G. Kondev – Physics Division, ANL, Argonne, IL, USA
J.K. Tuli – LBNL, Berkley, CA, USA
P. (Vivian) Dimitriou – IAEA-NDS, Vienna, Austria (IAEA Project Officer)
M. Verpelli - IAEA-NDS, Vienna, Austria

### 1. Introduction

A consultancy meeting was held to review the decay data for selected fission products that are relevant to the upcoming new IAEA Coordinated Research Project (CRP) on Updating Fission Yield data for Applications (CRP code F42007).
Participants included Tibor Kibedi (Australia), Balraj Singh (Canada), Monica Galan (Spain), Filip Kondev (USA), Jagdish Tuli (USA) and IAEA staff Paraskevi Dimitriou (PO), Marco Verpelli.
Representatives from CTBTO (Boxue Liu, Romano Plenteda, Robert Werzi) as potential user of this data were invited to give an overview of their needs for radionuclide monitoring.
Their interest in evaluated and high-quality decay data is not only for the analysis of daily accumulated radionuclide particulate spectra but also for performing high quality Monte Carlo simulations for identification and quantification of radionuclides. Data derived from ENSDF, such as atomic radiation data as well as beta spectra for selected noble gas Xe isotopes are also among their needs.

### 2. List of priority nuclides

As a result of the discussions, a list of the most important fission products relevant for both the CRP and monitoring applications was compiled, including the Xe isotopes for noble gas detection. A final list of top 27 radionuclides that forms the starting point of the decay data review project was prepared.

### 3. Project

To address the above data needs, the IAEA will coordinate an international team of decay data evaluators with the objective of producing a library of recommended decay data for the selected group of high priority fission products defined in section 2.

### 4. Contents of library

The library will be called ‘Recommended Decay data Library for Selected Fission Products’ and will consist of evaluated nuclear decay properties, atomic radiation data and beta spectra, based on the best nuclear structure information, therefore all relevant nuclear structure properties will be revised if needed.

The library will be produced in ENSDF format and will be hosted and disseminated by the IAEA (Decay Data Portal). The resulting data are intended for publication in a peer-reviewed journal.
The library will be directly available to users upon request.

## 5. Cooperation

If CTBTO wishes to further collaborate with the IAEA-NDS on nuclear data needs and formats, then it would be useful to have a framework of technical cooperation (in the form of a Memorandum of Understanding) set up between the two parties.

## 6. Effort and timeframe

Members of the project include the participants of this meeting and some other evaluators who have expressed interest to contribute. Each evaluator has agreed to take responsibility for the evaluation of 3-4 nuclides and for a similar number of reviews.

Kondev (ANL) agreed to be the technical coordinator for the evaluation and review processes.

The IAEA will create a shared repository to store the evaluated files, references and written comments made by the evaluators. Verpelli will be the contact point for collecting and disseminating the data.

It is expected that the project will be completed in approximately 2 years.

The IAEA will be responsible for organizing the review meeting to assess the final stages of the project.

Interim meetings will be hosted by the participants as needed in order to monitor progress and re-adjust the work program.

## 7. Common evaluation policies and procedures

In general, ENSDF policies, guidelines and nomenclature for evaluation will be used. Evaluators present at the meeting reviewed an existing ENSDF decay data set as an example and a list of specific procedures, policies and guidelines was recommended by the group:

1. The final evaluated data files should be provided in a folder for each given nuclide, which should also include all the references (pdfs) from which data were taken. Where it's difficult to find references, evaluators should contact the IAEA (contact point: Lidija Vrapcenjak, L.Vrapcenjak@iaea.org).
2. How to treat secondary references (conference proceedings, lab reports, theses, private communication): contact authors if possible; evaluators should judge on a case-by-case basis.
3. Evaluation of half-lives: The Guidelines for evaluating half-lives prepared by Nichols and Singh (INDC(NDS)-0687) will be adopted.
4. All relevant properties, such as parent and daughter level half-lives, gamma-ray energies and emission probabilities, multipolarities and mixing ratios etc., will be re-evaluated.
5. For levels populated in the decay data, gamma transitions and their properties, not observed in decay but confirmed in other measurements, should also be evaluated and included in the decay scheme.
6. Multiple measurements of evaluated quantities should be listed in Comments records: when used in the evaluation then both data and it's NSR keynumbers should be listed; when not used in the evaluation, only the NSR keynumbers plus some key information

should be listed. *This last point concerning data not used in the evaluation may be reconsidered in the process of the work.*

7. For Eγ measured with Ge detectors, uncertainties below 0.01 keV should be treated with caution [Note: curved-crystal spectrometers are known to give more precise numbers].
8. Calculated absolute gamma intensities, %IG, will be provided in the 2G gamma continuation record using the GABS code recently updated by Kibedi.
9. Conversion electron emission energies and absolute emission probabilities will also be provided in the same 2G record using: EK, %ECK for K CEs, EL, %ELK for L CEs etc. GABS will be adapted accordingly by T. Kibedi for this purpose.
10. Uncertainties in measured absolute gamma intensities below 0.5% should be treated with caution.
11. Indicators for γ-γ and β-γ coincidences in the Gamma record (col 78) and Beta record (col 77) are optional.
12. Inclusion of angular correlations, angular distributions and A2/A4 data is optional unless they are used to determine the mixing ratios.
13. Theoretical conversion coefficients for different shells will be provided in the SG gamma continuation record using the format prescribed in the ENSDF manual. In the case where E0 component is expected, evaluators should calculate the value based on experimental data.
14. Mixing ratios should be determined on the basis of angular correlation and distribution data, and conversion electron data. BrIccMixing code should be used to calculate the recommended mixing ratios.
15. Experimental total conversion coefficients (ECC) should always be given in the 2G continuation record.
16. For low-energy transitions, when spin and multipolarities are not known, assume E1, M1, and E2 and include [D,E2] in the file.
17. Measured Beta energies should be listed in the Comments record.
18. Rounding procedure: replace rounding to '25' with to '35' in ENSDF codes. Allow flexibility for evaluators.
19. Atomic radiation data will be derived from the final reviewed decay data file using the code NS_Radlist developed by Kibedi and will be compared with available measured data.
    Evaluators are encouraged to include the experimental X-ray and Auger data in the ENSDF file.
20. Beta spectra and logft values will be calculated using the most recent version of the code BetaShape developed by X. Mougeot (CEA Saclay).
21. For E0+M1+E2 transitions, it was recommended that NSDD network adopts the following nomenclature for the mixing ratio which should go into the 2G record:
    MRE0K = $q_k^2 = I_k(E0)/I_k(E2)$

P. (Vivian) Dimitriou 16 June 2019

## Annex II: 2nd Meeting on Decay Data for Monitoring Applications, 12 May 2020

**Meeting Minutes**
**(virtual meeting)**

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M. Galan - Madrid, Spain
A.L. Nichols – Dept. of Physics, University of Surrey, Guildford, UK (Rapporteur)
Jun Chen – NSCL-MSU, East Lansing, Michigan, USA
F.G. Kondev – Physics Division, ANL, Argonne, IL, USA
J.K. Tuli – LBNL, Berkeley, CA, USA.
R. Capote Noy – IAEA-NDS, Vienna, Austria (IAEA Project Officer)
M. Verpelli - IAEA-NDS, Vienna, Austria.

**Agenda**

The draft agenda as formulated and proposed by Dimitriou was unanimously adopted:
(a) Discuss and agree on review meeting to be held 26-28 August 2020, Athens, Greece.
(b) Consider and agree review methodology of evaluated IAEA/CTBTO decay data files.
(c) Any Other Business (AOB), as and when appropriate.

1. **Review meeting / Project timeline**

   Even though the proposed August meeting is over three months away, the coronavirus Covid-19 situation most clearly constitutes a major hurdle to any future proposed meeting in 2020. Any form of foreign travel in 2020 has already been prohibited for staff at ANU (Australia), McMaster University (Canada), Michigan State University (USA), and US national laboratories (e.g., ANL and BNL (foreign travel defined as "highly unlikely")). Quarantine regulations in countries such as Spain and the UK might also pose logistical problems.

   After some debate, the current status of the evaluations was defined and a realistic future timeline was agreed upon based on the various tasks, the duration of existing contracts, and relevant agreements made at the first IAEA Consultancy Meeting in May 2019:

   1). 6-8 May 2019 IAEA Consultancy Meeting – the project purpose comprises the evaluation of the complete decay data for 27 radionuclides defined as priority 1 in discussions with CTBTO staff;
   2). contracts based on completing all of their assigned evaluations by May/July 2020;
   3). contracts based on completing a limited number of their assigned evaluations by July 2020;
   4). some of the assigned evaluations not associated with such contracts are bound to a completion deadline commensurate with the August 2020 meeting;
   5). in view of the above, the balance of the 27 radionuclides remains to be evaluated and any further evaluation contracts to be agreed subsequently, to begin in September 2020 and end by 30 June 2021;
   6). detailed reviews of these decay-data evaluations to begin in 2020 as part of the various new contracts and continue on into 2021 as defined by file availability (see above).

Capote Noy emphasized the importance of the August 2020 meeting to determine what work remains to be done after the first year of the project. Such an exercise will enable new one-year contracts to be prepared with clearly specified tasks, deadlines and deliverables.

Under the circumstances, a series of virtual meetings of 1 to 2 hours duration per day was agreed for 26-28 August 2020, to discuss the review process in greater detail and, furthermore, to assign to individual project members the assessment and review of all evaluations as they arise. After completion of almost all existing contracts by August 2020, contract renewals would be discussed during these short virtual meetings in August 2020 and would be finalized by means of individual consultations between potential contract holders and the IAEA project officer.

An in-person meeting is postponed until sometime in 2021, hopefully either in Athens or Vienna (whichever is best suited to the possible ever-changing circumstances, and IAEA-NDS requirements at that time).

## 2. Project reports and contract issues (AOB)

R. Capote Noy outlined reporting on the work done in accordance with IAEA-NDS standards as follows:

(a) individual brief contract reports to cover the work period of their existence, of no more than one or two A4 pages per contract at the end of the contract year (i.e., short individual submissions) – as deliverables to the International Atomic Energy Agency, these reports should briefly summarize the resulting evaluated files;

(b) a comprehensive final technical report to be prepared upon conclusion of the project, covering all of the work undertaken by all project members – to be submitted to and published in a peer-reviewed journal.

At this point of discussions, the possibility of a third year of contract work was mentioned in order to evaluate the decay data of some of the lower priority radionuclides that had arisen during the meeting of 6-8 May 2019 and/or prepare the comprehensive final technical report that fully documents all of the 27 evaluations undertaken for the project.

IAEA-NDS is committed to the delivery of a high-quality and reliable evaluated decay-data library. Therefore, if a total of three years is required to complete/review the 27 evaluations and prepare a final technical report for publication, the IAEA will support the evaluators with the necessary contracts, as well as organize and implement appropriate meetings.

[Sec. note: at this point, Capote Noy left the meeting for another work-related commitment.]

## 3. Draft guidelines for evaluators and data-file reviewers

As requested, Kondev had prepared and distributed an advisory document entitled “Evaluator Guidelines”, which was a re-working of the draft guidelines outlined in the minutes of the 6-8 May 2019 IAEA meeting. He had only received comments from Nichols, and suggested corrections/modifications from Tuli. Kondev had also perused the existing eight sets of data files deposited in the shared Onedrive system as set-up by Verpelli, and observed their contents to be non-uniform in both depth of evaluation, content and nature of individual files. For example, some recommended values have been adopted from ENSDF Adopted Data sets without any explanation as to why; in other cases, there is insufficient argument or comment why a particular value was chosen, while the exclusion of other existing measurements in the evaluation is neither explained nor their relevant references documented.

Complete uniformity is not expected among the various recommended data files due to the fact that the content of each dataset depends on each particular nuclide, the nature of all relevant published data, and furthermore the evaluators may make a series of somewhat different subjective judgements during the course of such evaluations. However, what is expected from this new decay data library is adequate documentation of the process by which the evaluator reached the recommended value, as well as of all existing measurements that were not considered (and for what reason) in their evaluation process.

The new document prepared by Kondev (Annex VI) spells out in more detail the draft guidelines that were originally adopted in May 2019. Some corrections had arisen from communications with Tuli, while Nichols proposed that an introductory statement be added underscoring the fact that these new in-depth evaluations fully embrace the concept of subjective judgements by the evaluator who should not be bound at all to the existing evaluations in ENSDF, DDEP, etc. Rather she/he should evaluate all of the desired parameters themselves to their own satisfaction and include in their recommended files sufficient comments to detail the anomalies and inconsistencies that may remain despite their extensive evaluation efforts. While some members of the project had adopted this in-depth approach, others appeared to have only considered the most recently published data, with the existing ENSDF decay-data file constituting their main starting point rather than incorporating all measurements in their new evaluation. An important point to stress is that evaluators in this project are obliged to implement these guidelines in their evaluations. Otherwise the evaluated data library is in danger of being incoherent and inconsistent, which would undermine the primary aims and purpose of the project. If evaluators are unable to revisit their evaluations and ensure that they have correctly implemented the guidelines prior to review, this checking process and possible revision will be performed by the evaluator after the review stage of the exercise.

Technical issues discussed in detail:

- How do detector-related uncertainties affect the measured gamma-ray energies incorporated in the evaluation of the level scheme? How are they taken into account when such uncertainties are given by the authors? And what does the evaluator do when realistic systematic uncertainties are not given by the authors? This problem becomes more significant when the statistical uncertainties of the measured data are clearly very small, and systematic uncertainties have been poorly quantified.
- As related to the above queries and mentioned in the guidelines adopted in May 2019, caution must be exercised when dealing with very precise gamma-ray energies that are quoted to uncertainties lower than ± 0.01 to 0.02 keV. Furthermore, one should consider that for measurements with a curved/bent crystal spectrometer, uncertainties can be as low as approximately ± 0.001 keV. How one handles this type of issue depends on the individual case, i.e. there is no hard and fast rule.
- BrICC code should be used to calculate the internal conversion coefficients, while BrICCmixing code should be considered for adoption to determine mixing ratios. Some concerns were raised concerning BrICCmixing when assessing predominantly E2 transitions. Evaluators were also reminded that asymmetric uncertainties in the input data have to be symmetrized before they are fed into the BrICCmixing code, in contrast to the BrICC code which can read and symmetrize asymmetric uncertainties.

- Compile all relevant references as individual pdf files ordered by NSR keynumber in a common subfolder within the shared Onedrive system.
- Effort should be made to produce fully complete decay schemes. However, as mentioned above, the evaluator (and reviewer) should also bear in mind "….. to include in their recommended files sufficient comments to detail the anomalies and inconsistencies that may remain (in the decay scheme) despite their extensive evaluation efforts."

The evaluator guidelines prepared by Kondev (attachment) should also form part of the guidelines for reviewers – detail the agreed and adopted methodology and include all items the data-file reviewers should check. Kondev agreed to prepare an equivalent document for reviewers that defines and outlines the review process, which will be shared with the participants prior to the August 2020 meeting, to be agreed and adopted therein.

4. **Comprehensive file of references: access/availability in their published pdf form (AOB)**

   All project participants will be given access to the on-line EXFOR-NSR and EXFOR-ALL PDF databases maintained by NDS and NNDC to download references contained in NSR and EXFOR. [Sec. note: this action was completed on 13 May 2020 by V. Zerkin (IAEA-NDS).]

[Sec. footnote: This Skype meeting suffered from a number of individual audio issues that might need to be addressed accordingly, on the valid assumption that 26-28 August 2020 meeting will go ahead in a similar manner. Extending beyond two hours per day (potentially over the three specified days) is considered inadvisable because of the extensive time differences between individuals and maintaining a sound degree of concentration/ patience/sanity.]

A.L. Nichols 26 May 2020
P. Dimitriou

## Annex III: 3rd Meeting on Decay Data for Monitoring Applications, 25-27 August 2020

**Meeting Minutes**
**(virtual meeting)**

Participants:
T. Kibédi – Dept. of Nuclear Physics, ANU, Canberra, Australia
B. Singh – Dept. of Physics and Astronomy, McMaster University, Hamilton, Ontario, Canada
P. (Vivian) Dimitriou – NCSR Demokritos Institute of Nuclear and Particle Physics, Athens, Greece
S. Pascu – National Institute of Physics and Nuclear Engineering Horia Hulubei (IFIN-HH), Bucharest, Romania
A.L. Nichols – Dept. of Physics, University of Surrey, Guildford, UK
Jun Chen – NSCL-MSU, East Lansing, Michigan, USA
F.G. Kondev – Physics Division, ANL, Argonne, IL, USA
J.K. Tuli – LBNL, Berkeley, CA, USA
R. Capote Noy – IAEA-NDS, Vienna, Austria (IAEA Project Officer)
M. Verpelli - IAEA-NDS, Vienna, Austria.

Kondev was elected chair of the meeting, Chen and Dimitriou were appointed rapporteurs. The preliminary agenda was unanimously approved and adopted.

### 1. Introduction

Capote made some introductory remarks on the perspectives of the project at the IAEA, in view of the new measures that have been introduced in reaction to the spread of Covid-19, along with other developments at the IAEA:

- IAEA continues to support the project, and the efforts being made by participants.
- All IAEA in-person meetings in 2020 to be held virtually.
- All duty travels of IAEA staff have also been cancelled for the same period.
- All contracts will be brought into effect after conclusion of in internal IAEA review process.

Efforts will be made to hold a regular multi-attendee meeting by June 2021. In the meantime, the project will continue as planned with participants holding regular on-line meetings to discuss technical and organizational matters.

Another item raised was the need to validate the recommended decay data produced by the project. Capote emphasized the importance of understanding the differences between the new improved evaluations and other libraries/databases (ENSDF, DDEP, and others). A comprehensive table of comparisons and comments concerning the various differences might also be useful to the user. Although a study of the impact of the new decay data on monitoring applications is the task of the user (CTBTO and related metrology laboratories), there would be merit and interest to address the differences and discuss the possible impact on particular applications.

Singh commented that providing different values can be confusing for the user who will subsequently have to make a choice. On the other hand, the choice of data may depend on the nature of the proposed application. Tuli also remarked that the evaluator's job is to recommend what they believe to be the best value, and not to benchmark or validate such values. Dimitriou added that one source of differences between the new recommendations and equivalent data found within other libraries will arise from the guidelines adopted. Other reasons should also be considered and justified in the final publication.

The Decay Data portal developed at the IAEA is a website where users can compare all available nuclear structure and decay data from the various evaluated libraries (ENSDF, DDEP, IAEA CRPs). The new decay data library produced by this project can also be made available on this portal so that the user can rapidly compare all or selected elements of the content with the other available evaluations.

Kondev stressed the importance of making all new evaluated decay data more visible on the IAEA webpages and promoting them to the user community, as all too often the latter is unaware of the existence of the data or experiences difficulties in finding them.

## 2. New evaluations

### 2.1. $^{95}$Zr, $^{95}$Nb, $^{97}$Zr (Jag Tuli)

The latest evaluations of these radionuclides (RN) were retrieved, as well as NSR references and corresponding pdf files.

- **$^{95}$Zr, $^{95}$Nb**: although there are no new measurements, all quantities were updated (AME2016, re-evaluation of half-lives (HL) using weighted average). The new data sets do not change significantly.

- **$^{97}$Zr**: the new evaluation adopts results from 2014Kr11, which contains a very detailed and precise analysis of uncertainties, and exhibits no inconsistency with respect to the other measurements. The data from 2014Kr11 have already been compiled within XUNDL. Another positive feature of 2014Kr11 is that several previously unplaced γ transitions have been introduced into the decay scheme. All the other measurements of this RN were also included in the file in accordance with the Guidelines.

[Sec. note: At this point Capote left the meeting.]

**Discussion:**

Singh commented that since the data of 2014Kr11 are based on singles γ spectra, it is not clear how they are compatible with existing γ-γ coincidence data, or how the unplaced γ transitions are assigned in the proposed decay scheme.

Tuli noted that a new evaluation does not have to change the data necessarily, but should definitely not make them worse. The report on $^{147}$Nd (a measurement that used $^{95}$Nb as a standard) was not considered in the evaluation because this particular study does not directly contribute in any way to the decay data of $^{95}$Nb, and did not have an NSR keynumber. Singh will prepare the NSR entry to speed up the issue of such a keynumber.

### 2.2. $^{105}$Rh, $^{131m}$Te B$^-$ decay, $^{131m}$Te IT decay, $^{143}$Ce, $^{147}$Nd (Balraj Singh)

Singh prepared a short report (Appendix) on his evaluation approach (following the guidelines) and the main issues found in the evaluation of the four RNs. The report was sent to all the other evaluators prior to the meeting. In addition to the issues mentioned in the report, Singh also noted the following:

- Problems accessing Russian reports/papers in their English translation.
- ENSDF evaluators generally do not give a full description of all the available data, whereas he has included all this information in the new decay data files making them considerable larger in size.

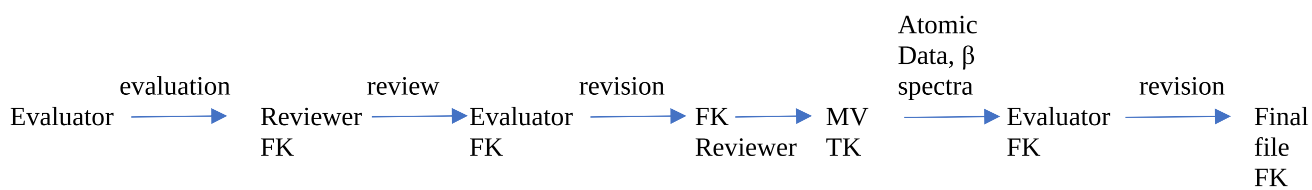
The 2019-ENSDF evaluations of $^{105}$Rh decay and the $^{105}$Pd adopted dataset suffer from some issues, related to uncertainties for gamma-ray energies. In the submitted evaluation of $^{105}$Rh decay, these issues have been discussed briefly. The $^{147}$Nd decay forms a part of the update of the A = 147 mass chain for ENSDF, in collaboration with N. Nica.

**Discussion:**
Kondev asked if the very precise new measurements of $^{147}$Nd are consistent - they are for the strongest transitions, but not for the full decay scheme. The evaluation will be completed after an important measurement by LLNL has been published.

A discussion followed on how to calculate the derived data: atomic radiation data and beta spectra. BetaShape (code by X. Mougeot, CEA-Saclay) will be used to produce beta spectra for all datasets. A new version of the code that treats EC is now also available and can be requested from Mougeot. Verpelli will perform these calculations after the ENSDF files have been reviewed, revised and checked. Verpelli will then send the output files obtained from BetaShape back to Kondev and the evaluators who will have to check for any required changes in $J^{\pi}$ arguments and assignments due to changes in log*ft* values. The evaluators will send their final files to Kondev. Should evaluators wish to run BetaShape themselves, they can do so in addition to Verpelli and communicate their results to both Verpelli and Kondev.

A similar procedure will be implemented for the atomic radiation data which will be calculated by Kibédi using the ANU BrIccEmis code after the review process is completed. The results from BrIccEmis will be sent to Kondev and the evaluators for final checks.

Decay Data Evaluation Project– envisaged workflow:




## 2.3. $^{127}$Sb, $^{144}$Ce (Alan Nichols)

Nichols gave an overview of his evaluation work – a Powerpoint version had already been circulated to all participants prior to the meeting. One notable problem he faced was that several publications relevant to his RNs were not included in NSR and the X4-NSR pdf database, and therefore he had to request the assistance of the IAEA-NDS to obtain copies. He had subsequently submitted these articles to NNDC in order to obtain an NSR keynumber for inclusion in the NSR database.

**Discussion:**

Singh commented that some experimental groups publish $E_\gamma$s they obtain from fitting their measured decay scheme, which gives a reduced $\chi^2 = 0$ in GTOL. Nichols tried to ensure that all $E_\gamma$ he selected for evaluation were measured energies. He had not found any substantial differences or inconsistencies between the newly generated GTOL-win $E_\gamma$ data and the current adopted-level ENSDF evaluations.

### 2.4. $^{115,115m}$Cd, $^{126}$Sb (Jun Chen)

Chen gave a short presentation on all the updates and re-evaluations performed for the three RNs that were assigned to him. He had taken into consideration all the available measurements of comparable quality and precision to produce adopted levels and gamma rays from the available decay data, instead of adopting a single measurement. The presentation can be found on the shared OneDrive folder.

**Discussion:**

Nichols commented on the statement that in a previous ENSDF evaluation of $^{126}$Sb the evaluator had adopted the $E_\gamma$ and $I_\gamma$ values from a single paper, while values with similar or better precision were available in other references. He viewed the gross adoption of a single set of such decay data from only one source as an insult to all of the other available/respectable measurements, and agreed completely with the overall approach adopted by Chen.

Singh asked whether there was a problem running GTOL with such low $E_\gamma$ uncertainties in the eV range - Chen stated that only one γ ray with $\Delta E_\gamma = 0.7$ eV was poorly fitted.

### 2.5. $^{106}$Ru, $^{139}$Ce (Vivian Dimitriou)

Dimitriou had evaluated the half-lives, ICCs (when necessary), and EC fractions, whereas the single γ transition energy for $^{139}$Ce $\beta^-$ decay was adopted from the evaluation of 2000He14. The presentation is available on the shared OneDrive folder.

**Discussion:**

Both Nichols and Kondev requested that BrIccMixing be used to estimate the MR, as stated explicitly in the Guidelines. Kibédi suggested that more recent measurements and/or evaluations of the $\omega_k$ should be used to obtain a more up to date recommended value for the EC fraction $P_k$.

### 2.6. $^{131}$I, $^{136,137}$Cs (Tibor Kibédi)

Kibédi gave a presentation of his evaluation of $^{137}$Cs decay data to cover half-life, ICCs, and EC fractions.

**Discussion:**

Tuli commented that one should be careful about revising previous evaluated values that have been obtained after detailed and laborious evaluation work. Dimitriou asked about the reduced $\chi^2$ that the LWM gave (value is 4.5). Singh also mentioned that he had worked on the re-evaluation of the $T_{1/2}$ together with Caroline Nesaraja, and they had obtained rather high values of $\chi^2$ when using the weighted-mean averaging methods. This was unsatisfactory, so he adopted the unweighted average value. A more detailed comment is given in the technical discussions.

Kondev raised the issue of the atomic radiation data calculated by the BrIccEmis code, and the fact that they are not accompanied by uncertainties; however, the corresponding data obtained from EADL library or Emission code and displayed in LiveChart and NuDat have been assigned uncertainties as required in many nuclear applications. Kibédi explained that calculating uncertainties in Monte-Carlo simulations is complicated by the fact that one has to consider not only the propagation of the uncertainties in the nuclear data ($E_\gamma$, $I_\gamma$, etc), but also the uncertainties in the atomic processes themselves. These calculations are cumbersome and, more importantly, lead to considerably increased uncertainties that are not comparable with the uncertainties listed in the atomic data from EADL or the Emission code of Schönfeld and Janβen.

After some discussions, Kibédi clarified that the propagation of uncertainties from nuclear data in BrIccEmis is straightforward and will be implemented in the code to provide uncertainties in the atomic radiation data for the CTBTO project. However, the uncertainties in the theoretical atomic transitions will not be considered in BrIccEmis, as this requires major modifications of the code. Instead, he recommended to include these uncertainties together with the uncertainties from nuclear data in the NS_RadList code.

BrIccEmis consists of two parts. One part, the BrIccEmis code, which reads the ENSDF file, performs the desired Monte Carlo simulations, and stores a list of energies with identification tags (gamma, CE, Auger, X-ray) onto the disk. This part is similar to running a physics experiment and collecting data in an event-by-event mode. The second part, ListEmis, sorts the files obtained from BrIccEmis, creates the lists, the ENSDF records, and plots of the atomic spectra. The NS_Radlist code operates the same way as ListEmis, i.e. on a set of pre-compiled spectra that have been calculated by BrIccEmis by considering vacancies on every possible shell. An example is an MXY Auger spectrum that follows an initial vacancy on the K-shell. It is possible to assign an uncertainty to each of these pre-calculated spectra (about 100 different types in total). NS_Radlist adds these spectra together with appropriate weighting factors that can also be used to "propagate" uncertainties, including those from nuclear decay data and EADL. The uncertainties will appear in the energy and intensity list of the atomic radiations.

### 2.7. $^{141}$Ce (Filip Kondev)

Detailed comments on all the updates and re-evaluations have been included in the ENSDF file which is available on the shared OneDrive folder.

Kondev pointed out that several laboratories quote uncertainties at the 3σ confidence level which means they have to be converted back to the 1σ confidence level before being included in the averaging process. More specifically, Geel and Saclay quote to 3σ, whereas PTB and Canadian laboratories quote to 1σ.

## 3. Revision of assignments

After the withdrawal of Monica Galan from the project, the four RNs that had been assigned to her were re-distributed among the remaining participants. Tuli informed the group of his plans to withdraw from the project by July 2021 so he would not be contributing to any further evaluations. Nichols has $^{99}$Mo/$^{99m}$Te in equilibrium and pure $^{99m}$Tc to evaluate; however, the final decision on whether he will undertake this work will be taken as soon as the IAEA reactivates the contracts system. The Romanian ENSDF evaluators, A. Negret and S. Pascu, have agreed to join the project adding to the available evaluator resources.

After discussions, participants agreed to the following re-distribution of the remaining RNs:

$^{133,133m}$Xe: Dimitriou
$^{135}$Xe: Singh

$^{133}I$, $^{140}La$: Pascu for the Romanian team

The spreadsheet with the assignments was updated accordingly.

## 4. Review process

All participants agreed to start working on their assigned reviews of the existing evaluations, and to submit at least one review by the end of 2020. Nichols expressed some concern about the duration and outcome of the on-going IAEA review of consultancies, although he is willing to perform 1-2 reviews within 2020. Tuli will be able to work on reviews until June 2021. A tentative list of assigned reviews was proposed by Kondev, which after some discussions was revised and accepted by participants .

Participants agreed to the following items regarding the review process:

- Reviewers can download all the relevant files from the OneDrive folder.
- Reviewers could inform Kondev and evaluators when the review of a RN has started (optional).
- Reviewers will send their comments/review to both the evaluator and Kondev. The evaluator will revise and send the final modified file to Kondev and reviewer for additional checks. Subsequent stages of the decay data evaluation process are shown as a timeline at the end of Sub-section 2.2, Discussion.
- Reviewers should feel free to discuss the review with the evaluators and exchange whatever material they consider necessary. Discussions could also involve other members of the group if judged to be necessary.
- The Romanian team will undertake two RN evaluations, and will contribute to the reviewing process for the remaining RNs after their full evaluation.
- Kondev and Verpelli will re-organize the structure of the OneDrive folder to accommodate the reviewed files.

## 5. Technical discussions

[Sec. Note: Sorin Pascu from the Romanian team joined the meeting on the last day.]

All items listed in the Agenda were covered in the discussions, including some additional items proposed by Singh and Tuli.

### 5.1. Averaging of $T_{1/2}$ for $^{137}Cs$

Singh recommended an unweighted average of the $T_{1/2}$ data for $^{137}Cs$, since when weighted average methods are used, the final $\chi^2$ is much larger than twice the critical $\chi^2$ at a confidence level of 95%. The actual value of $\chi^2$ depends on the confidence level and the number of data points. In general, the reduced $\chi^2$ should not be larger than the critical value at 95% confidence level.

### 5.2. Guideline for lower limit on $\Delta E_\gamma$

Participants agreed that it is very difficult to make universal statements about which type of measurement is good or inadequate, and therefore such judgements are a subjective decision by the evaluator on a case by case basis.

The current guidelines on the lowest acceptable uncertainties for $E_\gamma$ measurements are sound and should be followed by the evaluator. However, the following additions to the existing Guidelines were agreed (highlighted text):

– As related to the above queries and mentioned in the guidelines adopted in May 2019, caution must be exercised when dealing with very precise gamma-ray energies (as measured by means of Ge and Si detectors) that are quoted to uncertainties lower than about 0.01 keV (equivalent to <10 ppm ). Furthermore, measurements with a curved/bent crystal spectrometer can produce uncertainties as low as approximately 0.001 keV. How one handles this type of issue depends on the individual case, and there is no hard and fast rule.

### 5.3. Comment on γ-energy calibration standard

Experimentalists should provide information on the standards they use to obtain the absolute values in their measurements. However, very often this information is missing from publications, and evaluators cannot make a safe assessment of the reported precision. The $E_\gamma$ calibration standards reported in 2000He14 are reliable and should be adopted if listed, unless better measurements are available.

Kondev noted that the γ-ray energy evaluations of 2000He14 need to be updated to account for new precise measurements and the most up to date values of the fundamental constants (CODATA).

***Recommendation:*** IAEA should consider how best to formulate a programme in order to update the γ-ray energy calibration standards.

### 5.4. Use of fitted $E_\gamma$ or measured $E_\gamma$ in the adopted decay scheme

Discussions on whether to adopt fitted or measured/evaluated $E_\gamma$ data have occurred over many years. Debate concerning $\Delta E_\gamma$ as defined above supported no change in policy for adopted $E_\gamma$, which specifies the adoption of measured/evaluated values.

### 5.5. 1974HeYW $E_\gamma$ and $I_\gamma$ catalogue

Singh mentioned that the 1974HeYW catalogue of $E_\gamma$ and $I_\gamma$ data is a very useful source of information on measured γ-ray spectral data that is frequently overlooked by evaluators due to previous incorrect keywording in NSR (and mistakenly classifies this report as a compilation). Correct and detailed keywording of 1974HeYW by Singh, listing almost 300 decays in this catalogue, has been entered in the NSR database. Evaluators are advised to consult the catalogue, which together with two enhanced editions assembled in 1998-2000 are available on the shared OneDrive folder. Evaluators should note that the more colorful 2000 editions contain recommended ENSDF data that originate from 1998, while some of the γ-ray spectra first appeared in 1974HeYW. These latest (color) editions of the Idaho catalogues will also be entered in the NSR with suitable keywording by Singh.

### 5.6. Other independent evaluations

A list of independent evaluations of high quality that evaluators can consult and adopt was provided for consideration (based on the subjective judgements of the evaluators):

- $E_\gamma$ calibration standards from 2000He14;
- Q-values from 2017Wa38;
- fluorescent yields from evaluation of 1996Sc06;
- mixing ratios from re-analyses of γ angular correlation data by K.S. Krane:
  1975Kr16: ADNDT 16, 383 (1975): even-even: $A \geq 152$,

1976Kr21: ADNDT 18, 137 (1976): odd-A: A > 150,
1977Kr13: ADNDT 19, 363 (1977): odd-A: A = 59-149,
1977Kr17: ADNDT 20, 211 (1977): even-even: A = 58-150,
1978Kr19: ADNDT 22, 269 (1978): A ≤ 57, all A,
1980Kr22: ADNDT 25, 29 (1980): odd-odd, all A + supplement to all above.

### 5.7. Averaging intensities

According to Tuli, it is not normal practice to average the γ-ray intensities – instead evaluators average the branching ratios from each level (branching ratios in ENSDF are averaged within the adopted dataset, and not within the decay dataset). Therefore, one should choose all γ-ray intensity values from a single spectral measurement which is judged to be "well done, complete and consistent with other measurements", and preferably the latest published paper as the decay scheme will be largely based on the findings of previous measurements.

Singh, Kondev and Nichols were of the opinion that $I_\gamma$ values from different experiments judged to be consistent, can and should be averaged to obtain the recommended $I_\gamma$ data. Amongst other problems, there are serious difficulties implementing highly-subjective judgements to identify a single set of experimental data that can be safely described as "the best". Furthermore, many extremely good precise measurements do not always constitute a complete and fully comprehensive data set for decay-scheme analyses, and would be lost from the evaluating process, as proposed.

### 5.8. Time-dependent $I_\gamma$ (from isomer decay)

If $T_{1/2}$ of isomer is comparable to the parent $T_{1/2}$, combined $I_\gamma$ data are time-dependent and should not be given in the RI field. Instead, resulting equilibrium values should be included within the comments.

### 5.9. $J^\pi$, $T_{1/2}$, multipolarity, MR

All the values given in the adopted decay-data set need to be self-standing, i.e., explanation needs to be given as to why they have been adopted, along with a complete reference list. Some evaluators have re-evaluated all these quantities, while others have judged that the values in the ENSDF adopted datasets are well-established and therefore adopted. The arguments and references for both approaches need to be included in the relevant sub-folders.

## 6. Other items

Assembly of the library and validation will be considered more comprehensively in future meetings.

## 7. Next meeting: 16 November 2020

Participants agreed to hold regular on-line meetings to discuss technical issues and keep up to date on progress with the project. The next meeting was agreed to be held on Monday, 16 November 2020, at the same time and over the same duration (2 hours) as the daily meetings in August.

Jun Chen 14 September 2020
P. (Vivian) Dimitriou

APPENDIX

**Report of the evaluation of long-lived fission products for the IAEA-NDS-CTBTO project.**
Prepared by Balraj Singh, evaluator of the isotopes described here (August 24, 2020)

May-July 2019: evaluation of the decays assigned to me and their submissions to the IAEA-NDS:

1. $^{105}$Rh β- to $^{105}$Pd decay: 35.340(24) h: submitted May 10, 2020.
2. $^{131m}$Te β- to $^{131}$I decay: 32.54(18) h submitted August 20, 2020.
3. $^{131m}$Te IT decay to $^{131}$Te decay: 32.54(18) h: submitted August 20, 2020.
4. $^{143}$Ce β- to $^{143}$Pr decay: 33.05(3) h: submitted May 6, 2020.
5. $^{147}$Nd β- to $^{147}$Pm decay: 11.03(3) d: submitted Nov 10, 2019.

General comments:

1. Guidelines discussed at the May 2019 meeting have been followed as much as possible. There does not seem any obvious deviation. Except for $^{131m}$Te decays, all the other evaluations were submitted prior to the second set of guidelines. Hopefully, all the evaluations meet the requirements of the second set of guidelines as well.
2. All the previous evaluations published in Nuclear Data Sheets since the 60's, and one (for $^{147}$Nd decay) in DDEP, along with TOI (1978) and TORI (1986) have been consulted.
3. All the papers going back to day one of a particular isotope have been consulted: ~40 for $^{105}$Rh decay, ~25 for $^{131m}$Te decays, ~70 for $^{143}$Ce decay and ~100 for $^{147}$Nd decay, and copies of most of these were included in the packages sent to the IAEA-NDS. Copies of only a few older papers were not available to the evaluator, but it does not seem these will affect the submitted evaluations in any significant way.
4. All data e.g. half-lives of parents and daughters (the latter when radioactive), gamma-ray energies and intensities, gamma-multipolarities and mixing ratios with supporting arguments, associated conversion coefficients, gamma-normalization factors, beta feedings, photon emission probabilities (intensities per 100 decays of the parents), log *ft* values, level energies, spins and parities of parents and daughter levels with supporting arguments, and half-lives of excited states have been compiled and evaluated, with the exception of gamma-ray energies and intensities measured prior to 1965 or so using NaI(Tl) detectors, as for all the above nuclides, high-resolution data collected using Ge detectors are available.
5. Starting from datasets in the current ENSDF database, all datasets have been independently compiled and evaluated, with detailed commentary provided, as obvious from a comparison of file size (number of records in .ensdf format) for each decay: $^{105}$Rh (430 records vs 90 in ensdf), $^{131m}$Te β- (1540 vs 410 in ensdf), $^{131m}$Te IT decay (80 records vs 35 in ensdf), $^{143}$Ce (1360 records vs 220 in ensdf), and $^{147}$Nd (870 records vs 350 in ensdf).

6. All the relevant computer codes relevant to decay data sets in the ensdf format have been employed for all the evaluations. **Exception**: code for deducing the atomic radiations, and Xavier's new Beta-shape code for log *ft* values and associated details of β radiations have not been run on any of the datasets, as from discussion at the May 2019 IAEA meeting, I have been under the impression that these code will be run on all the decay data sets at a later date. I need a clarification on this point. At present, I do not have these codes working on my computer.

7. While significant differences are found between the submitted evaluations and those presently available in the ENSDF database, detailed comments pointing out these differences have been provided, as the evaluator feels that the purpose of this exercise is not to validate or invalidate recommended data in the current ENSDF and/or DDEP databases, although, a few selected issue are briefly discussed. The submitted data sets should be considered/judged on their own right.

8. No significant new/recent papers with data for gamma-ray energies and intensities were found for the above isotopes, although quite a lot of data from publications missing in the Previous evaluations were added in the present work.

Comments for individual isotopes:

1. $^{105}$Rh β- decay to $^{105}$Pd: 5 γ rays and 5 levels. ENSDF evaluation is from April 2019. No DDEP evaluation is available. The photon emission probabilities for the two most intense γ rays of 306.3 and 319.2 keV are 4.69(7) and 16.99(7), respectively. While these values agree with those in the ENSDF, but it seems that ENSDF evaluators have ignored direct measurement of the emission probability of the 319.2-keV γ ray by 4πβγ-coin method in 2005Mo07. Serious issues were found by this evaluator in the evaluation of the $^{105}$Ag EC decay to $^{105}$Pd and the Adopted dataset for the $^{105}$Pd nuclide in the ENSDF database. The evaluator responsible for the evaluation of these datasets, and the ENSDF manager were informed about the issues several months back, but no response has been received to date.

2. $^{131m}$Te β- decay to $^{131}$I: ENSDF evaluation is from July 2006. No DDEP evaluation is available. About 190 γ rays and 39 levels are reported in literature, several (weak) unplaced γ rays, and many (weak ones) with uncertain or double placements. The decay scheme, in detail, has only been studied at Livermore in 1975. One new paper 2019Al03 has reported lifetimes of four excited states studied in the decay of $^{131m}$Te, and another new paper 2008Ea01 has reported re-measurement of the half-life of $^{131m}$Te decay. Half-life of $^{131}$I daughter includes the revised result from NIST reported in an Erratum published in Appl. Rad. Isot. 159, 108976 (2020) has been considered. There are many measurements of the half-life of this important isotope, some quite precise from metrology labs, but the overall data set is discrepant, and I have resorted to unweighted averaging. It appears that the spread of the measured values is due to varying amounts of contribution from the decay of the 11.86-d $^{131m}$Xe fed by about 1.1% through β- decay of 8.0-d $^{131}$I decay, i.e. by what amount Xe activity, as gas, escapes the sample. Couple of measurements addressing this issue have not provided definite conclusions. Strangely enough, no metrology lab has

evaluated this effect quantitatively. For %β- branching ratio, see note below for $^{131m}$Te IT decay. Even though, photon emission probabilities for the eight most intense (>5% absolute intensity) γ rays agree reasonably well with those in the ENSDF database, yet a dedicated study of this decay using state-of-the-art Ge detector array is required to establish a more definite decay scheme from detailed γ-γ coincidence data. Two levels have non-physical negative beta feedings of ~0.45% each, which still need to be resolved. In addition, half-life of $^{131}$I decay seems to need a better measurement, with the consideration of contribution from the decay of the $^{131}$Xe isomer with half-life somewhat longer than that of $^{131}$I.

3. $^{131m}$Te IT decay to $^{131}$Te: ENSDF evaluation is from July 2006. No DDEP evaluation is available. Only one gamma ray of M4 multipolarity to the ground state. In the present evaluation, branching ratio for the IT decay mode has been adopted from 1975Ja03, Livermore work in place of that from 2002Re30 from Karlsruhe, as the latter does not provide measured gamma-ray intensity data in their experiment, which can be evaluated. 2006-ENSDF evaluation adopted the IT branching ratio from 2002Re30. I contacted the evaluator of the 2006 NDS evaluation for rationale to adopt value from 2002Re30, but did not receive a convincing reply. The two values marginally agree within 2σ.

4. $^{143}$Ce β- decay to $^{143}$Pr: ENSDF evaluation is from May 2011. No DDEP evaluation is available. This data set has data for 52 γ rays connected between 16 levels. Only one new paper 2012To09 for half-life of $^{143}$Ce decay. Gamma-ray energies, intensities, multipolarities and mixing ratios have been re-evaluated using the reliable data available using Ge detectors. Many additional details about various type of measurements are provided.

5. $^{147}$Nd β- decay to $^{147}$Pm: ENSDF evaluation is from November 2008, corrected γ-normalization factor Dec 2013. DDEP evaluation is from March 2011. An updated A=147 evaluation for ENSDF from Texas A&M, with some of my participation for the evaluation of this decay and the entire $^{147}$Pm nuclide, was submitted to NNDC Oct 2019, and is in the pipeline. Second most intense γ ray of 531.0 keV is of importance as it is used for monitoring nuclear events as well as determining experimental fission yields from different systems. NDS-2009 reported %Iγ=13.4(11), and Dec 2013 correction in the ENSDF reported 13.4(3)%, with $I_\beta$ feeding of <0.15% to the g.s., while DDEP-2011 reported 12.9(9)%, with $I_\beta$ feeding of 0(5)% to the g.s. Fairly significant differences and apparent large uncertainties in the γ-normalization factors and $I_\beta$ feeding to the g.s. made it difficult to use this isotope to determine precise fission yields. Perhaps for this reason, two new experiments were commissioned, one Livermore – Texas A&M – ANL collaboration, second CEA-Saclay group. The ENSDF and DDEP evaluations depended heavily on the latest publication for this decay: 1997Sa53 in PRC 56, 2468 (1997). During my evaluation, I found several issues in this paper, about the existence of several newly reported gamma rays, including some very low-energy transitions, based solely on singles gamma and conversion electron spectra, unrealistic low uncertainties for energies and intensities, and inconsistencies with in-beam γ-ray data where the same levels were populated. I communicated with the first author of 1997Sa53, and explained him the issues. He seemed to agree with most of the

items of questionable nature in the paper. The current evaluated dataset differs significantly from the 2009/2013 ENSDF and 2011 DDEP evaluations. Several γ rays attributed to $^{147}$Nd decay by 1997Sa53 have been omitted and a couple of levels dropped. In June 2020, results from the experiment by Livermore – Texas A&M – ANL collaboration appeared in LLNL-TR-811617 report, and last week a peer-reviewed paper from CEA-Saclay, presented at the 22nd ICRM-2019 conference, appeared in Appl. Rad. Isot. 166, 109349 (2020). I contacted Dr. Nicholas Scielzo (Livermore) whether the results in the report were the final numbers. He advised to wait for a former journal publication as the numbers may possibly still change a bit. I will need to revisit this decay when a paper from Livermore becomes available. In the meantime, following table compares photon emission probabilities for four most intense (>1%) γ rays in my recent evaluation with the results from the two experiments described above

| Egamma | My evaluation (Nov 2019) %Ig | LLNL (June 2020) %Ig | CEA-Saclay (Aug 2020) %Ig |
|---|---|---|---|
| 91.1 | 28.2(8)% | 29.02(40)% | 28.70(35)% |
| 319.4 | 1.98(6)% | 1.917(13) | 1.959(16) |
| 439.8 | 1.21(4)% | 1.189(10)% | 1.195(10)% |
| 531.0 | 13.00(34)% | 13.019(53) | 13.11(13) |

531.0 γ is of critical importance as it is used for monitoring nuclear events as well as for fission yield determinations in various systems. Value of emission probability has not changed in the new measurements, but the precision has certainly improved from 2.6% to ~0.5%.

## Annex IV: 4th Meeting on Decay Data for Monitoring Applications, 16 November 2020

**Meeting Minutes**
**(virtual meeting)**

Participants:
T. Kibédi – Dept. of Nuclear Physics, ANU, Canberra, Australia
Balraj Singh – Dept. of Physics and Astronomy, McMaster University, Hamilton, Ontario, Canada
P. (Vivian) Dimitriou – NCSR Demokritos Institute of Nuclear and Particle Physics, Athens, Greece
A. Negret – National Institute of Physics and Nuclear Engineering Horia Hulubei (IFIN-HH), Bucharest, Romania
S. Pascu – National Institute of Physics and Nuclear Engineering Horia Hulubei (IFIN-HH), Bucharest, Romania
Jun Chen – NSCL-MSU, East Lansing, Michigan, USA
F.G. Kondev – Physics Division, ANL, Argonne, IL, USA
J.K. Tuli – LBNL, Berkeley, CA, USA
R. Capote Noy – IAEA-NDS, Vienna, Austria (IAEA Project Officer)
M. Verpelli - IAEA-NDS, Vienna, Austria.

[Sec. Note: Alan L. Nichols could not attend.]

The meeting was informal and did not have a provisional agenda or chairman and rapporteur. Notes were taken by Vivian Dimitriou.

Capote welcomed everyone to the meeting and made the following announcements:
After conclusion of the IAEA internal review, the various contracts can now be submitted for approval.

[Sec. note: Capote left the meeting after the discussion]

**1. Technical discussions:**

Kondev mentioned that he had received two completed reviews, one by Nichols, and the other by Singh. Two issues were raised in their reviews:

- For application purposes it would be interesting and worthwhile to evaluate the decay chain of some of the long-lived priority nuclides in the CTBTP priority list and not only the initial decay. In some cases, the daughter nuclei in the decay chain are already included in the priority list and have therefore been assigned to an evaluator. This effectively leaves 6 additional nuclei that decay to stable nuclei and need to be evaluated.

  The 6 new nuclei will be added to the priority list and evaluators will inform Kondev about which nuclei they would like to add to their assignments.
- Singh suggested a different approach to averaging discrepant data from the traditional unweighted mean (UM) in the review of $^{106}$Ru decay. The new approach accounts for the uncertainties in contrast to the normal UM.

  Following discussions on the different averaging approaches adopted by the evaluators, it was suggested that an effort should be made to converge these approaches into one common approach for the CTBTO project.

Participants agreed to ask Singh to give a presentation on the different averaging methods and where/how they should be used. After the presentation, the other evaluators would also have the chance to present examples of discrepant data and the averaging approaches they adopted from their own evaluations.

Both the presentation and discussion on averaging approaches for the evaluation of $T_{1/2}$, $I_\gamma$, $E_\gamma$ data should take place at the following meeting.

## 2. Next meeting: 17 December 2020

Participants agreed to hold the next meeting on 17th December 2020, one hour earlier than the previous ones, i.e. at 13:00 CET.

P. (Vivian) Dimitriou 16 November 2020

## Annex V: 5th Meeting on Decay Data for Monitoring Applications, 17 December 2020

**Meeting Minutes**
**(virtual meeting)**

Participants:
T. Kibédi – Dept. of Nuclear Physics, ANU, Canberra, Australia
B. Singh – Dept. of Physics and Astronomy, McMaster University, Hamilton, Ontario, Canada
P. (Vivian) Dimitriou – NCSR Demokritos Institute of Nuclear and Particle Physics, Athens, Greece
A. Negret – National Institute of Physics and Nuclear Engineering Horia Hulubei (IFIN-HH), Bucharest, Romania
S. Pascu – National Institute of Physics and Nuclear Engineering Horia Hulubei (IFIN-HH), Bucharest, Romania
A.L. Nichols – Dept. of Physics, University of Surrey, Guildford, UK
Jun Chen – NSCL-MSU, East Lansing, Michigan, USA
F.G. Kondev – Physics Division, ANL, Argonne, IL, USA
J.K. Tuli – LBNL, Berkeley, CA, USA
M. Verpelli - IAEA-NDS, Vienna, Austria.

[Sec. Note: R. Capote, IAEA, was absent.]

The meeting was informal and did not have a provisional agenda or chairman and rapporteur. The notes were taken by P. Dimitriou.

### 1. Balraj Singh, Averaging methods

Singh gave a presentation on the different averaging methods included in the Java program V.AveLib, written by Michel Birch (ex McMaster student) under Singh's direction. He also mentioned the method 'Power Moderated Mean' published by S. Pomme in Metrologia 52 (2015) S200–S212.

Following the meeting, Singh prepared some notes for the evaluators (see Appendix) summarizing the discussions.

Some of the main takeaways from the discussions are given here:

Agreement was reached on the confidence level (CL) to be used for calculating the mean value: CL=95% which corresponds to a 2σ interval, i.e. 95% of the time the true mean value will fall within the 2σ interval.

Selection of a set of measured values from the available values, based on methodology and uncertainty quantification, is a subjective, but important criterion.

Singh expressed serious reservations about using the Unweighted Mean Method (UWM) as it does not take into account the uncertainties on data points. As an alternative, he proposed using the larger of the external or internal uncertainties obtained from the statistical analysis of the data, or another method such as Bootstrap, Mandel-Paule, which include uncertainties on data points and give results that are close to those obtained with the unweighted average.

The identification of outliers and treatment of discrepant data are also subjective calls, however, evaluators should consider all the available methods and try to avoid those that manipulate the data excessively. For example, the RT method can modify the cited uncertainties by several factors to lower the reduced $\chi^2$ to acceptable levels, which is not advisable. A more moderate adjustment of the uncertainties, as implemented in the NRM method, is regarded as a more reasonable way of treating somewhat discrepant data.

Evaluators should consult the 1978 Table of Isotopes, Edition (1978LeZM), which contains many older publications. Also, older evaluations in the Nuclear Data Sheets, as well as DDEP evaluations for selected nuclei, can be useful for finding older references.

1980Hu17: a publication containing several measured half-lives relevant to this project. The results are generally quoted with high precision, and given the absence of a detailed uncertainty analysis, it is recommended to treat these data with caution.

Evaluators are encouraged to discuss with each other should they have questions about the experimental data they are dealing with.

## 2. Additional priority nuclides based on the decay chain

The question was raised whether the six additional daughter nuclides proposed for evaluation at the previous meeting [see Minutes of Meeting of November 16th 2020], namely, Nb-97; Rh-106; Te-127; I-132; Pr-143; Pr-144, are indeed relevant to CTBTO monitoring applications and therefore need to be evaluated within this project.

Out of the above six daughter nuclides, only I-132 and Pr-144 are listed in the actual CTBTO International Data Center (IDC) nuclear data library, which means that the other 4 radioisotopes are not used in the CTBTO monitoring applications at all. However, I-132 and Pr-144 are not included in the priority list that was provided to the IAEA for the needs of the project. For these reasons, none of the above six listed radioisotopes need to be considered in this project. This concludes the discussion on additional evaluation needs that started at the November 2020 meeting.

## 3. Other

- Additional columns indicating whether a nuclide is being evaluated, reviewed, revised post-review or in the final checking stage of the process, have been added to the tables of priority nuclides (master file).

  Evaluators and reviewers are asked to provide all these dates to the technical coordinator (FK) and project officer (PD) when possible.
- The new home-based Special Service Agreements with the IAEA (contracts) will be submitted for approval this new year.
- Next meeting: 29-31 March 2021

  The next meeting will be held as an official IAEA Technical Meeting (virtually). Participants agreed to hold the meeting at the end of March, with most probable dates being 29-31 March 2021.

P. (Vivian) Dimitriou 12 January 2021
B. Singh

APPENDIX

**Notes on Averaging of experimental data, B. Singh**

1. When more than one measurement of a certain nuclear quantity is available in literature, select carefully and critically which data you plan to use. In literature, priority should be given to peer-reviewed publications. Selection criteria could include methodology, number of half-lives measured, overall statistics, and uncertainty analysis. Secondary literature such as non-peer reviewed conference proceedings and annual lab reports without checking with the authors about the validity of contents, and theses without checking with the supervisors should also be consulted but used with caution. Private communications, or e-mail correspondence should be OK as these are sent by the authors, as we rely on the credibility of what they say. Data in literature without uncertainties should not be used if values with uncertainties are available. Also, use only the latest measurement from a group or lab, who have reported their previous measurements using the same methodology.

2. When a selected data set is consistent (i.e. non-discrepant) as judged from reduced $chi^2$ below the critical $chi^2$ at 95% confidence level (or 2 sigma) by using weighted averaging, then use this method.
In some non-discrepant cases, critically review the assigned uncertainties in data points. It may be the case that uncertainties in a certain work are overly precise, in which case, weighting averaging procedures (such as WM, NRM) may not be valid. Either inflate the overly precise uncertainty, giving adequate rationale, or select another method which gives limited preference to very precisely quoted data points.

3. If the selected data set is discrepant, then try weighted average by assigning maximum of 50% weight to the most precise result in the set, which is essentially LWM method, but without its other two restrictions.

4. If the data set is still discrepant, try the NMR method, which tends to make minor adjustments in the input uncertainties. Look at the changes in uncertainties it has made.
If these changes seem reasonable, and reduced $chi^2$ is acceptable i.e. below the critical $chi^2$ at 95% confidence level, then accept this with adequate documentation.

5. If the data set is still discrepant, try Mandel-Paule, Bootstrap, or the new method from Geel Power-moderated mean (PMM), the last one is becoming quite popular in recent literature for both the discrepant and non-discrepant data. The PMM method is available on an Excel sheet. Balraj can send a copy upon request or Dr. Stefan Pomme can be contacted for a copy.

All these methods consider uncertainties in data points. Avoid unweighted average as the traditional formalism does not consider uncertainties, and it goes against the general precept in data analysis that a measured number without uncertainty is meaningless. Unweighted averaging can be used only if you consider upper and lower bounds within the quote uncertainties in data points.

## Annex VI: Evaluator Guidelines

**Revised on March 26, 2021**

The Guidelines provide a common framework and methodology that participants agreed to follow at the IAEA kick-off meeting in May 2019. Subjective judgments in the evaluation of various data are encouraged, but all related evaluator actions and decisions need to be justified and documented. Revisions to the Guidelines are made at the meetings and are published in the meeting minutes or reports.

### Parent (Parent record must be provided):

**Ex (keV):** 0.0 keV for the ground state. For an isomeric state, the Adopted Levels of the ENSDF evaluation should be consulted. If the recommended value differs from ENSDF, the adopted value must be explained.

**Jπ:** The Adopted Levels of the ENSDF evaluation should be consulted. If the recommended value(s) differ from ENSDF, these adopted value(s) must be explained.

**T1/2: must be evaluated.** All available data must be given in the comments, and a statement made as to how the recommended value and uncertainty were obtained. Follow the Guidance for Half-life Evaluation by A.L. Nichols and B. Singh from 29 April 2015: https://www-nds.iaea.org/nsdd/docs/Half-life_eval_guidelines_NSDD15_final.pdf.

**Q values:** From AME2016 (2017Wa10).

### Daughter:

#### Level:

**E [in keV]**: From a least-squares fit to Eγ (use ***GTOL*** program).

**Jπ [JPI]:** The Adopted Levels of the ENSDF evaluation should be consulted. If the recommended value(s) differ from ENSDF, these adopted value(s) must be explained.

**T1/2:** The Adopted Levels of the ENSDF evaluation should be consulted. If the recommended value differs from ENSDF, the adopted value must be explained.

> The half-life data for excited levels in the daughter nucleus must be given if known along with proper documentation. If the half-life is comparable to or longer than that of the parent state, one needs to consider the equilibrium condition, and therefore the half-life **must be evaluated**.

**%IT,%IB-,%IB+: must be evaluated.** When the lifetime of the excited level is very long (often greater than 1 s for the nuclei considered in the present exercise), so that decay branches other than IT are possible, the corresponding branching ratios must be evaluated.

#### Gamma:

**Eγ [EG, in keV]: must be evaluated.** All available data must be given in the comments, and a statement made as to how the recommended value and uncertainty were obtained.

Precise gamma-ray energies are available in some cases from various reaction data, for example, energies measured using bent-crystal spectrometers. Caution must be exercised when dealing with very precise gamma-ray energies (as measured by means of Ge and Si detectors) that are quoted to uncertainties lower than about 0.01 keV (equivalent to <10 ppm). Furthermore, measurements with a curved/bent crystal spectrometer can produce uncertainties as low as approximately 0.001 keV. How one handles this type of issue depends on the individual case, and there is no hard and fast rule.

**Iγ [RI]: must be evaluated.** All available data must be given in the comments, and a statement made as to how the recommended value and uncertainty were obtained.

When weakly populated states are present in a particular decay data set or some of the intensities are given as a limit, one may consider branching ratios from various reaction data sets where the level of interest may be more strongly populated.

**Mult [M]: must include a value**. The Adopted Levels of the ENSDF evaluation should be consulted. However, if no value is given in ENSDF, use Jπ values of the initial and final level to determine **Mult**, which should be listed as [**Mult**] in such a case. Use **[M1,E2]** for ΔJ=0, 1 γ-ray transitions when the parities of the initial and final state are the same. Use **[E1]** for ΔJ=0, 1 γ-ray transitions when the parities of the initial and final state are different. If the parity of either the initial or final level is unknown, use **Mult=[D,E2]**. Normally, **Mult**=M2 would require a substantial lifetime for the initial level, unless the gamma-ray energy is significantly large, say >1 MeV.

**δ [MR, mixing ratio]: must be evaluated.** All available data must be given in the comments, and a statement made as to how the recommended value and uncertainty were obtained. Use ***Briccmixing*** to determine MR when multiple data are available.

> Mixing ratios measured from angular distributions and correlations data, as well as values for the electron conversion coefficients and sub-shell conversion electron ratios that can be used to determine δ, have sometimes been measured in various reaction studies. These data should be considered when determining recommended mixing ratios.

**$\alpha_T$ [CC]:** use ***BrIcc*** to calculate the total electron conversion coefficient. If the adopted value is not taken from ***BrIcc,*** this avoidance should be explained, and the evaluator needs to make sure that the corresponding ***Mult*** and ***MR*** (if any) are consistent.

### Beta [$\beta^-$, ε, $\beta^+$]:

**IB [for $\beta^-$] or TI [for I(ε+$\beta^+$)]: must be evaluated.** Explain how the value and uncertainty were obtained. Often, these parameters are determined from the decay scheme and the intensity balance, so a general comment for **IB** is sufficient. However, special attention should be paid when a ground-state to ground-state transition between the parent and daughter is involved (e.g. no gamma ray or conversion electron emission is emitted in the decay branch). In such a case, a detailed explanation should be given concerning the adopted value and uncertainty for **IB**, and all known values should be listed. One should distinguish between what was actually measured and what was assumed by the authors' values, and if averages are used; the evaluator should make sure that all values are consistently on the same footing. Ensure that first forbidden unique and second forbidden unique transitions are denoted as '**1U**' and '**2U**', respectively, in columns **78-79**.

## Normalization (N record must be provided):

**NR: must be evaluated.** Generally, **NR** = [100 – **IB**(to gs)]/SUM[**TI**(to gs)]. When considering a γ-ray cascade, the evaluator may select other transitions within the cascade in order to determine **NR**. Use ***GABS*** or ***GTOL*** to determine **SUM**[**TI**(to gs)] and/or **NR**, and provide a comment on how **NR** was determined.

**BR: must be provided**. The Adopted Levels of the ENSDF evaluation should be consulted. If the evaluated and recommended value is different from ENSDF, this difference needs to be explained.

## Some useful tips:

- Run ***FMTCHK***, and correct all errors.
- Run Java ***ConsistencyCheck*** program, and correct all errors.
- Run ***Briccmixing*** to determine the adopted mixing ratio. Avoid averaging.
- Run ***GTOL*** to determine **IB [for $\beta^-$]** or **TI [for I(ε+$\beta^+$)].**

- Run ***GTOL*** to determine the daughter level energies – this code uses a least-squares fit to Eγ data.
- Run ***GABS*** on the final file to determine **%Iγ.** The program can also be used to determine **NR** and **SUM**[**TI**(to gs)] (see Normalization section above).
- Run ***Java-NDS*** to produce a pdf file along with suitable decay-scheme drawings.
- Run ***LOGFT*** on the final file to determine **EAV** and **log *ft*** values. Note that at the meeting we adopted ***BetaShape*** code to perform these calculations. However, the code is not available for all Operating Systems – since **EAV** and **log *ft*** are derived quantities, this can be done at the end by IAEA.
- Use ***NSR*** key numbers for referencing papers. When papers used in the evaluation do not already possess ***NSR*** key numbers, request new key numbers from the NSR manager.
- Manuals for various programs are available at: https://www-nds.iaea.org/public/ensdf_pgm/index.htm.
- ENSDF manual at: https://www-nds.iaea.org/public/documents/ensdf/ .

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