https://doi.org/10.61092/iaea.thns-5efz

IAEA
International Atomic Energy Agency

INDC(NDS)-0735
Distr. G, ND

INDC International Nuclear Data Committee

Summary Report of the

3rd Research Coordination Meeting

Development of a Reference Database for Beta-Delayed Neutron Emission

IAEA Headquarters, Vienna, Austria
12 – 16 June 2017

Prepared by

Iris Dillmann
TRIUMF
Vancouver BC, Canada

Paraskevi Dimitriou
IAEA Nuclear Data Section
Vienna, Austria

and

Balraj Singh
Department of Physics and Astronomy
McMaster University
Hamilton, Canada

November 2017

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

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

Printed by the IAEA in Austria

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Abstract
The 3rd Research Coordination Meeting of the IAEA Coordinated Research Project (CRP) on the Development of a Reference Database for Beta-Delayed Neutron Emission was held from 12 to 16 June 2017 at the IAEA Headquarters, Vienna. Participants reported and reviewed the overall progress made regarding the objectives and main outputs of the CRP, and agreed on the content and structure of the final document of the CRP. Summary reports of the presentations as well as an outline of the final technical document are given in this summary report.

November 2017

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Annexes

1. Introduction

A Coordinated Research Project (CRP) was approved in August 2012 with the aim of producing a Reference Database of beta-delayed neutron emission data. The CRP proposal and program was based on the recommendations of the Consultants' Meeting held from 10 to 11 October 2011 [1.1].

Three Research Coordination Meetings (RCMs) were held during the course of the CRP to help monitor progress and re-adjust the individual and group work plans in order to achieve the goals of the CRP in a timely manner.

The 1st Research Coordination Meeting (RCM) [1.2] of the CRP was held from 26 to 30 August 2013 at the IAEA headquarters in Vienna to determine the plan of the experimental, theoretical and evaluation work, assignments to participating groups, and CRP outputs.

The 2nd RCM was held from 23 to 27 March 2015 at IAEA in Vienna, to monitor the progress and revise the work plan accordingly. The revised list of assignments and summary of the discussions are published in the summary report [1.3].

The 3rd and final RCM was held from 12 to 16 June 2017 at IAEA in Vienna, to discuss the final results, determine the final items of the work plans that remain to be completed and agree on the content and structure of the final document describing the CRP.

Arjan Koning, Head of the Nuclear Data Section, welcomed the participants to the IAEA and wished them success in their work. The Agenda was approved without changes (see Annex 1) and the meeting began with participants' presentations according (See Annexes 2 and 3 for participant's list and links to presentations, respectively).

1.1 Objectives

The objectives of the CRP on Reference Database of beta-delayed neutron emission are to create a reference database of

- compiled and evaluated microscopic (precursor) data ($T_{1/2}$, P_n, delayed-neutron (DN) spectra), and
- recommended macroscopic quantities (total delayed neutron yield, group parameters for the time-dependent DN activity, and total DN spectra for fissile materials of interest)

In order to achieve the above two objectives, it was clear from the very outset of the CRP that the scope of the work by the members of the CRP had to focus on the following specific items:

1. Track progress of new measurements at major facilities around the world
2. Assessment of methods of measuring $T_{1/2}$, P_n and DN spectra (terminology adopted by this CRP on P_{1n}, P_{2n}, P_{3n} etc, P_n and neutron multiplicity has been defined in Refs. [1.1, 1.2])
3. Compilation and evaluation of standards for P_n and reference DN spectra
4. Compilation and evaluation of all available and published data on ($T_{1/2}$, P_n)
5. Empirical systematics of ($T_{1/2}$, P_n), and comparison with available theoretical calculations
6. Compilation and evaluation of available total DN yields per fission (ν_d) [or as commonly used in evaluated libraries: average number of DN per fission ($\bar{\nu}_d$)], time-dependent parameters and 6-, 8-group constants, total DN spectra

7. Summation calculations of total DN yields and spectra using different evaluated libraries
8. Sensitivity studies of total DN yields and spectra with respect to DN precursor data
9. Re-evaluation of group constants for thermal and fast neutron-induced fission of ^{235}U

In this 3rd RCM, participants reviewed the progress made on all the above listed items, and discussed what necessary actions are needed to ensure that the objectives of the CRP are achieved in a timely manner. The complete revised lists of actions and work assignments are included in Appendix 1.

References

[1.1] Summary Report of the CM on beta-delayed neutron emission evaluation, 10-11 October 2011, Vienna, INDC(NDS)-0599

[1.2] Summary Report of the 1st RCM of the CRP on Reference Database for beta-delayed neutron emission, 26-30 August 2013, Vienna, INDC(NDS)-0643

[1.3] Summary Report of the 2nd RCM of the CRP on Reference Database for beta-delayed neutron emission, 23-27 March 2015, Vienna, INDC(NDS)-0683

2. Summaries of presentations

2.1 bDN Evaluation and digitization at VECC related to the CRP, Gopal Mukherjee, VECC

The work on compilation and evaluation of beta delayed neutron probabilities and the digitization of neutron spectra that were assigned to VECC group at the 1st and 2nd RCMs is presented here:

bDN evaluation

We have completed the compilation and evaluation of beta-delayed neutron emitters for all the nuclei in the range Z = 41- 48. We have considered all the known beta-delayed neutron emitters as well as the “potential” beta delayed neutron (bDN) emitters. The potential bDN emitters are estimated from the Q-value and the neutron separation energies S_n / S_{2n} / S_{3n} values of the daughters. The evaluated parameters are: halflife of the parent ($T_{1/2}$), the probability of 1-neutron emission (P_{1n}). Apart from these the detailed comment on the methods of each of the measurements are also put in the table.

We have completed the compilation and evaluation of 93 bDN emitters or potential bdN emitters, including some nuclides with isomers The above mentioned parameters on all the measurements for a single nucleus were compiled in the first table. In the second table, a single evaluated value for each parameter has been given. The method of evaluation is also noted. The compiled values which were taken for consideration in order to obtain the adopted evaluated value were also marked. The compiled and evaluated tables have been sent to the coordinator, B. Singh.

Apart from the compilation and the evaluation work, we have also checked the compilation and evaluation table done by the other groups as sent to us by the coordinator.

Digitization of neutron spectra

The digitization of all the Rb and Cs spectra from the publication of 1990Re03 and 1985Gr15 have been completed and put in the bDN CONNECT site. About 20 spectra from these two reports were digitized. Presently the digitization of about 20 neutron spectra from various isotopes of Ga, As, Br and Rb from the thesis of Michaele Clarice Brady (1989BRZT) is under progress.

Other work

Apart from those, the preliminary results of the β-decay measurements of ^{43}K done at VECC, Kolkata, India using total absorption spectroscopy (TAS) and high resolution spectroscopy (HRS) as well as the works being performed on the neutron detectors (mainly on the data acquisition system) were also presented.

2.2 Summary report of evaluation the beta-delayed neutron emission data for Z=51-57 nuclides at CNDC, Huang Xiaolong, China Nuclear Data Center

Selecting precursors

64 potential beta-delayed neutron emitters in the Z=51-57 region have been selected based on AME-2016 and $Q_{\beta\text{-}n} = Q_\beta(A,Z) - S_n(A,Z+1)$. The literature cut-off date is March 31, 2017.

Compilation & evaluation

Based on NSR, about 55 potential beta-delayed neutron emitters for half-lives were compiled, together with experimental P_{1n} values for 38 delayed one-neutron emitters, one measurement for P_{2n}, but no measured data for three-neutron emitters.

After carefully analysis for each experiment, based on the details and methods described in the paper and in comparison with other experiments, the recommended data were obtained from a statistical analysis of the selected measured data. In present evaluation, we generally adopted the weighted average (WA), and sometimes adopted the normalized residual method (NRM) or the unweighted average (UWA) for some discrepant data. We considered asymmetric uncertainties if the measured data that were adopted had asymmetric uncertainties.

Results of evaluation

We compiled and evaluated the $T_{1/2}$ of 55 beta-delayed neutron emitters in total, P_{1n} of 38 delayed one-neutron emitters and P_{2n} of one delayed two-neutron emitter in the Z=51-57 region. Some typicaly results are provided. A potential beta-delayed neutron emitter, ^{146m}La, was proposed and needs to be identified by future experiments.

Two tables in EXCEL format were available. One is the table of compiled data & comments for P_{1n}, P_{2n}, P_{3n} and half-lives with all the available references; another is the table of adopted/recommended half-life and P_n data with data processing method.

These two data files have been submitted to review by other groups. Also we checked the evaluation in Z=30-40, 49, 50 from another group.

Future work

In consultation with the coordinator, we will re-evaluate the P_{1n} value for ^{137}I precursor based on the new measurements and discussions. Finally the CRP document will be prepared.

2.3 ^{95}Rb beta decay half-life determination from BELEN at IGISOL, Alejandro Algora, IFIC-University of Valencia

The beta decay half-life of ^{95}Rb was determined using the data from two BELEN experiments performed at IGISOL IV (Univ. of Jyväskylä, Finland). The two experiments used different polyethylene matrices. The I162 experiment (spokespersons: Tain, Gomez) used a matrix, which was designed to optimize the flatness of the neutron efficiency and the I181 experiment (spokesperson: I. Dillmann) employed a matrix that maximized the neutron efficiency. In the experiments different beta detectors were employed. Both experiments used the beta decay of ^{95}Rb as a calibration source for the determination of the neutron efficiency of the setups. ^{95}Rb was produced at IGISOL and separated using the JYFL Penning trap.

The reason for the request to determine the half-life from these recent measurements at IGISOL was to check the inconsistency in the half-life value of this decay determined from a recent measurement (M. Quinn et al. PRC85, 035807) at MSU when compared with the adopted value from ENSDF. The value obtained by M. Quinn et al. is 412(1)(13) ms to be compared with the adopted value of 377.7(8) ms.

From the two IGISOL experiments three half-lives were determined. From the I181 experiment it was possible to determine the half-life of ^{95}Rb from the growth and decay curve obtained from the beta detector (376(4) ms) and from the growth and decay curve of the neutron detector (379(4) ms). From the I162 experiment only the growth and decay curve of the neutron detector was used (378(4) ms). This last analysis provided the best fit. The beta detector of the I162 experiment was not used for the determination of the half-life because of its possible gamma sensitivity (phoswich detector).

The mean value of the three measurements that can be considered independent only to a certain extent is 377.7 (23) ms, in excellent agreement with the adopted value.

2.4 Compilation and evaluation of P_n and half-lives of Beta-delayed neutron emitters across the whole nuclear chart: Part 1: Z=2-28 region. Part 2: Z>28 region, Balraj Singh, McMaster University

This work presents the first comprehensive, up-to-date and independent compilation and evaluation of beta-delayed neutron emission probabilities and half-lives of all the experimentally known beta-delayed neutron precursors, with provision of complete bibliography. Detailed systematics of P_n, half-lives and Q values (using the three known approaches) were presented, using all the evaluated data in current work.

Part 1: Z=2-28 region: This work was carried out in 2013-15 by M. Birch and B. Singh (McMaster), I. Dillmann (TRIUMF), E. McCutchan, A. Sonzogni and T. Johnson (NNDC, BNL), and D. Abriola (CNEA, Argentina), and was published in **NDS 128**, 131-184 (October 2015). All the pertinent data files were sent to the IAEA-NDS for reference database created and organized by M. Verpelli and P. Dimitriou (IAEA). We are keeping a record of papers published after the literature cutoff date of August 2015 for the NDS publication. At a later data, sometime in 2018, this region will again be updated to include newer data.

Part 2: Z>28 region: This work on about 400 nuclides was carried out from 2015 onwards by J. Liang, B. Singh, M. Birch and A. Chen (McMaster), I. Dillmann (TRIUMF), E. McCutchan, A. Sonzogni and T. Johnson (NNDC, BNL), X. Huang, J. Wang and M.X. Kang (CIAE, Beijing), G. Mukherjee and K. Banerjee (VECC, Kolkata), A. Algora (Valencia,), D. Abriola (CNEA, Argentina), and K. Miernik (Warsaw). First draft of all the relevant data files was sent to the IAEA-NDS in April 2017, and was also communicated to the participants interested in calculating macroscopic quantities in the fission process of relevant nuclides. Later the files were revised for several current papers, as well as for the AME-2016, when its tabular text files became available at the end of April 2017. The reference standards were revisited in view of some recent data for decays of ^{137}I, ^{138}I, ^{145}Cs, ^{146}Cs and ^{147}Cs. Detailed systematics of P_n, half-lives and Q values were presented at the meeting. A paper based on the above work for Z>28 nuclei is under preparation and it is expected to be submitted for publication in the NDS by about September 2017. At that time, updated version of all the data files will be submitted to the IAEA-NDS.

2.5 Relative abundances of delayed neutrons and half-lives of their precursors from fission of ^{232}Th, ^{238}U, ^{239}Pu, ^{237}Np, ^{241}Am by neutrons in the energy range 14.2-18 MeV and 1 GeV protons, Vladimir Piksaikin, Institute of Physics and Power Engineering

Data on the relative abundances and periods of delayed neutrons from fissionable materials in the energy range in the vicinity of 14 MeV are important for the development of safeguard and reactor fuel assay instrumentation. But large discrepancies in these data are one of the obstacles on the way of its implementation. The present work is devoted to the investigation of the energy dependence of the relative abundances of delayed neutrons and half-lives of their precursors from the fission of ^{232}Th, ^{238}U, ^{239}Pu, ^{237}Np, and ^{241}Am by neutrons in the energy range 14.2-18 MeV. The experimental set-up employed in the present work was installed on the beam line of the electrostatic accelerator CG-2.5 at IPPE. The T(d,n)^{4}He neutron source was employed in the measurements. The experimental method used in the experiments is based on periodic irradiations of the fissionable samples in a well defined neutron flux followed by the measurement of the time dependence of the delayed neutron activity. In preliminary experiments two effects were found that can be considered as sources of existing discrepancies in the 14 MeV data. The first effect is due to the concomitant neutron source D(d,n)^{3}He due to the implantation of deuteron ions in the backing of the tritium target. Therefore special experiments were conducted with the purpose to develop an empirical model allowing the simulation of the intensity of the concomitant neutron source D(d,n)^{3}He in correlation with the number of deuteron ions implanted in a tritium target. Data on the intensity of the D(d,n)^{3}He neutron source in correlation with the ion charge accumulated in the tritium target allowed to account for the effect of the concomitant neutron source The second effect is related to the degradation of the neutron detector counting rate characteristics in an intense field of high energy neutrons from the T(d,n)^{4}He reaction. A special experiment for the measurement of count rates of the neutron detector after its irradiation by neutrons from the T(d,n)^{4}He reaction was made. In this experiment the time dependence of count rates from an Am-Li neutron source was measured immediately after irradiation of the neutron detector by the T(d,n)^{4}He neutron flux of different intensities in the energy range 14-18 MeV. The procedure was developed to account for this effect. As a result, the data on the energy dependencies of the relative abundances of delayed neutrons and half-lives of their precursors from the fission of ^{232}Th, ^{238}U, ^{239}Pu, ^{237}Np, and ^{241}Am by neutrons in the energy range 14.2-18 MeV was obtained including appropriate covariance data. The data for ^{237}Np and ^{241}Am was obtained for the first time.

Relative abundances of delayed neutrons and half-lives of their precursors from fission of ^{238}U by 1 GeV protons have been measured in the interaction of relativistic protons with ^{238}U using a beam of the synchrocyclotron of the Petersburg Institute of Nuclear Physics, Gatchina. It was shown that the emission of delayed neutrons in this reaction takes place in the asymmetric fission channel in which the most probable fissioning nucleus is ^{234}U*. The obtained data were compared with the appropriate delayed neutron data measured in direct kinematics and data obtained by the summation technique from the isotopic distributions of products measured in the inverse kinematics, ^{238}U(1 A GeV)+p. The comparison made in terms of the average half-life of the delayed neutron precursors showed that all data agree within their uncertainties. It was shown that in the present study the measured average half-life of the delayed neutron precursors ($\langle T \rangle$ = 7.12±0.12) significantly differs from the corresponding value ($\langle T \rangle$ = 12.39± 0.25), obtained in the low-energy fission of ^{233}U by fast neutrons, as well as from the value calculated using the systematics developed on the basis of the fast neutron induced fission data. It was shown that this discrepancy can be explained if one takes into account the energy dependence of the average half-life of delayed neutron precursors $<T(E_n)> = 12.66 - 0.108 \cdot E_n$. The accounting of this relationship allowed to estimate that the excitation energy of the fissioning compound nucleus $^{234}U^*$ in the asymmetric fission channel by the interaction of relativistic protons with ^{238}U is about 57 MeV.

2.6 Delayed neutron summation calculations and the identification of important precursors using the new CRP P_n values, Robert Mills, National Nuclear Physics Laboratory

Mills presented an update to his previous work calculating the total delayed neutron emission per fission values $\bar{\nu}_d$ for a few fissioning systems using the preliminary draft P_n values being exchanged within the CRP. His initial results lack the uncertainties from the P_n data sets, as a method to correctly propagate the uncertainties of the P_{1n}, P_{2n}, and P_{3n} values combined with the beta emission probabilities within his codes will need to be developed. The results show similar values to the previous work, although there is a general increase in the $\bar{\nu}_d$ values.

Comparisons of the most important radionuclides contributing to some fissioning systems were performed, and $\bar{\nu}_d$ values were shown between JEFF-3.1.1 and the draft of the experimentally determined P_n set for this CRP. Mostly the same nuclides were shown in the same order, but some differences appeared. These differences may be partially due to the incomplete list of P_n values from the CRP experimental measurement analysis and the assumption in Mills' work on the isomeric state to assume for some of the P_n values. There is also an increase of the P_n values of some important delayed neutron emitters (e.g. ^{90}Br).

Mills summarised the JEFF delayed neutron data. The JEFF general purpose files provides aggregate time dependence and spectra in 8 groups based upon the data recommended by the WPEC sub-group 6 prepared by Campbell and Spriggs. The radioactive decay data file (RDD) includes P_n values (per decay) for all delayed neutron emitters but only includes a few nuclides with, presumably experimental, delayed neutron spectra. It is not recommended that these individual delayed neutron spectra from the JEFF RDD file are used as they are only included for a few nuclides and their source is uncertain.

Mills stated that when the final experimentally determined P_n set and best estimate theoretical estimates of the unmeasured radionuclides are available he plans to repeat this work on $\bar{\nu}_d$ values and use the data to calculate the "mean half-life" value, delayed neutron time dependence and the neutron spectra.

In discussion, Mills agreed to produce a listing of the current JEFF-3.1.1 and ENDF/B-7.1 isomeric states for delayed neutron emitters to assist the evaluators.

From this discussion, it appears that the JEFF-3.1.1 fission yields and the ENDF/B-7.1 radioactive decay data files would be the best current sources of data for aggregate delayed neutron calculations as the JEFF decay data does not include delayed neutron spectra except for a few nuclides with historic data. The decay data would need to be augmented by the new data produced by this CRP for the benchmarking calculations.

2.7 Energy Dependence of Delayed Neutron Yields and several short reports, Futoshi Minato, JAEA, Michigan State University

Delayed neutron yields (DNYs) from neutron induced fission depend on the incident neutron energy. This is a consequence of the energy dependence of fission product yields. For the moment, the energy dependence of DNYs (MF=1, MT=455) in ENDF, JEFF, JENDL libraries were just evaluated by interpolating experimental data or recommended values by structure-less lines. In order to evaluate it in a more practical way and give a realistic curve, we analyzed the DNYs of uranium and plutonium isotopes by theoretical fission yields parametrized by the five Gaussian method with Katakura's systematics and the Z_p model. A phenomenological energy dependence was introduced in the most probable charge and the odd-even effect in the fission yields. The parameters in the model were determined by the least square fitting to the existing delayed neutron experimental data. It was reported that the energy dependence of DNYs were successfully reproduced by the obtained parameter set. Because several nuclei such as ^{234,237}U and ^{238,240}Pu have no experimental data, we adopted a prescription that gives a large uncertainty to the parameters for them. It was concluded that the uncertainties of them are able to be reduced if new DNYs for those nuclei up to several MeV were measured.

Anomalously large yields of ^{86}Ge, ^{88}As, ^{100}Rb, and ^{131}Cd were reported. They were re-calculated and now compiled in JENDL/FPY-2011 (version: Feb. 2017). We also reported a bug found in the JENDL/FPY-2011, which has been already corrected.

Finally, the delayed neutron activity and its uncertainty with the newly evaluated CRP decay data were reported. The calculation was performed with the JENDL/FPY-2011. It must be noted that JENDL/FPY-2011 used in this work is not consistent with the CRP decay data, and does not properly take the correlations between fission product yields into account. However, this approach would be able to give some implications. It was reported that significant changes in the uncertainty were found in the delayed neutron activities of ^{235}U(thermal), ^{238}U(fast), ^{235}U(fast), ^{232}Th(fast). The responsible precursors changing the uncertainties were also reported.

It was also briefly discussed that the gamma-decay is still effective at energies above the neutron threshold by showing the Hauser-Feshbach model calculations.

2.8 Summation calculations and uncertainty analysis of delayed neutron yield, half-time and temporal group constants, Pierre Leconte, CEA-Cadarache

Summation calculations of the average delayed neutron yield $\bar{\nu}_d$ and average delayed neutron precursors' half-life $\bar{T}_{1/2}$ have been performed and compared with recommended data from the literature. They are used for a macroscopic validation of delayed neutron precursors' evaluated data in nuclear data libraries. Among the different sets of cumulative yields 'CY' (JEFF-3.1.1, ENDF/B-VII.1, GEFY-5.3) and delayed neutron emission probabilities 'Pn' (ENDF/B-VII.1, Pfeiffer 2002, JEFF-3.1.1) that were tested, the best agreement on ^{235}U, ^{238}U and ^{239}Pu thermal and fast fission is achieved with the combination of JEFF-3.1.1 CY and P_n data from Pfeiffer2002 or ENDF/B-VII.1. The uncertainty on $\bar{\nu}_d$ and $\bar{T}_{1/2}$ has been calculated with a Monte-Carlo method, assuming as a first step the independence between P_n and CY, and affecting either 0% or 100% uncertainty for parameters with missing uncertainties. It is shown to vary from 3 to 10%, with the most important contribution due to CY.

Since JEFF-3.1.1 fission yields failed to reproduce the energy independence of $\bar{\nu}_d$, a test has been done by using the GEF-5.3 energy model to obtain JEFF-3.1.1 fast CY from JEFF-3.1.1 thermal CY. The improvement is very significant for ^{235}U, resulting in an almost energy independence of $\bar{\nu}_d$ between thermal (25 meV) and fast (400 keV) energies.

Meanwhile, independent yields from JEFF-3.1.1 and delayed neutron emission probabilities from ENDF/B-VII.1 have been used to derive delayed neutron emission rate curves by the summation method. The procedure was repeated a thousand times, by sampling P_n and CY according to their standard deviations. For each curve that was generated with this approach, a new set of 8-groups abundances has been derived through a nonlinear Least-Square-Fit (fixing the decay constants to the JEFF-3.1.1 values). From the statistical treatment of thousand sets of abundances, we obtained average estimates, standard deviations and a correlation matrix between the 8-group parameters. These data were used in reactor kinetics equations to evaluate the impact on the dynamic reactivity from the measurement of reactor period. It is concluded that these summation calculations are in pretty good agreement with results obtained from the JEFF-3.1.1 8-group abundances, while the 6-group set from ENDF/B-VII.1 is strongly inconsistent.

The next step will be to fix the abundances of the first 3 groups to the ratio $\nu_{d,i}/\overline{\nu_d}$, where $\nu_{d,i}$ is the partial DN yield of group i (^{87}Br, ^{137}I and ^{88}Br, respectively). In this way, only 5 parameters would be needed for the fit. Another work to be done is to evaluate the effect of the fission yields covariances on the delayed neutron yield uncertainty.

Finally, to verify the exactness of the summation calculation and improve the current uncertainties associated to the 8-group abundances, a new experiment is expected to be performed at ILL Grenoble, where the delayed neutron emission rate curve will be measured for various irradiation time conditions.

2.9 Validation of delayed neutron data based on various reactor experiments, Pierre Leconte, CEA-Cadarache

Various reactor experiments were considered for the validation of the effective delayed neutron fraction β_{eff} and for the validation of the inhour equation linking the dynamic reactivity to the reactor period. Mostly based on neutron noise techniques, the measurement of β_{eff} is usually achieved with an uncertainty of 2-3%, so that it can be used to check the correctness of evaluated delayed neutron yields, assuming the total (delayed+prompt) neutron yield to be a reference data.

The different experiments are covering cores loaded with U or U/Pu fuels, of thermal or fast spectrum. They offer a comprehensive validation for PWR and SFR applications. The analysis of these experiments was recently revised using reference methods (adjoint-based) implemented in the TRIPOLI-4 Monte-Carlo code, so that the comparison between experimental and predicted results can be better attributed to the delayed neutron data that were used in the calculation. The main conclusions are that the current evaluations of delayed neutron yields in both, JEFF-3.1.1 and ENDF/B-VII.0, for ^{235}U and ^{239}Pu are correctly predicting the β_{eff}, within experimental uncertainties. However, based on the average of many independent experiments, the 1.585% value for the thermal fission of ^{235}U, adopted in ENDF/B-VII.1, seems to be working better than the 1.62% one in JEFF-3.1.1.

For the validation of the 6/8-group decay constants and relative abundances, as used in dynamic reactivity inferred from the measured reactor period, the IPEN international benchmark was used. The average delayed neutron half-life computed from JEFF-3.1.1 parameters is shown to be in much better agreement with the experiment than the ENDF/B-VII.0 ones. The consequence is straightforward on the dynamic reactivity: on one hand, a better prediction is achieved with JEFF-3.1.1 library, thanks to better evaluated data and the description of delayed neutron emission in 8-groups instead of 6-groups in other nuclear data libraries. On the other hand, the 6-group ENDF/B-VII.0 data are strongly underestimating the dynamic reactivity, by more than 10% for typical reactivity ranges of -0.3 to 0.3. An interesting conclusion is also derived from the 6-group JENDL-4.0 data, which are working as well as JEFF-3.1.1 data for such low reactivities, but are showing larger underestimation for strong negative reactivity (-0.8 to -1), confirming the conclusions of the OECD/WPEC-6 report on the better description of the dynamic behavior of under-reactive cores.

In the future, other experimental results of β_{eff} are expected from the EOLE and MINERVE zero power reactors. A project is also under investigation to measure the reactor transfer function thanks to a reactivity modulating system, so that more accurate estimates of relative abundances could be obtained.

2.10 Importance of Simulation Tools and Nuclear Data for Safeguard, Sandrine Cormon, IAEA – Department of Safeguards – Division of Operations C

The purpose of IAEA safeguards is to verify states' legal commitments under their respective safeguards agreements with the IAEA. In order to do so, as a first step, a safeguards approach is developed for a state (State Level Approach – SLA). The approach is based on an Acquisition Path Analysis (APA), which is a structured method used to analyze the plausible paths by which, from a technical point of view, nuclear material suitable for use in a nuclear weapon or other nuclear explosive device could be acquired. The frequency and the level of accuracy of verification activities depend primarily on the nature of the nuclear material[1] and whether it is irradiated or not. They also depend on the results of the APA, on the conclusion the Agency was able to draw on the state's activities and on the range of activities the Agency is able to perform in accordance with the safeguards agreements in force.

For innovative fuel cycle and/or reactors not yet under safeguards, approaches need to be developed by analyzing the flow of nuclear material and the prospective misuse[2] scenarios. Due to the innovative nature of the fuel and/or facility, the observables of interest need to be identified based on simulations of the evolution in time of the nuclear material both under irradiation and afterwards. Such simulations are conducted using the coupling of a code determining the reactivity of the core, the neutron flux shape and the amount of fission products at a given time with a code resolving the so-called "Bateman Equations" which describe the evolution in time of the nuclei through neutron irradiation and radioactive decay. They widely depend on nuclear data (mainly: interaction with neutron cross-sections, fission product yields, beta-delayed neutron emission and beta-decay data). Presently, such simulation methods are the only way to perform nuclear safety studies for non-existing reactors (e.g. beta-delayed neutron fraction, decay heat …), and a large effort has already been undertaken to improve the error bars induced by the nuclear data and their propagation in order to accurately reproduce known data and evaluate the accuracy of predictions. This effort is in clear synergy with safeguards needs: such simulations would allow the evaluation of the expected spectra emitted by innovative unirradiated and irradiated fuels and an estimation of the feasibility of misuse scenarios. This would allow an early development of safeguard approaches that could also be integrated in the design of new facilities.

The improvement of nuclear data of cross sections, fission product yields, beta-delayed neutron emission, and beta-decay are therefore of high interest of the Safeguards Department.

2.11 BNL Report, Alejandro A. Sonzogni, National Nuclear Data Center, BNL

Our contributions to this part of the CRP has been a) to check the recommended P_{xn} and $T_{1/2}$ values, b) to derive systematics for P_{1n} and $T_{1/2}$, c) to obtain delayed nu-bars and neutron activities. Based on this work, a few suggestions regarding the format of the recommended values file are made.

[1] We distinguish "Direct Use Material" (namely: plutonium, high enriched uranium (>20% ^{235}U) and ^{233}U) from "Indirect Use Material" (namely: thorium, natural uranium, depleted uranium and low enriched uranium).

[2] An example of misuse of a facility is an undeclared operation of the facility in order to produce undeclared material.

The checking of the recommended P_{xn} and $T_{1/2}$ values included a) careful reading of tables and documentation, b) comparison with ENSDF and 2016 Nubase values, c) plotting to spot possible typos and verify trends.

For the P_{1n} values, we obtain the parameters of the Kratz-Herrmann, $P_n = a(Q_{\beta n}/(Q_\beta\text{-C}))^b$, and McCutchan *et al.*, $P_n/T_{1/2} = a\ Q_{\beta n}{}^b$ systematics. For the $T_{1/2}$ values we obtain the parameters for the Kratz-Hermann systematics, $T_{1/2} = a(Q_\beta\text{-C})^b$, observing some interesting trends in the way the points align. For Z < 36 or Z around 50, the half-lives seem to be longer than for the rest of the nuclides.

Delayed nu-bars and neutron activities were compared using the JEFF fission yields. We observed a good agreement with the values obtained using the ENDF/B-VII.1 decay data sub-library. We observe that in order to obtain uncertainties, fission yield correlation matrices are needed.

Finally, we share our experience on translating the evaluated values into numbers. In particular, we recommend that a purely numerical version of the evaluated file is created, including level energy, spin and parity, percentage of beta-minus decay, and Q_β, $Q_{\beta n}$, $Q_{\beta 2n}$, $Q_{\beta 3n}$ values. This file would include symmetrized uncertainties for half-lives and P_{xn} values.

2.12 Summation calculations, Gross theory and Surrogate method, Satoshi Chiba, Tokyo Institute of Technology

1. Summation calculation of the time-dependence of decay heat and delayed neutron yields after burst fission was carried out by using fission product yield data from various sources: JENDL, ENDF, JEFF, GEFF and GEF model calculations. Decay data were taken from JENDL/DD-2011. Initially, it was demonstrated that JENDL FPY data can reproduce the decay heat for thermal neutron induced fission of ^{235}U, but seriously fail to describe the decay heat values. It was pointed out that it is due to a mistake (in ENDF FPY) of the independent yield of ^{86}Ge. After modifying it by reducing with a factor or 1,000, agreement with the delayed neutron data became much better, while some inconsistency still remains. Then, we did sensitivity analysis, and adjusted the independent FPY of about 10 nuclei to yield better reproduction of the delayed neutron yield as an ad-hoc improvement. Then, that data was used to calculate the decay heat, and it was found that this modification does not affect the prediction for the decay heat, giving very good reproduction. Furthermore, the PIE (Post Irradiation Examination) analysis was done by using the modified data, and no noticeable deterioration with respect to the original JENDL FPY data was found. Then, the delayed neutron yield was fitted by a 6-group representation, and reactivity versus reactor period was calculated by the inhour equation, which almost coincides with the data by Keepin. Therefore, we can conclude that consideration of the decay heat, delayed neutron yield and PIE data simultaneously is a way to improve the FPY yield, which will eventually give reliable data for the aggregate delayed neutron yield.
2. The status of the measurements of FPY by the surrogate method was reported. We have used a ^{18}O beam on ^{232}Th, ^{237}Np, ^{238}U and ^{248}Cm. Mass distribution data for a number of new fissioning nuclei were determined.
3. The Langevin equation for nuclear fission was extended to 4D shape variables. This new version can reproduce the mass distribution for known and new data from the surrogate method quite well, and also the total kinetic energy of the fission fragments. It will be soon connected to the Hauser-Feshbach model code to yield prompt neutron multiplicities.

4. The Gross theory of beta decay was improved by taking account of the shell effects in the level density prescription. The steep decrease of the half-lives at magic numbers is resolved, and it gives much better reproduction of the P_n data. It was used to calculate the reactor anti-neutrino spectra, which can be favorably compared with data from ILL Grenoble.
5. By combining the theory starting from the compound nuclei to scission (Langevin), prompt neutron emission (Hauser-Feshbach) and beta decay (Gross theory), we are going to construct a systematic computation method of fission phenomena.

2.13 Beta decay and delayed neutron emission near shell-closures, Ivan N. Borzov, NRC Kurchatov Institute Moscow and BLTP JINR Dubna

Given a spectacular progress on the β-decay data of fission and fragmentation products from the radioactive beam facilities, the combined analysis of the β-decay half-lives and multi-neutron emission probabilities provides a unique possibility to reconstruct the beta-strength functions. The latter contain unique information on the structure and parameters of nuclear density functional in the high isospin-asymmetry regime [1,2]. The fully microscopic beta decay models have appeared recently ensuring more reliable extrapolation of nuclear data to extreme N/Z ratios than the micro-macro global approaches.

Review. In the period after the RCM-2, the continuum quasi-particle random-phase approximation (CQRPA) [3] for the allowed Gamow–Teller (GT) and first-forbidden (FF) beta decays theory has been further improved and used for new large-scale calculations. The approach is based on the self-consistent description of the ground state properties within the local energy–density Fayans functionals (DF3,3a, FaNDF_0 and the newly developed FaNDF_1). A critical comparison has been performed of the latest self-consistent models in their application to global calculations of the beta decay half-lives and DN emission: our DF+CQRPA model [3], relativistic DC3*+RQRPA [4] based on the covariant energy density function; SkO'+Finite Amplitude Method (pnFAM) [5], and the Interacting Shell Model [6]. An improvement of the T=0 proton-neutron effective interaction and inclusion of the quasi-particle-phonon coupling is needed for the QRPA models.

Main results. The new code has been developed for the ground-state calculations in the deformed nuclei with the FaNDF0 functional [7]. New deformed calculations have been done of the energy releases (Q_β) and multi-neutron emission thresholds (S_{xn}). A modified DF+CQRPA model has been applied for β-decay strength functions, half-lives and multi-neutron emission rates of spherical nuclei with the neutrons filling the orbitals beyond the major shells at N > 50 near ^{78}Ni and at N>82 near ^{132}Sn. A region of interest are heavy K, Ca and Sc isotopes with N>28, in which the evidences of the new magic N=34 shell has been obtained recently. A stabilization of the beta decay half-lives ($T_{1/2}$) versus mass number A is predicted [8] in the mass regions corresponding to the ground-state spin inversion. Such behavior exists in the regions of N > 50 around ^{78}Ni and N>82 near ^{132}Sn in agreement with the data [9,10]. It is expected in Ca and K isotopes with N>32, 34 for which the measurements are underway. High two-neutron probabilities are predicted in ^{52,53}K, as well as a giant P_{2n}>80% in ^{54}K which can be verified at ISOLDE-CERN [9]. It is of prime importance to quantify an (anti)correlation between the high P_{2n} values and unexpectedly large charge radii measured recently in ^{51,52}Ca and $^{49-51}$K. Comparison of the recent theories [3-6] shows that deviations of these results near closed shells are mostly due to the difference in energy density functions (EDFs) and estimated shares of the FF decays to the total rate (%FF). The impact of quasi-particle phonon coupling on the half-lives [11] and delayed multi-neutron emission rates near [12] has been also studied.

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2.14 Large-scale calculations using the Relativistic Mean Field model, Tomislav Marketin, University of Zagreb

The decay properties of neutron-rich nuclei are important in a wide range of applications where they determine the dynamics of a physical system: from astrophysical applications where beta-decays set the time scale of the r-process, to very practical applications in maintaining criticality. Therefore, it is crucial to compile a table of known and predicted values of beta-decay half-lives and beta-delayed neutron emission probabilities for all relevant nuclei.

As most of these nuclei are beyond the capabilities of current experimental facilities, good theoretical predictions become vital for better modeling of physical systems. We have employed a fully microscopic theoretical framework based on the relativistic nuclear energy density functional (RNEDF) in order to calculate the decay properties of all neutron-rich nuclei from the valley of stability to the predicted neutron drip-line. The results were presented and published in Physical Review C 93, 025805 (2016).

Further analyses have shown that while the description of beta-decay half-lives has very good predictive capabilities when compared with newest measurements, the description of beta-delayed neutron-emission probabilities could be significantly improved. To address this issue, we have selected three possible approaches: (i) improving the underlying nuclear energy density functions, (ii) improve the nuclear binding energies used in the calculation of emission probabilities, and (iii) improve the model used in the description of neutron emission.

The isovector properties of the nuclear interaction are of key importance for a good description of decay properties of neutron-rich nuclei. To better constrain this component of the interaction we have extended the set of observables used in the process of constraining the model parameters to also include the positions of the Gamow-Teller giant resonance in ^{48}Ca, ^{90}Zr, ^{112}Sn, ^{116}Sn, ^{120}Sn, ^{124}Sn, and ^{208}Pb. Because the calculation of excitations is computationally expensive, the study has not yet been finalized. However, the preliminary results are promising as they show a steeper multidimensional surface around the optimum in the parameter space.

Just as important are nuclear masses as they determine the neutron separation energies that are used in the calculation of emission probabilities. We have engaged in the construction of a new nuclear energy density functional focused on providing the best possible description of known nuclear masses. In this calculation we perform fully self-consistent calculations of ground state energies of both spherical and deformed nuclei. Preliminary results show an improvement in the description of deformed nuclei, especially for the lantanides and actinides.

Finally, to improve the calculation of the beta-delayed neutron emission probabilities, we leave the simple approximation that is commonly used. We employ the emission cross sections obtained with the statistical de-excitation codes and fold them with the decay strengths obtained from our calculation. We observe large improvements in some isotopic chains (such as Mg and Si) and are now able to take into account the competition between the gamma-, one-, and two-neutron emission.

2.15 β-delayed neutron studies for heavy isotopes, Iris Dillmann, TRIUMF

The beta-delayed neutron detector (BELEN [1-3]) is a versatile neutron detector consisting of ^{3}He-filled long counters, surrounded by a polyethylene moderator that can be adapted to the respective facility environment, and a state-of-the art digital data acquisition system [4].

BELEN has been utilized at the IGISOL facility in Jyvaskyla (2009, 2010 and 2014) [3, 5-7], at the Fragment Separator at GSI Darmstadt (2011) [8, 9], and at the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig/ Germany (2013) [10]. Recently it has been merged with more ^{3}He neutron detectors into the BRIKEN project ("β-delayed neutron measurements at RIKEN") in Japan and it was successfully commissioned in November 2016.

The design of the BELEN detector has evolved and its neutron detection efficiency subsequently increased up to 60% for the latest version (BELEN-48 at IGISOL 2014). Extensive Monte Carlo simulations have been carried out to improve the efficiency curve "flatness" and the detection efficiency [11]. These steps were important prerequisites for the design of the BRIKEN hybrid detector with presently 140 counters and two clover detectors [12].

Recent experimental results include the β-decay half-lives and neutron-branching ratios of the heaviest β -delayed neutron emitters ever measured ($^{204-206}$Au, $^{208-211}$Hg, $^{211-216}$Tl, $^{215-218}$Pb, and $^{218-220}$Bi) [8, 9], one of the two β -delayed two-neutron-emitter above A>100, ^{136}Sb [7], as well as many isotopes which were labelled as "top priority" for re-measurements in the previous IAEA reports of this Coordinated Research Project. These neutron-branching measurements were performed with two designs of the BELEN-48 detector at the IGISOL facility in Jyvaskyla/ Finland and included the following isotopes: ^{95}Rb, ^{98,98m}Y, ^{99}Y, ^{136,138}Te, ^{135,136,137}Sb, ^{137,138,139,140}I [13].

Since 2016 the BELEN detector is part of the BRIKEN project at RIKEN Nishina Center in Japan. The BRIKEN hybrid detector has an unsurpassed one-neutron detection efficiency of 70% (and respectively a two-neutron detection efficiency of 49%). It has been used for the measurement of more than 100 of the most exotic β-delayed neutron emitters between ^{76}Co and ^{167}Eu that can be accessed nowadays, many of them for the first time. Further experiments for the lighter and heavier mass range are planned in the near future.

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2.16 β-Delayed Neutrons from the Reference Activity ^{137}I Measured with MTAS, B. Charles Rasco, University of Tennessee and Oak Ridge National Laboratory

The response of a large NaI based total absorption spectrometer, the Modular Total Absorption Spectrometer (MTAS), to neutrons was described. The beta-delayed neutron emitter ^{137}I was studied in particular. The large NaI detector MTAS has approximately a 15% efficiency for detecting fast neutrons from beta-delayed neutron decay. The combination of the neutron efficiency, the very high gamma-ray efficiency and its ability to measure betas with greater than 2 MeV of energy allows MTAS to measure all of the components of beta decay. By comparing separate decay components MTAS provides an excellent way to measure neutron branching ratios, P_n, within a single experiment. For ^{137}I we find a P_n of 7.9±0.2(fit)±0.4(sys)%. This presentation is based on the work reported in reference [1].

[1] B.C. Rasco et al., Phys. Rev. C**95**, 054328 (2017)

2.17 Update on relevant proposals on beta-delayed neutron emission, recent experiments and evaluated data, Krzystof P. Rykaczewski, ORNL Physics Division

There were three main topics related to the beta-delayed neutron emission from atomic nuclei covered in the presentation.

A short update on the multinational BRIKEN project was given. This research project started around 2012-2013 coinciding with the IAEA CRP on beta-delayed neutron emission. This project is aiming in the determination of many new beta-delayed one-neutron and beta-delayed multi-neutron branching ratios in very neutron-rich nuclei using radioactive beams at RIKEN. These beams of exotic nuclei are produced in the fragmentation of high-energy heavy ions like ^{238}U accelerated to the energy of about 82 GeV. The multinational collaboration is led by C. Doming-Pardo from IFIC Valencia (Spain). He presented the construction proposal at RIKEN in 2013 and got it approved. Individual proposals were presented to the RIKEN Program advisory committee in 2014 and 2016 (and referred to the active IAEA CRP) and four experiments received approval so far. The main contributors to the BRIKEN detector array are ORNL and UTK from Tennessee (US), IFIC Valencia (Spain) leading a group of European universities and laboratories, and a team from University of

Edinburg (UK) operating the most advanced ion implantation and decay array AIDA. The initial testing and tuning of the BRIKEN array was performed in a parasitic mode in late 2016 and early 2017. Three experiments were run in May/June 2017 for beta-n precursors beyond doubly-magic ^{78}Ni and ^{132}Sn, and for neutron-rich isotopes in the rare-earth region. A very preliminary analysis presented by J.L. Tain at this meeting pointed to over 100 new P_{1n} values measured in May/June 2017. For example, the part of nuclear chart between ^{75}Co and ^{96}Br obtained in the BRIKEN run has a potential to yield 24 new P_{1n} values and get 23 nuclei, potentially β2n-emitting, inspected for β2n emission.

Several beta-gamma-neutron studies were performed on fission products with high gamma energy resolution at the HRIBF laboratory at ORNL (Oak Ridge, TN, US) before ceasing its operation. The highlights include the determination of beta-delayed neutron branching ratio with so called “ranging out” of post-accelerated fission fragment beams and a first identification of a beta-delayed 2-neutron activity of ^{86}Ga. The beta decay measurements on N=51 to N=55 isotones revealed low energy levels populated in the beta decay and provided some guidance about the spins and parities. Shell model analysis had some but not full success in explaining the energies and spins of observed states. Some of these studies were supported and inspired by the IAEA CRP on bn-emission, see, e.g., [1]

The measurements performed by means of total absorption spectroscopy (TAS) technique provide true beta-strength distribution and associated radiation. The Modular Total Absorption Spectrometer (MTAS) is the largest and respectively most efficient spectrometer of this kind. Most recent MTAS experiments were run also after ceasing HRIBF operations using 36 MeV to 40 MeV proton beams of few nA to 70 nA intensity accelerated in the ORNL Tandem, in late 2015 and early 2016. The total number of fission products studied with MTAS reached 77 activities [2]. It includes many activities abundantly produced in nuclear reactors and requested to be studied with TAS technique in the recent assessments by Nuclear Energy Agency of OECD and most recently by IAEA. The so far evaluated results point to the decay heat increase up to 3%, and to the reduction of so called “reactor anti-neutrino anomaly” due to the redistribution of anti-neutrino intensities [3]. However, after accounting for new MTAS results on fission products, the reactor anti-neutrino energy spectrum still shows a surprising “bump aka shoulder” at the energy range from 4.5 MeV to 8 MeV [4].

There are 12 βn-emitters in the lower mass fission region ($^{87-91}$Br, ^{92}Kr, $^{93-96}$Rb and $^{97-98}$Y) and 10 βn-emitters in the upper mass fission peak (^{134}Sn, $^{137-140}$I and $^{141-145}$Cs) measured with MTAS. Full beta-strength function, for neutron-bound and unbound daughter states, can be derived from MTAS measured spectra using the beta-n energy evaluation technique presented by B.C. Rasco at this meeting, see [5].

[1] A. Korgul et al., Phys. Rev. **C95**, 044305, 2017.
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3. Detailed Review of Work Program

The CRP work program was thoroughly reviewed and revised with the complete list of updated actions and individual work plans listed in Appendix 1.

3.1 P_{1n} - Standards

The list of nuclides (^{9}Li, ^{17}N, ^{87}Br, ^{88}Br, ^{94}Rb, ^{95}Rb, ^{137}I and ^{138}I) that were adopted as standards for P_{1n} measurements at the 1st RCM [1.2] including new proposals from the 2nd RCM [1.3] was reviewed and finalized as follows:

^{9}Li: following correspondence with the authors of the most recent article [3.1], it was decided to exclude the latter data from the evaluation.

^{138}I: the existing measurements are not considered adequate for the precision required for standards, therefore it was also removed from the list of potential standards. New measurements for the P_{1n} value were performed using the BELEN detector in November 2014, and the TAS detector in February 2014 are still being analyzed.

As far as the remaining candidate nuclei for standards are concerned, it was agreed to adopt the following:

^{9}Li, ^{17}N, ^{87}Br, ^{88}Br, ^{94}Rb, ^{95}Rb, ^{137}I: with 5% uncertainty

^{82}Ga, ^{144,145,146,147}Cs: with 10% uncertainty

^{95}Rb: a re-evaluation of the half-life of this precursor based on the new recent measurements with BELEN@IGISOL was performed by J. Agramunt and A. Algora following an action from the 2nd RCM (see Sect. 2.3). The new results confirm the previously evaluated P_{1n} value of 8.94(57)%.

^{137}I: the Beta-decay Paul trap (BPT) at Argonne National Laboratory has remeasured this values with three methods (Yee et al., [3.2]). The values derived from low-energy recoils, β-delayed γ's and β singles were all included in the new recommended value. The new recommended P_{1n} value is 7.27(23)%.

^{49}K: This nuclide was proposed as a new standard as two independent measurements for the P_{1n} value exist. However, at present the precision of the measurements is 10%, therefore, new measurements with improved precision down to 5% are desired. A proposal to measure delayed neutron (DN) spectra at CERN/ISOLDE was approved and the measurement has been completed. The data are being analyzed and will probably be published in the near future.

^{135}Sb: this nuclide was removed from the list due to lack of independent measurements. A recent remeasurement with the BELEN detector at IGISOL shows a good agreement with the value from 1993Ru01 [3.3]; these results will be published soon.

3.2 Standards for Delayed Neutron (DN) Spectra

For a proper evaluation of the reference spectra in Brady's thesis [3.4], a digitization was needed. This work was undertaken by the VECC group (Mukherjee, Banerjee) and the IAEA and is described in Sect. 3.5.

The following actions from the 2nd RCM report remain active:

- V. Piksaikin: compare these digitized DN spectra with his compilation and benchmark against his measured composite spectra. Make the results of this study available on the bDN Connect site.
- J.L.Tain, D. Cano Ott, R. Grzywacz, V. Piksaikin: assess the digitized DN spectra and the results of the comparison with the composite DN spectra of V. Piksaikin with a view to make recommendations of reference DN energy spectra.
- DN spectra from ENDF/B VII.1 should also be included in the comparison.
- ^{137}I: DN spectra have been measured at MTAS and published by Rasco et al. The new data should be compared with Brady's data.
- ^{17}N: the DN spectrum has also been measured using VANDLE and should be reviewed once it has been published (Madurga et al).
- ^{85}As and ^{135}Sb were also discussed as possible candidates for reference DN spectra. They have been measured by VANDLE@CARIBU (Argonne National Lab) by R. Grzywacz and collaborators and the data analysis is in progress.

The following recommendations from the 2nd RCM remain active:

- K. Rykaczewski and R. Grzywacz: pursue new measurements with VANDLE on ^{87,88}Br, ^{94}Rb. Remains a continuous action.
- Action on J.L. Tain and A. Sonzogni: provide absolute γ-intensities (incl. β- and βn-intensities of daughter, J^{π} of mother, daughter, and grand-daughter) for nuclides ^{94}Rb and ^{95}Rb, and verify the same properties for ^{137}I and ^{138}I. These data should be checked together with B. Singh and then the respective ENSDF evaluators should be contacted.

3.3 Measurements

New data that are expected to be measured in the remaining course of the CRP are presented in Table 1. These data will be provided to the coordinator (B. Singh) for compilation and evaluation in the new Reference Database, when they become available in regular publications or preprints or when the researchers feel confident to submit them.

Also, a list of nuclides with discrepant data that require new measurements has also been published in Ref. [3.5]. Several of these nuclides have been proposed for measurements at BRIKEN (see Table 1).

3.3.1 High priority list for applications

Different sensitivity studies have been performed in the course of the CRP, to ascertain the nuclides that are important for applications in reactor operation and safety, as well as in anti-neutrino spectrum calculations. The results of these studies should be combined in one single high-prioity list of nuclides whose delayed neutron properties are important for integral quantities such as total neutron yields (nubar), group parameters and DN spectra, and should be included in the final report.

This list should include ^{137,138}I and bromine isotopes, and should also cover the results for the systems ^{233}U-thermal/fast and ^{232}Th-fast.

Action on: R. Mills, A. Sonzogni to check the sensitivity of CFYs on the new evaluated P_n values.

3.3.2 High-priority list for nuclear structure studies

Apart from a high-priority list for applications, the CRP has also discussed putting together a similar list for nuclear structure studies. Beta-delayed neutron emission data can shed light on magic numbers and shell structure as we approach the drip line, and can also be used to study nuclear shapes.

Action on: K. Rykaczewski, A. Algora: to prepare a short document highlighting the above-mentioned nuclear structure needs for beta-delayed neutron emission data.

Action on: M. Madurga, R. Grzywacz: produce a similar high-priority list of nuclides for measurements of DN spectra.

Table 1. Experiments expected to be performed in the future

Name/ Group	Isotopes	Expected date
BRIKEN@RIKEN Proposal 1 (Rykaczewski, Tain, Grzywacz, Dillmann) Proposal 2 (Estrade, Lorusso, Montes)	First measurement of P_{1n}: ^{76}Co, ^{78,79}Ni, ^{80,81}Cu, $^{83\text{-}85}$Zn, ^{85,87}Ga, $^{87\text{-}90}$Ge, $^{88\text{-}91}$As, ^{90,92}Se First measurement of P_{2n}: $^{80\text{-}82}$Cu, ^{83,84}Zn, ^{84,85,87}Ga, ^{87,88}Ge, $^{88\text{-}91}$As First measurement of P_{1n}, P_{2n}, and P_{3n}: $^{121\text{-}127}$Rh, $^{128\text{-}129}$Pd, $^{130\text{-}131}$Ag, $^{133\text{-}134}$Cd, $^{135\text{-}136}$In, $^{138\text{-}140}$Sn, $^{140\text{-}141}$Sb, $^{142\text{-}143}$Te, $^{144\text{-}146}$I, $^{147\text{-}148}$Xe, $^{149\text{-}151}$Cs, $^{150\text{-}152}$Ba	2016-2017
VANDLE@ ISOLDE	$^{130\text{-}132}$Cd, $^{49\text{-}53}$K	July 2015 Oct. 2015
VANDLE@ CARIBU	^{109,110}Mo, A=136,137	April 2015
BPT @ CARIBU (Scielzo)	^{134,135,136}Sn, ^{98m,99,100,101,102,103}Y	2016-2018
GRIFFIN+DESCANT@ TRIUMF	^{145,146}Cs	>2018
TAS@ ALTO	$^{130\text{-}134}$In, ^{133,134,136}Sn	2015-2016

3.4 Compilation and Evaluation

The compilation and evaluation of nuclides in the region Z = 2 - 28 has been published in Nuclear Data Sheets (Ref. [3.5], M. Birch et al., NDS128, 131 (2015)). The compiled and recommended data for $T_{1/2}$ and P_{xn} values, along with new systematics and comments on the evaluation method, have also been made available to the CRP participants through the bDN Connect site and have also been incorporated in the new CRP bDN database.

The next task was to compile and evaluate the nuclides in the region Z = 29 - 57 region and also additional nuclides in Z > 57 region for which new data might become available. This has also been completed and preliminary tables with evaluated $T_{1/2}$, P_{xn} and $Q_{\beta xn}$ values from the latest AME2016 have been provided to the IAEA, and have been uploaded on the bDN web site.

The discussion focussed on the data for isomers and how they are labelled in the tables, especially those cases when it is not know which state is the isomer and which the ground-state.

Another point was made that asymmetric uncertainties are not normally used in applications (e.g. for the summation method). Therefore, it may be more useful to prepare and make available another numerical table with bDN values, where the isomeric states will be labelled in a computer-code readable way, and the uncertainties will be symmetric. Such a numerical table would be more useful for practical calculations in the application fields.

Action on B. Singh: carefully review the isomer data and introduce a clear and computer readable labeling convention.

Action on R. Mills and A. Sonzogni: retrieve isomers from JEFF-3.1 and ENDF/B-8 (beta) to compare with CRP bDN tables.

Recommendation: those involved in benchmarking studies should report any problems with bDN data tables or any unusual results arising from the new data tables, to the coordinator B. Singh.

3.5 Digitization of delayed neutron (DN) energy spectra for individual precursors

The effort has been undertaken by B. Singh and M. Birch for nuclides in the lower mass region (Z = 2 - 28), and K. Banerjee, G. Mukherjee and the IAEA for nuclides in the fission mass region. Several digitized spectra have already been submitted to IAEA NDS for inspection and have been approved (nuclides in 1980Re03 [3.6] and 1985Gr15 [3.7]) and uploaded to the bDN CONNECT Sharepoint site. Most of the original measured spectra in Brady's thesis (Ref. [3.4]) have also been made available on this site.

V. Piksaikin has also digitized DN spectra from the literature and has created a library containing a total of 47 spectra including DN spectra from JEFF 3.1, and the Greenwood data. He has used these DN spectra in combination with the summation method to produce composite spectra to compare with his measured spectra for neutron-induced fission on ^{235}U. Following the 2nd RCM actions, these spectra have also been provided to the IAEA and have been made available on the bDN CONNECT site.

Regarding DN spectra for the Z = 2 - 28 region, B. Singh and collaborators have digitized about 20 spectra and have sent them to IAEA NDS (V. Semkova) for checking and compilation. These spectra are now available on the bDN CONNECT site.

Several new actions resulted from the presentations and discussions at this RCM:

Action on Mukherjee and NDS-IAEA:

- add one line in digitized file for detector energy resolution
- include both, original and adjusted spectra

- transform spectra to equidistant spectra (10 keV bins) and also upload them on bDN CONNECT site (for use in summation calculations)

Action on NDS-IAEA: send sample of EXFOR files with data dependent on incident and outgoing energy for consideration as possible solution for compiling TAS spectra in EXFOR.

3.6 Systematics and Theory

Empirical formulas and their predicted values will be included in the CRP bDN database. The systematics on the lighter mass region Z = 2 – 28 have already be determined and published [3.5]. The following systematics will be applied to the new evaluated $T_{1/2}$ and P_n values in the heavier fission mass region:

1) Kratz-Herrmann formula (Ref. [3.8]), which is still widely applied, and describes the P_n values in terms of energies Q_β and the neutron separation energies S_n
2) McCutchan et al [3.9], which is similar to the Kratz-Herrmann approach but describes P_n in terms of (Q_β-S_n) and the β-decay half-life $T_{1/2}$.
3) Miernik [3.10], which describes the P_n values in terms of nuclear level density of the β-decay daughter nucleus.

Systematics (1) and (2) will also be revised on the basis of the new evaluation of Birch et al. [3.5] for Z = 2 - 28 and will be uploaded on the database.

The theoretical $T_{1/2}$, P_n tables of Marketin et al [3.11] and Möller et al [3.12] have already been included in the database. Borzov plans to send his tables for the near –spherical nuclides in the near future.

An action from the 2nd RCM on Borzov, Marketin, and Minato to review existing microscopic (and macroscopic) models used to calculate β-decay properties by the 3rd RCM was completed and the conclusions/recommendations are given in Appendix 2.

3.7 Macroscopic (integral) data

Summation calculations of total DN yields, decay parameters, and DN spectra have been performed using the following input data libraries:

a) FPYs: JEFF 3.1, ENDFB/VII.1, JENDL –fixed
b) P_n, $T_{1/2}$: JEFF 3.1, ENDFB/VII.1, JENDL –fixed; current ENSDF

The results were shown and discussed at the 2nd RCM. In this meeting, similar studies were performed using the new evaluated bDN tables provided by B. Singh and evaluators (see Sect. 2).

The new calculations were performed for ^{235,238}U and ^{239}Pu, for thermal and fast neutrons, to begin with. Preliminary results indicate that there is a problem when interpreting the uncertainties (0 or 100%), treating asymmetric uncertainties, and also in some cases certain data were missing.

Detailed feedback will be provided to B. Singh and evaluators. The tables will be updated to take into account all the feedback, as well as new published data, and will be prepared for publication by the end of 2017. The improved tables will be sent to all those involved in the benchmarking studies by the end of October 2017.

An inter-comparsion of the various summation calculations and benchmarks will be performed to assess the results, and agree on final recommendations, as well as the content of the final document. For this purpose, a meeting will be held at the IAEA in December 2017.

3.8 Reference Database

A preliminary version of the microscopic and macroscopic databases was presented at the meeting by IAEA-NDS (P. Dimitriou, M. Verpelli).

The microscopic database included all the data for Z = 2 - 28 and Z > 28 nuclei based on the preliminary data provided by B. Singh. The tables, additional downloading capabilities using CSV files, and plotting tools were demonstrated and improvements were discussed. In addition to the tabular display, a numerical table for use in practical calculations for the various applications was recommended.

The macroscopic database including the compilation of experimental total DN yields and group constants was discussed, and suggestions were made to include data from the evaluated libraries and all the necessary references.

Action on NDS-IAEA: make available a complete and improved version of the database to CRP participants for testing by the end of November 2017.

The bDN CONNECT site will continue to serve as an inventory for documents and data of relevance to the CRP.

References

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[3.11] T. Marketin, L.Huther, G. Martinez-Pinedo., Phys. Rev. **C93**, 025805 (2015).
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4. Final CRP report

The second main output of this CRP is a document describing all the work that was carried out during the course of the CRP, the results that were obtained and the recommendations that were made as a result.

The contents of this document, as well as the authors and type of publication were discussed at length at this last meeting. A detailed outline is given in Appendix 3 with sections, subsections and assigned authors.

Participants decided to publish this document in Nuclear Data Sheets. The dates of submission of first draft and final publication were discussed after the meeting with the Editor of Nuclear Data Sheets, and were agreed as follows:

- Submission of first draft by 1 June 2018
- Publication of article in December 2018

The overall coordinator of the preparation of the report (IAEA Scientific Secretary) will in collaboration with the coordinators of the sections determine additional deadlines for submission and review the various individual sections.

The joint preparation will be performed using the Overleaf application based on LaTeX and will adopt the Nuclear Data Sheets template and style. All sections will be sent to the IAEA for some basic editing before submitting to Nuclear Data Sheets.

Participants agreed on authorship and also possible referees for the article.

5. Conclusions

The 3rd Research Coordination Meeting (RCM) on the development of a Reference Database for β-delayed neutron emission data was held at the IAEA, Vienna, from 16 to 20 June 2017.

Participants reviewed the current status with respect to measured, compiled and evaluated delayed-neutron data, systematic approaches and theoretical models, and discussed the results of integral calculations using the newly evaluated data compared to existing nuclear data libraries.

A preliminary version of the microscopic database for $Z = 2 - 28$ and $Z > 28$ nuclei, as well as the macroscopic database for total neutron yields, group parameters and aggregate spectra, was presented and suggestions for improvement were made.

The final publication of the CRP technical report was discussed in detail. The contents were agreed and the authors were assigned. The document will be submitted for publication in Nuclear Data Sheets in December 2018, so the first draft of the report will have to be prepared by June 2018.

The work plan of the participants was reviewed and revised to ensure that the objectives of the CRP are met in time. The revised lists of actions are included in Appendix 1.

Participants were encouraged to publish their work acknowledging the CRP. Acknowledging the CRP is important to acknowledging and making visible the work that this group has performed during these last four years, therefore there are different ways of doing it:

- If a contract is involved then the CRP and contract number should be mentioned
- If the article is on measurements or calculations that have been discussed, assessed or anticipated by the CRP, then the CRP can be mentioned in the Introduction or in the Acknowledgements
- If a paper is relevant to beta-delayed neutrons then the CRP can be simply mentioned in the Introduction.

Appendix 1

List of Actions

Revised at 2nd RCM		
No.	**Responsible**	**Action**
1	NDS-IAEA/P. Dimitriou	Collect relevant articles from literature on bDN data and upload on CRP website **Continuous** (also Lab Reports) In case of conf. proceedings, also include comments about existence of published article
2	I. Dillmann, B. Singh, K. Rykaczewski, J.L. Tain, R. Grzywacz	Provide IAEA with list and links and files of older and current PhD theses concerned with P_n data **Continuous**
3	All participants with access to aggregate data	Send aggregate data to NDS-IAEA/ P. Dimitriou **Continuous**
4	All experimentalists ($T_{1/2}$, P_n, neutron spectra (singles TOF or energy spectra))	Keep evaluation coordinator B. Singh updated about new analyzed data which researchers feel confident to communicate **Continuous**
5	J.L. Tain, D. Cano-Ott, G. Mukherjee, K. Rykaczewski	Review the DN energy spectra which have been used as a reference for efficiency calibration purposes **Continuous** – **when Brady spectra are digitized then they will be assessed together with the corresponding new MTAS/VANDLE measured spectra (^{137}I) and compared with the ENDF/B spectra – to be completed for inclusion in final CRP document**
6	I. Dillmann, B. Singh	Check for possible DN P_n standards for fission mass region. **In progress - Done** **^{87,88}Br;^{94,95}Rb;^{137}I (5% precision)** **^{82}Ga;^{145,146,147}Cs (10% precision)**

Revised at 2nd RCM		
No.	**Responsible**	**Action**
7	B. Singh	Check if fine-structure DN data branches (per final level) are made available in ENSDF or XUNDL A<21: checked and found complete files Z<28: reasonably complete **Continuous** **ORNL provided publications**
8	B. Singh, K. Banerjee, NDS-IAEA	Contribute to effort of digitizing DN spectra **Continuous – adjusted Brady spectra remain to be done**
9	NDS-IAEA (P. Dimitriou, M. Verpelli)	Prepare preliminary version of bDN Database with microscopic data for Z=2-28 **Continuous-updating and maintenance**
10	R. Mills (coordinator), V. Piksaikin, A. Sonzogni, D. Cano-Ott, K. Rykaczewski, S. Chiba, F. Minato, M. Fallot	Prepare high-priority list of nuclides important for applications (reactor kinetics and equilibrium) based on an inter-library comparison (JEFF, ENDF/B, JENDL) and sensitivity check of macroscopic data (nu-bar, group parameters) with respect to the microscopic quantities such as P_n and fission yields included within each library. To be completed by end of 2015. **In progress: partly done** **Final list needs to be submitted for inclusion in CRP document (outstanding issues with $^{137,138}I$)** **Using Jeff FYs and CRP P_ns** **New: check if new P_n values affect CFY significantly** **(^{235}U, ^{239}Pu)-thermal;($^{235,238}U$-, $^{239,240}Pu$)-fast; ^{232}Th-fast, ^{233}U-thermal/fast** **Vivian to interact with Robert (coordinator)**

Revised at 2nd RCM		
No.	**Responsible**	**Action**
11	I. Dillmann, P. Garrett, J.L. Tain, K. Rykaczewski, R. Grzywacz	Provide feedback from nuclear structure community on nuclides with DN P_n that are important for nuclear structure studies **Continuous** **Conclusions/recommendations to be provided by Krzysztof**

New Actions from 2nd RCM - **revised**		
No.	**Responsible**	**Action**
12	B. Singh (Coordinator) with X. Huang, K. Banerjee, G. Mukherjee, D. Abriola, A. Algora, and with I. Dillmann, E. McCutchan, A. Sonzogni, T. Johnson,S. Chiba, G. Lorusso	Compilation and evaluation of $T_{1/2}$ and P_n data for nuclides with Z=29-57 and selected higher mass nuclides Reviewing/checking effort **Done-publication in preparation**
13	I. Dillmann, P. Garrett, R. Grzywacz, J.L. Tain, K. Rykaczewski,	Same as Action 13 but for DN spectra **Feedback to be provided by ORNL group**
14	R. Grzywacz	^{49}K possible new standard for Z=2-28 region- **evaluation pending the analysis of the data**: measurement at ISOLDE in Fall 2015 **- done**
15	I. Dillmann	Upload nuclear astrophysics papers on sensitivity studies related to bDN data in bDN site **Continuous**
16	I. Dillmann, P. Garrett, K. Rykaczewski	Produce priority list of nuclides in Z=2-28 region that need to be re-measured because of discrepant data **List of discrepant data exists (published in NDS)**

New Actions from 2nd RCM – revised cont'd		
No.	**Responsible**	**Action**
17	R. Grzywacz	Contact the authors of the recent article on ^{9}Li, Y. Hirayama et al, PRC 91, 024328 (2015), for more information about the measurement and data analysis to clarify their results for P_n – send feedback to B. Singh **Balraj communicated directly Hirayama – based on this feedback P_n value is not used in the evaluation. Also neutron spectrum (E vs Intensity) could not be provided by authors)** **Madurga: possibly repeat a measurement at ISOLDE**
18	A. Algora	Extract $T_{1/2}$ of ^{95}Rb from data measured by BELEN@IGISOL in 2014 **done**
19	B. Singh	Check when evaluating ^{135}Sb and ^{144,145}Cs if existing data are adequate to propose them for 'standards' in the mass region of fission products **^{144,145}Cs: can be accepted as standards** **done**
20	A. Algora, J.L. Tain	Send TAS data to B. Singh who will explore how best to compile them in XUNDL **Done: but needs to be further explored**
21	NDS-IAEA/P. Dimitriou	Send sample EXFOR files with TOF spectra for experimentalists to comment and provide feedback **A different EXFOR sample file will be sent for feedback (on a format closest to describing a level scheme)**

New Actions from 2nd RCM – revised cont'd		
No.	**Responsible**	**Action**
22	K. Banerjee, G. Mukherjee, NDS-IAEA/P. Dimitriou	Digitize DN spectra of Rudstam, Greenwood and Kratz included in thesis of Brady as a top priority **To be completed soon**
23	NDS-IAEA/P. Dimitriou	Upload digitized DN spectra from Action 23, as well as 47 DN spectra provided by V. Piksaikin, to bDN CONNECT site and notify CRP participants **Continuous-explore downloading of multiple files/or use zip files**
24	R. Mills, NDS-IAEA/P. Dimitriou	Inform CRP the source of DN spectra available in JEFF library **Done**
25	V. Piksaikin	Benchmark digitized DN spectra from Actions 23-24 against his measured composite DN spectra **Continuous pending completion of Action 24**
26	V. Piksaikin, J.L. Tain, D. Cano, R. Grzywacz	Make detailed assessment of DN spectra made available through Actions 23-25 taking into account the results of Action 26 **Continuous – pending Action 24**
27	I. Borzov (coordinator), T. Marketin, F. Minato	Review existing theoretical models and in particular how they treat the isoscalar pairing interaction **Review and conclusions provided** **Borzov: data tables will be prepared and provided for inclusion in the database.**

New Actions from 3rd RCM		
No.	**Responsible**	**Action**
28	G. Mukherjee, NDS-IAEA	Add one line with detector energy resolution to the digitized spectra files Digitized both original and adjusted spectra Transform to equidistant 10 keV bins for use in summation calculations
29	B. Singh	Check isomer data in tables

		Introduce label 0/1/2 similar to FissionYields tables for isomers In Z<29 tables, separate the methods used for $T_{1/2}$ and P_n measurements into two columns Consider symmetrizing the asymmetrixc uncertainties for use in practical calculations
30	R. Mills, A. Sonzogni	Extract tables of isomers from JEFF-3.1 and ENDF/B-8
31	X. Huang	Re-evaluate ^{135,136}I adding IGISOL data (Caballero-Folch, Agramunt) Consider ^{137}I: how does MTAS data fit, include IGISOL data (Caballero-Folch, Agramunt) Use lowest experimental uncertainty if weighted average uncertainty is lower
32	A. Algora	New $T_{1/2}$ from weighted average method for ^{95}Rb: 377.7(23) ms (check uncertainty, 4ms?) Send data to Balraj Singh, prepare "internal report" or get NSR key number for "priv. comm." ??
33	I. Dillmann	Check PhD thesis of Matthew Quinn (Notre Dame) for more data
34	B. Singh	Prepare text with criteria for a ‘good’ standard
35	R. Mills, A. Sonzogni, V. Piksaikin, D. Cano, S. Chiba	Send feedback (missing data, problems with uncertainties, interpretation etc) on new Z>28 tables to Singh et al
36	V. Piksaikin	Add references to expanded groups in Reference database
37	R. Mills, A. Sonzogni	Check which new P_n values affect the calculation of the CFYs
38	J.L. Tain	Provide list of high-priority nuclides measured at IGISOL

Appendix 1

REVISED WORK PLAN (2nd RCM: 23-27 March 2015)

Participant	Institute	Country	Proposed Work
I. Borzov	IPPE	Russia	New DF3+CQRPA calculations of beta-decay rates and DN P_n for key quasi-spherical nuclei. Comparisons of new calculations with data from HRIBF, GSI, RIKEN, TRIUMF. ~~Combine with HF code to get DN P_n and energy spectra.~~ **~~Done except for combination with HF code. Preliminary (beta) version to be published in INDC(NDS) report and include in NSR and database~~.**
D. Cano	CIEMAT	Spain	Experiment using BELEN at IGISOL-JYFL (proposal by Algora, Cano, Gomez-Hornillos, Jokinen). **Preliminary data sent. Final data to be published as PhD thesis and paper.** Same experiment with MONSTER at IGISOL-JYFL (Spokespersons: as above). **(uncertain)** Experiment with ^{9,11}Li at ISOLDE (Spokespersons: Delaunay, Cano Ott). **Done. Data under analysis.** Review of different sensitivity studies on bDNs for reactors. **Done-including benchmarking.** Characterization of new scintillators to be used as neutron detectors at metrology labs. **Experiments done and analysis in progress. Also done summation calculations. Next: Analysis of data. Sensitivity studies.**
S. Chiba	Tokyo Inst. Techn.	Japan	Construction of apparatus for surrogate method to measure FFMD. **Done-data on ^{238}U, ^{232}Th, ^{248}Cm to be published. Next: ^{237}Np. Done** Extension of Langevin Eqs to predict independent FYs. **In progress (need to correct calculation of prompt neutrons). Done** Use DN P_n and $T_{1/2}$ data produced by CRP to improve the Gross Theory. **To be done when CRP database is complete. Contribute to checking of evaluations in fission mass region (coordinated by B. Singh) To be done**
M. Fallot, A. Porta	SUBATECH-Nantes	France	Preparation of a new TAS experiment proposal on bDN emitters in collaboration with IFIC (Tain, Algora) for submission to JYFL PAC or ALTO facility. **Done. Experiments will take place in 2015-2016 on following nuclides: $^{130-134}$In, ^{133,134,136}Sn. Spokespersons:** A. Algora, M. Fallot, A. Porta, B. Rubio and J.-L. Taín. **Not yet. Measured ^{138}I. Analysis ongoing.**

WORK PLAN cont'd

Participant	**Institute**	**Country**	**Proposed Work**
P. Garrett I. Dillmann A. Chen B. Singh	Univ. Guelph TRIUMF McMaster Univ.	Canada	Commissioning of DESCANT and GRIFFIN. **Coming up in May 2015. Partially done.** Publications of 8π results on n-rich Rb isotopes. **^{102}Rb submitted for publication. published** Measurements @ TRIUMF (3Hen). **Not done- currently status of proposal degraded to LoI.** Evaluation of bDN with Z=2-28. **Completed. Submitted for publication. Published.** **Next: B. Singh will continue with compilation and evaluation of P_n and $T_{1/2}$ data for selected nuclei in Z=29-57 region and additional nuclei in the higher mass regions where new data become available. He will also coordinate this effort for Z=29-57 region with the CIAE group (Huang) and VECC group (Banerjee).** **I. Dillmann will participate in this effort in checking the evaluated and compiled data, and publication of a paper of this work. Done**
G. Mukherjee, K. Banerjee	VECC	India	Literature survey and compilation-evaluation of existing bDN data in fission region. **In progress.** Digitization: **Rb, Cs isotopes submitted to NDS IAEA. Done** Characterization and testing of neutron detector systems developed at VECC which will be part of MONSTER. **Done.** **Next: Compilation/evaluation of mass region Z=41-48. Done** **Digitization. Ongoing** **Develop a few more MONSTER modules. Onging**

WORK PLAN cont'd

Participant	**Institute**	**Country**	**Proposed Work**
V. Piksaikin	IPPE	Russia	Least-squares fit of DN decay curves for each isotope to obtain 6- and 8-group models at different incident neutron energies. **In progress. Most of them done.** Obtain Covariance data for delayed neutron parameters (a_i,T_i) . Produce new data: 1) (a_i,T_i) for main fissile materials and minor actinides (Np, Am) for neutron energies 14-18 MeV and 2) Composite DN spectra from thermal neutron-induced fission of ^{235}U **In progress. Ongoing** **Measured DN energy spectra and corresponding INDC(NDS) report in preparation. Published** **Verification of FPYs to be published in Prog. Nucl. Energy. Published** **Next: Complete (1), re-evaluation of 6- and 8-group models with the purpose to produce new recommendations for some nuclides. Contribute to Macroscopic database. To be done for the whole set of nuclides that have already recommended data (WPEC/SG-6)**
K. Rykaczewski, R. Grzywacz	ORNL, U. of Tennessee	USA	Submission of HRIBF data on fission products. **Done-14 papers and conf. proceedings sent.** Preparation of approved experiments at TRIUMF ISAC-1 and CARIBU-ANL. **TRIUMF experiment deferred-status is currently that of LoI. CARIBU experiments almost complete. Data under analysis.** **Ongoing** **Next: More data ready for submission for publication on A = 82, 83, 86, 87. Partly done. CERN and NCSL proposals: approved for 2015-2016. CERN: nuclear orientation for ^{87}Br, ^{137}I. [Cd and very neutron rich K decays done]. Pending repair of fridge. NSCL: Co decays. done** **BRIKEN: joint proposal of Rykaczewski, Tain, Dillmann, and Grzywacz was approved. 4 proposals approved and 2 ½ were run.**

WORK PLAN cont'd

Participant	**Institute**	**Country**	**Proposed Work**
J.L. Tain A. Algora	IFIC Valencia	Spain	Exp. With BELEN at IGISOL-JYFL in 2013 (same as Cano) to measure Y and Sb isotopes. **Done in 2014.** Contribution to new evaluation of old DN P_n data**. Done.** New sensitivity study to identify additional DN emitters of interest in advanced nuclear reactors. **Done and submitted.** Provide data on DN emitters, $T_{1/2}$ and P_n from GSI measurements. **Data to be published. One missing** **Upgrade of BELEN to BELEN-48. Done** **BRIKEN: joint proposal mentioned above and preparation of experiment. Done** **Evaluations for Z>57 in fission mass region (Coordinated by B. Singh) Done**
X. Huang	CNDC	China	Evaluation of selected potential FP nuclides (Z=51-57): review and collection of measured data, assessment of exp. technique and use of suitable averaging method. **Done.**
F. Minato	JAEA	Japan	Calculate DN emission with Ohsawa's approach: make computer code to calculate DNY and investigate energy dependence of FF**. Now using existing Japanese code. Results will be published in a JAEA report. To be submitted** **Provide results of Skyrme-Hartree-Fock calculations of DN $T_{1/2}$ values (even-even nuclei). Done also including P_{xn} values and Total DN spectra for individual precursors for odd and odd-even nuclei as well. Will extend to drip-line nuclei. To be published in ARIS conf. proceedings and submitted to CRP bDN database. In progress**
T. Marketin	Univ. of Zagreb	Croatia	Extend Covariant DFT to treat FF transitions. **Done. Data to be submitted to CRP bDN database. Done** Employ finite amplitude method to solving relativistic QRPA eqs., including deformation. **In progress.** Goal is to calculate beta-decay rates for all nuclei, both spherical and deformed**. Done for spherical (incl. P_n). To be submitted to CRP bDN database. Done** **Continue on deformed [in progress] and correlations [done but inconclusive].**

Appendix 1

WORK PLAN cont'd

Participant	**Institute**	**Country**	**Proposed Work**
R. Mills	NNL	UK	Benchmarking studies of new evaluated DN P_n database for nu-bar using existing fission product yields and potentially 8-group parameters. **Pending on CRP data becoming available in relevant mass region. To be done** **Performed Nubar and <$T_{1/2}$> calculations for recent FPYs and Decay Data sets. Provided component contribution for major evaluations (JEFF 3.1.1, ENDF/B 7.1, JENDL 2011). Done**
Advisors			
A. Sonzogni, T. Johnson E. McCutchan	BNL	USA	Systematics for P_{2n}. **Data not adequate. To be revisited as database grows. Performed systematics for new evaluations in Z=2-28 region.** Sensitivity study to identify most relevant bDN emitters to delayed nu-bars. **Done.** Perform first experiment for ^{138}I to measure decay and $T_{1/2}$ (provided the exp. is scheduled at CARIBU). **Cancelled.** Calculation of DN energy spectra. **Cancelled.** Contribute to evaluation and documentation effort. **Done.** **Next: calculate covariances for DN group parameters and contribute to macroscopic database. To be done in collaboration with Cano and Piksaikin.** **Contribute to checking of evaluations in fission region (Coordinated by B. Singh) Ongoing**
G. Lorusso	NPL	UK	**Provide data from EURICA experiments for inclusion in the CRP bDN database. In progress** ~~**Contribute to checking the evaluations in the fission mass region (coordinated by B. Singh)**~~

Appendix 1

Appendix 2

Review of status of beta-decay theories (I.N. Borzov, T. Marketin, F. Minato)

1. A notable achievement of the recent years is an increasing performance of the global self-consistent beta decay models based on the energy-density functional approach. In the global models, the parameters defined from a limited set of sample nuclei are kept the same for whole nuclear chart. Different density functionals have been developed in the quest for the universal description of the nuclear ground state properties and spin-isospin excitations. A definite success has been gained within global approach in describing the ground state (Q_β, S_{xn} values) and beta decay properties ($T_{1/2}$, P_{xn} values) of the short-lived nuclei important for astrophysics with the quality better than of the standard FRDM.

   One should mention, that the spherical pnQRPA models based on the D3C* relativistic functional (RHB+RQRPA) have been applied to all nuclei including the deformed ones [1], and the spherical continuum pnQRPA based on the Fayans functional (DF3, DF3a+CQRPA) [2] has been applied for ~300 (quasi) spherical nuclei with low or zero deformation. The efficient iterative procedure for deformed nuclei [3] is based on the Skyrme energy-density functional SkO' and proton-neutron finite amplitude method (pnFAM) which sidesteps the QRPA eigenvalue problem. It is now possible to apply the pnFAM in principle to whole nuclear chart. Importantly, all these models include the contributions of the first-forbidden (FF) transitions fully microscopically and on equal footing with allowed Gamow-Teller transitions (GT).

   A variety of the local self-consistent QRPA models both for spherical and deformed nuclei exist on the market. They either has been applied to a limited set of nuclei or use an adjustment of the key parameters to the "output" half-lives for specific isotopic chains of interest [4-6] similar to the technique adopted by the "gross theory". Usually only the GT decays are taken into account.

   Recently new self-consistent models beyond the QRPA have appeared which study the important impact of the quasiparticle-phonon coupling on the beta decay properties [7-10]. The basic nuclear properties, such as binding energies and low-energy spectra, are a result of a complex interplay between various many-body correlations that cannot be perfectly described within the density functional theory. DFT can, however, provide an excellent basis for extended models pretending a more detailed description of the nuclear response. One such model is the so-called Finite Range Separable Approximation of the second QRPA based on the well-known V.G. Soloviev's Quasi-Particle-Phonon approach. It has been applied to the beta decay half-lives of the isotopes near the closed shells and delayed multi-neutron emission of Cd isotopes [7]. Another model is based on the time blocking approximation developed in [8]. Its relativistic version has been applied recently for the studies of the spin-isospin transitions such as the Gamow-Teller response in ^{208}Pb [9] and to the beta-decay half-lives of Ni isotopes [10]. Rather accurate reproduction of available data for isotopes with a closed proton shell has been achieved without the use of an extra pairing interaction in [10, 11].

   The most stringent criteria of the model reliability would be producing the beta-decay strength functions in compliance with the experimental decay schemes. However, the latter are usually not complete, thus one has to rely on the available intergral beta decay properties: the half-lives and beta-delayed (multi) neutron emission probabilities, and neutron spectra. The percentage of the FF (GT) decays to the total rate turns out to be a very important structural indicator. The integral quantities (just few numbers) codify important information on the full beta strength distributions and can be efficiently used to constrain the models. The natural interrelation of these integral characteristics has given a rise to new beta decay systematics [12-13].

2. One has to admit the existing deviations in the beta decay characteristics predicted by the different models. In particular those concern the isotopes in the vicinity of the closed shells. Mostly they stem from the difference of the energy-density functionals used. Thus, it is of prime importance to describe accurately the known ground state properties which are important for the beta decay theory: the total beta decay energy release (Q_β window) and the neutron emission threshold (S_{xn}-values). These quantities constrain the phase spaces for the main beta decay processes of interest. As the Q_β and S_{xn}-values in the self-consistent scheme are naturally connected to the quasi-particle energies, the deviations are translated to the β–strength function, half-lives and beta-delayed (multi) neutron emission probabilities.

3. It is also necessary to cross-check the existing theoretical tables of the beta decay properties against the number of criteria. For instance, the share of the FF decays in the total rate (%FF) is an important "marker". Naturally, it should be in agreement with selection rules and, in particular, with reduction factor for unique FF with respect to non-unique FF. Important is a comparison with the evaluated data and especially with available experimental decays schemes.

4. The inclusion of first-forbidden transitions into the description of nuclear decay introduces additional complexities. It is accepted practice to use an effective value of the axial-vector coupling constant of unity (g_A = 1.0), introduced because models systematically overestimate the amount of GT strength at lower energies. This is most likely due to the lack of complex configurations in the model basis and may be solved with second RPA. However, there is no accepted practice concerning the quenching of the axial-vector coupling constant in forbidden transitions, nor is there any data available. Some calculations quench the coupling constant in all transitions, and some only in the Gamow-Teller channel. The recent interacting shell model study [14] has tackled this issue in detail stressing the problem of anti-quenching of the relativistic operator.

5. The QRPA normally operates with small fluctuations around fixed mean field. This come in contradiction with the large amplitude oscillations produced by collective T=0 pn-paring. A too strong T=0 pairing interaction leads to the QRPA collapse with unphysical zero energies solutions. Having in mind extreme importance of the T=0 pn-pairing interaction for amplifying the spin–isospin response at low-excitation energy (reducing the half-lives), the approximations for T=0 pn-paring that we have employed so far can be too simplified.

One should consider the competing effects: QPC and tensor interaction both soften and spread out the strength distribution.

In practice, an unpleasant feature of the T=0 pn-pairing interaction is a lack of universal strength. Thus, its mass dependence should be treated very accurately. Assuming the existence of the so-called QRPA instability in the particle-particle channel, a recipe of direct fitting of the T=0 pn-interaction strength to the "output quantities" of the half-lives may not be that successful in a wide region of nuclei. Absolutely no warranty exists that such a fitting would not bring the T=0 pn-interaction strength g'_{pp} to unphysical regions close to the instability point. For instance, as not enough experimental data exist for extreme N−Z values, such fitting may fail in those regions (see [15]). Probably a safer choice would be using a (much more tedious) routine applied for the analysis of pion condensation instability in [16].

It is finding the critical constant value first (on nucleus to nucleus basis) and then using the condition of equal proximity to the instability point $g' = g_{pp} - g'_{crit}$ = const.

One should mention the systematic studies of T=0 pn-interaction from point of view of the importance of the tensor interaction [17] which may weaken the mass dependence of the T=0 pn-interaction. The limits of applicability of the QRPA to nuclear structure problems andcomparisons with the Generator Coordinate Method have been studied in [18]. This developments, as well as an inclusion of the QPC effects may improve the T=0 pn-interaction used in systematic β-decay calculations.

Recommendations

1. To continue efforts on improving the energy-density functionals which are the key ingredient of the self-consistent approach to the β-decay. Pairing part of the functional deserves a special attention. A recent proposal by [19] is very promising: to develop a hybrid density functional adopting the Skyrme structure for the normal part and taking an advantage of the pairing part depending on the gradient of pairing density, as done in the Fayans functional [20]. Such density dependence offering an excellent simultaneous description of the odd-even staggering effects in the Q_β-values and charge radii [21] is expected to have a strong impact on the two-neutron emission probabilities [22].
2. The necessary (and practically feasible task) is to work out an extension of the pnFAM for such a hybrid functional(s) in order to treat the half-lives and P_{xn}-values of deformed nuclei.
3. The necessary (though a difficult task) is to work out practically efficient global beta-decay models which account for the quasi-particle coupling (QPC). Correlations between the half-lives, P(x)n-values and < R2ch > can be used for constraining the QPC strength.
4. It is necessary to find better behaving isoscalar effective pp-interaction with less mass dependence. The estimate should be offered for the competing effects of the QPC and tensor interaction.
5. To explore the fragmentation of the Gamow-Teller and spin-dipole transitions for a variety of nuclei using a second RPA model [7] (or an equivalent particle-vibration coupling model) [8-10]. Estimate the spreading of the GT strength and quenching of the measured strength compared to the calculated results. Establish a consistent approach to quenching in the forbidden transitions.

Actions

1. To cross check the existing theoretical tables of the beta decay properties with respect to a number of additional criteria. First of all, the share of the FF decays in the total rate (%FF) should agree with selection rules, unique FF reduction factors, and with available experimental decays schemes.
2. To continue with finding a better behaving isoscalar effective pp-interaction with less mass dependence. Estimate the impact of the competing effects, for instance QPC and tensor interaction.

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Appendix 3

Outline of final report – revised at CM on Benchmarking new bDN data, 13-15 December 2017, IAEA, Vienna

<table>
<tr><td colspan="2">Section 1: Introduction
Coordinator: P. Dimitriou,
Contributors: B. Singh, I. Dillmann</td></tr>
<tr><td>1.1 Historical background/ motivation</td><td rowspan="6"></td></tr>
<tr><td>1.2 Objectives</td></tr>
<tr><td>1.3 Deliverables/Output</td></tr>
<tr><td>1.4 Outcome</td></tr>
<tr><td>1.5 Scope</td></tr>
<tr><td>1.6 Structure of document</td></tr>
<tr><td colspan="2" align="center">Part A. Microscopic data</td></tr>
<tr><td colspan="2">Section 2: Methods and Measurements
Coordinators: J.L. Tain, K. Rykaczewski, I. Dillmann
Contributors: M. Madurga, R. Grzywacz, B.C. Rasco, A. Algora</td></tr>
<tr><td>2.1 Methods for measurements
(Rykaczewski)</td><td>2.1.1 Delayed neutron emission probabilities
Methods listed in reports (1 and 2-RCM, CM 2011) (Rykaczewski, Algora, Dillmann)
Ranging-out: included under ion-gamma counting method (Rykaczewski)
Pure Gamma-counting (Algora, Lorusso)

What is needed: review pros and cons of each method

2.1.2 Delayed neutron spectra
He3 (Tain)
Proton recoil spectrometers (Tain)
TOF (Grzywacz, Madurga, Cano, Banerjee)

2.1.3 New methods
TAS – a comprehensive report on method (Tain, Rasco)
Ion-recoil (Madurga in collaboration with Scielzo)
CLYC (Cano)
Potential MR-TOF (Dillmann)</td></tr>
</table>

2.2 List of priorities for new measurements (Tain)	**2.2.1 For Fission Reactor technologies based on inter-library comparisons of delayed neutron yields** (Tain, Mills, Cano, Minato, Fallot): List which isotopes have been measured, which not **2.2.2 For Nuclear Structure and Nuclear Astrophysics** (Marketin, Dillmann, Rykaczewski, Grzywacz) **2.2.3 Anti-neutrinos** (Fallot, Sonzogni)
2.3 New data (Dillmann): to contact all relevant parties	**List of data measured and published since beginning of CRP (2013) – also not yet published-ALTO-Future measurements/what is left to be done**
Section 3: Compilation and Evaluation Coordinator: B. Singh Contributors: I. Dillmann, G. Mukherjee, X. Huang, McCutchan, Sonzogni, Liang, Birch, Chen, Miernik, Tain, Dimitriou	
3.1 Compilation and evaluation methodology (Singh)	
3.2 New evaluated data for Z=2-28 and possible updates for Z>28 (Singh)	Tables of recommended data and Q-values (AME2016); compilation tables in annexes
3.3 P1n – Standards (Singh)	
3.4 Systematics (Singh)	**3.4.1 McCutchan et al** (McCutchan, Sonzogni) **3.4.2 Miernik** (Miernik) **3.4.3 Kratz-Hermann?**
3.5 Reference Delayed Neutron (DN) Spectra (Tain)	**3.5.1 Digitization of delayed neutron (DN) energy spectra** (Mukherjee, Dimitriou, Piksaikin) **3.5.2 Evaluation of published spectra used as references for calibration purposes** (Tain, Madurga) Greenwood, Reeder, Kratz, Rudstam, incl. those in Brady's thesis

Section 4: Theory Coordinator: I. Borzov Contributors: T. Marketin, F. Minato, S. Chiba	
4. Description of models (Borzov)	Overview of existing models (based on draft circulated at 3RCM incl. comparative tables) Incl. FAM (Engel), new QPC models (Litvinova), Skyrme (Milano)
	4.1.1 Self-consistent models (Borzov, Marketing, Minato) -3 global: D**F3+cQPRA, RMF, HFBCS+QRPA** **4.1.2 Microscopic-Macroscopic** (Borzov,Marketin) - Moeller et al 2012, Mumpower and Kawano **4.1.3 Macroscopic-Microscopic** (Chiba) - Gross theory
4.2 Comparison with new T1/2 and Pn tables	Annexes: include results in tables along with evaluated data: two tables for T1/2 and Pn respectively Figs. In text
4.3 Conclusions and recommendations: limitations, perspectives	Based on theory review in Appendix 2

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Part B: Macroscopic Data – revised at CM on Benchmarking new beta-delayed neutron evaluated data, 13-15 Dec. 2017	
Section 5: Measurements, analysis and compilation (10 pages) Coordinator: V. Piksaikin Contributor: F. Minato	
5.1 Methods (Piksaikin) 5 pages	**5.1.1 Delayed neutron yields** (Piksaikin, Minato) **5.1.2 Delayed neutron integral spectra** (Piksaikin) **5.1.3 Time-dependent parameters** (Piksaikin) Energy dependence GEF calculations for U235, Pu-239 energy dependence from 0 to 6 MeV (Mills)
5.2 New measurements and compilation (Piksaikin) 5 pages	Covering all three above listed areas – mention future plans for measurements (IPPE, Cadarache)- 1 paragraph each
Section 6: Basic summation calculations, uncertainty analysis and validation Coordinator: R. Mills, Contributors: A. Sonzogni, V. Piksaikin, D. Cano, M. Fallot, D. Foligno	
6.1 CRP (T1/2,Pn) file for practical applications (Sonzogni)	Creation of a definitive numerical file of T1/2 and Pn values for use in applications spanning reactor technologies, anti-neutrino spectra and nuclear astrophysics
6.2 Delayed neutron yields Coordinator: Mills, Contributors: Sonzogni, Cano, Piksaikin, Fallot, Foligno	Jeff-3.1.1 FYs, ENDF/B-8.0 + CRP Pn values using definitive numerical table Jeff-3.1.1 FYs: Robert will check released version and send corrected one (137I) **6.2.1** Basic inter-comparison of nu-bars and main contributors for all systems using CFYs + IFYs (decay data JEFF-3.1.1; ENDF/B-VIII.0, ENDF/B-VIII.0+CRP (T1/2,Pn), CRP (T1/2,Pn)) For all fissioning systems **6.2.2** Inter-comparison for time-dependence for U-235 thermal; (decay data: ENDF/B-VIII.0+CRP (T1/2,Pn)); Specific conditions will be set after this meeting (Mills, Foligno, Fallot)

	6.2.3 Comparison with recommended total delayed neutron yields from evaluated libraries-discussion on differences-identification of important precursors that give rise to the differences: use IFYs Use decay libraries: ENDF/B-VIII.0+CRP (T1/2,Pn) Fission systems: thermal U-235, Pu-239; fast U-235, 238: Th-232, Pu-239; U-233 Specific conditions for time-evolution calculations to be set after the meeting (Mills, Foligno, Fallot) **6.2.4** Uncertainty analysis on summation calculations using CRP (T1/2,Pn) values **(Cano)** Quadrature, Monte Carlo **6.2.5** Recommendations Describe problems in other FY libraries (e.g. 86Ge) and how it has been corrected, mention also other corrections in JENDL/JEFF etc
6.3 Delayed neutron integral spectra Coordinator: Piksaikin	Comparison of measured spectra with summation calculations using the ENDF/B-VIII.0+CRP (T1/2,Pn) tables for all systems with available data Internal comparison of calculations with Mills – Vladimir to provide irradiation conditions
6.4 Time-dependent parameters (Coordinator: Foligno, Contributors: Sonzogni, Mills)	From summation calculations: decay data ENDF/B-VIII.0+CRP(T1/2,Pn) For U-233 fast, 235 thermal and fast, 236 fast, 238 fast; Pu-239 thermal and fast; Th-232 fast; Am-241 fast, Np-237 fast Comparison with measured by Piksaikin (Foligno, Piksaikin) Uncertainty analysis with Monte Carlo (Foligno)

Section 7: Integral calculations- Impact of CRP (T1/2, Pn) on specific reactor designs Coordinator: D. Cano, M. Fallot	
7.1 Comparison with integral experiments (Cano)	Calculate and compare k_eff, beta_eff for 8 fast and one thermal systems
7.2 Study of impact of new CRP (T1/2,Pn) data on reactor calculations (Cano, Fallot)	liquid metal reactors, PBMR, FBR include sensitivity analysis
Section 8: Systematics of macroscopic DN data Coordinator: V. Piksaikin Contributors: A. Sonzogni, S. Chiba	
8.1 Time-dependent parameters (Piksaikin)	Formula + figures; <T1/2>
8.2 Delayed neutron yields vs degree of evenness of Z and N, mass asymmetry (Sonzogni, Chiba)	
Section 9: Recommended data Coordinator: V.Piksaikin	
9.1 Group constants (Piksaikin)	**Supply 6- and 8-group constants** (10 pages) Based on new experimental data appearing after WPEC/SG-6 for the whole set of nuclides that already have recommended data (WPEC/SG-6)
Section 10: Reference Database Coordinator P. Dimitriou	
10.1 Microscopic data	Retrieval interface, content, plotting and downloading tools
10.2 Macroscopic data	Retrieval interface, content, plotting and downloading tools
10.3 subsidiary databases (ENSDF, ENDF/B, JEFF, JENDL, ROSFOND, BROND)	Input from Mills, Sonzogni, Minato, Piksaikin
10.4 Beta-delayed neutrons in EXFOR	

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Section 11: Conclusions Coordinator: Rykaczweski, Mills, Piksaikin	
Split into microscopic and macroscopic sections	-achievements of this CRP -limitations of current approaches -new detection and data acquisition technologies -needs for further developments for applications (SG, innovative reactors/ADS, assay of nuclear materials, nuclear astrophysics)

Appendix 3

Annex 1

3rd Research Coordination Meeting on
Reference Database for Beta-delayed Neutron Emission Evaluation

IAEA Headquarters, Vienna, Austria
12-16 June 2017
Meeting Room M0E27

ADOPTED AGENDA

Monday, 12 June

08:30 - 09:00 **Registration** (IAEA Registration desk, Gate 1)

09:00 - 9:30 **Opening Session**

Welcoming address and Introduction
Election of Chairman and Rapporteur
Adoption of Agenda
Administrative matters

9:30 - 12:30 **Report Presentations by participants (about 30 min each)**

Neutron detectors, compilation, evaluation and digitization, Mukherjee

Report of CNDC (compilation, evaluation), Huang

Pn values in neutron-rich nuclei for astrophysics, Johnson

^{95}Rb decay half-live from the Belen measurements at IGISOL, Algora

Compilation and Evaluation of Pn and half-lives for beta-delayed neutron emitters across the nuclear chart, Singh

Coffee break as needed

12:30 – 14:00 ***Lunch***

14:00 – 18:00 **Report Presentations by participants (cont'd)**

Relative abundances of delayed neutrons and half lives of their precursors from fission of ^{232}Th, ^{238}U, ^{239}Pu, ^{237}Np and ^{241}Am by neutrons in the energy range 14.2-18 MeV and 1 GeV protons, Piksaikin

Delayed neutron summation calculations and the identification of important precursors using the new CRP Pn values, Mills

Neutron energy dependence of delayed neutron yields and several short reports, Minato

Summation calculations and uncertainty analysis of delayed neutron yield, half-time and temporal group constants, Leconte

Importance of Simulation Tools and Nuclear Data for Safeguards, Cormon

Coffee break as needed

Tuesday, 13 June

09:30 - 12:30 Report Presentations by participants (about 30 min each)

Validation of delayed-neutron data based on various reactor experiments, Leconte

Report, Sonzogni
Report, Chiba
Beta-decay and β-delayed neutron emission in very neutron-rich nuclei,
Report, Borzov
Report, Marketin

Coffee break as needed

12:30 – 14:00 Lunch

14:00 – 18:00 Report Presentations by participants (cont'd)

Beta-delayed neutron studies for heavy isotopes, Dillmann
Report, Tain
Beta-Delayed Neutrons from the Reference Activity ^{137}I Measured with MTAS, Rasco
Update on relevant proposals on beta-delayed neutron emission, recent experiments and evaluated data, Rykaczewski
Beta-delayed neutron spectroscopy of fission fragments with VANDLE and the IDS Neutron Detector, Madurga
New bDN database, Dimitriou

Coffee break as needed

Dinner at local restaurant (19:00)

Wednesday, 14 June

09:00 - 12:30 Round Table Discussion

-results of the work assigned at the 2nd RCM and also of the individual work programs/review of actions lists (please look at actions lists of the summary report of the 2nd RCM):
new experimental data; new evaluated T1/2, Pn tables; standards and reference spectra; systematics; comparison of new evaluations with data, theory and previous compilations; benchmarking of new evaluations against nubars and DN spectra; group constants

-conclusions from above studies; recommendations

-new database and retrieval interface (for microscopic and macroscopic data)

-final technical report of the CRP: content, assignment of chapters, publication (IAEA, peer-reviewed journal)

Coffee break as needed

12:30 – 14:00 Lunch

14:00 – 18:00 Round table discussion (cont'd)

Coffee break as needed

1. Thursday, 15 June

09:00 - 12:30 Round Table Discussion (cont'd)

Coffee break as needed

12:30 – 14:00 Lunch

14:00 – 18:00 Round table discussion (cont'd)

Coffee break as needed

2. Friday, 16 June

09:00 - 12:30 Drafting of the summary report

Coffee break as needed

12:30 Closing of the meeting

Annex 1

3rd Research Coordination Meeting on
Reference Database for Beta-delayed Neutron Emission Evaluation

Vienna, Austria
12 - 16 June 2017

List of Participants

Canada

Dillmann Iris
Triumf
4004 Wesbrook Mall
VANCOUVER
BRITISH COLUMBIA
CANADA
Email: dillmann@triumf.ca

Singh Balraj
McMaster University
A.N.Bourns Science Bldg 241
1280 Main Street West
L8S 4M1 HAMILTON, ON
CANADA
Email: balraj@mcmaster.ca

Liang Johnson
McMaster University
Department of Physics and Astronomy
A.N. Bourns Science Building 241
1280 Main Street West
HAMILTON, ONTARIO L8S 4MI
CANADA
Email: liangj27@mcmaster.ca

China

Huang Xiaolong
Division of Nuclear Physics of CIAE
P.O. Box 275(41)
BEIJING
CHINA
Tel:0086 10 6935 8119
Email: huang@ciae.ac.cn

Croatia

Marketin Tomislav
University of Zagreb
Faculty of Science
Horvatovac 102a
10000 ZAGREB
CROATIA
Email: marketin@phy.hr

India	Mukherjee Gopal Variable Energy Cyclotron Centre 1/AF Bidhan Nagar KOLKATA INDIA Email: gopal@vecc.gov.in
Japan	Chiba Satoshi Tokyo Institute of Technology 2-12-1-N1-9, Ookayama 152-8550 TOKYO MEGURO-KU JAPAN Email: chiba.satoshi@nr.titech.ac.jp
	Minato Futoshi Nuclear Science and Engineering Directorate; Japan Atomic Energy Agency (JAEA) 2-4, Shirane-shirakata; Naka-gun TOKAI-MURA, IBARAKI-KEN JAPAN Tel:0081292825266 Email: minato.futoshi@jaea.go.jp
Russian Federation	Piksaikin Vladimir Institute for Physics and Power Engineering (IPPE) Ploshad Bondarenko 1 249033 OBNINSK RUSSIAN FEDERATION Tel:007 48439 58477 Email: piksa@ippe.ru
	Borzov Ivan NRC Kurchatov Institute 1, Akademika Kurchatova pl. Nuclear Physics Complex Theoretical Computataions Laboratory 123182 MOSCOW KALUZHSKAYA OBLAST RUSSIAN FEDERATION Email: ibor48@mail.ru
Spain	TAIN Jose Inst. De Fisica Corpuscular Univ. Valencia Apdo. Correos 22085 46071 VALENCIA SPAIN Email: tain@ific.uv.es
	Algora Alejandro Instituto de Ficica Corpuscular Centro Mixto CSIC-Univ. Valencia Apdo. Correos 22085 46071 VALENCIA SPAIN Email: algora@ific.uv.es

United Kingdom

Mills Robert
National Nuclear Laboratory Limited
5th Floor, Chadwick House
Warrington Road, Birchwood Park
WARRINGTON
UNITED KINGDOM
Email: robert.w.mills@nnl.co.uk

France

Leconte Pierre
Centre d'Etudes Nucleaires de Cadarache
13108 SAINT-PAUL-LEZ-DURANCE
FRANCE
Email: pierre.leconte@cea.fr

USA

Sonzogni Alejandro
Brookhaven National Laboratory
National Nuclear Data Center
Building 817, PO Box 5000
11973-5000 UPTON, NY
UNITED STATES OF AMERICA
E-mail: sonzogni@bnl.gov

Rykaczewski Krzysztof
Division of Physics; Oak Ridge National Laboratory (ORNL)
P.O. Box 2008
OAK RIDGE, TN
UNITED STATES OF AMERICA
Tel:001 865 574 1268
Email: rykaczewskik@ornl.gov

Bertis Charles Rasco
Oak Ridge National Laboratory, Physics Division
Joint Institute for Nuclear Physics and Applications
P.O. Box 2008
OAK RIDGE TN 37831
UNITED STATES OF AMERICA
E-mail: brasco@utk.edu

Miguel Madurga Flores
Department of Physics and Astronomy
University of Tennessee
KNOXVILLE, TN 37996
UNITED STATES OF AMERICA
Email: mmadurga@utk.edu

IAEA

Dimitriou Paraskevi – Scientific Secretary
Vienna International Centre
P.O. Box 100, Wagramer Strasse 5
1400 VIENNA, AUSTRIA
Email: p.dimitriou@iaea.org

Capote Noy Roberto Mario
Vienna International Centre
P.O. Box 100, Wagramer Strasse 5
1400 VIENNA, AUSTRIA
Email: Roberto.CapoteNoy@iaea.org

Koning Adrianus Johannes
Vienna International Centre
P.O. Box 100, Wagramer Strasse 5
1400 VIENNA, AUSTRIA
Email: A.Koning@iaea.org

Verpelli Marco
Vienna International Centre
P.O. Box 100, Wagramer Strasse 5
1400 VIENNA, AUSTRIA
Email: m.verpelli@iaea.org

IAEA-SGOC

Cormon Sandrine
Vienna International Centre
P.O. Box 100, Wagramer Strasse 5
1400 VIENNA, AUSTRIA
Email: s.cormon@iaea.org

3rd Research Coordination Meeting on
Reference Database for Beta-delayed Neutron Emission Evaluation

Vienna, Austria
12 - 16 June 2017

Links to Presentations

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1	G. Mukherjee	PDF
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20	S. Cormon	PDF

Group picture

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

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