(*To be published in* Nuclear Physics A 624, Oct. 97) (*Version* v 25 jul 97)

The NUBASE evaluation of nuclear and decay properties

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Abstract

This paper presents the first version of the NUBASE evaluation of nuclear and decay properties of nuclides in their ground- and isomeric-states. All nuclides for which some experimental information is known are considered. NUBASE has basically been derived from the "Evaluated Nuclear Structure Data Files" and from the "Atomic Mass Evaluation" of 1995, but it also includes information from recent literature or literature missed in one of these two evaluations and is meant to cover all experimental data along with their references. In case no experimental data is available, whenever possible, trends in the systematics of neighboring nuclides have been used to derive estimated values (labeled in the database as non-experimental). Adopted procedures and policies are presented.

1. Introduction

We considered that the nuclear physics community from basic physics to applied nuclear sciences would greatly benefit from a database which contains values for the main basic nuclear properties such as masses, excitation energies of isomers, half-lives, spins and parities, decay modes and their intensities. A requirement is that all the information should be properly referenced in that database to allow checks on their validity.

One of the applications of such a database is the "Atomic Mass Evaluation" (AME) in which it is essential to have clear identification of the states involved in a decay, a reaction or a mass-spectrometric line. Furthermore, calculations requiring radioactive parameters for nuclear applications (e.g., reactors, waste management, nuclear astrophysics) need to access this basic information on any nuclide. In the preparation of a nuclear physics experiment, such database could also be quite usefull.

Most of the data mentioned above are in principle already present in two evaluated files: the "Evaluated Nuclear Structure Data Files" (ENSDF) [1] and the "Atomic Mass Evaluation" of 1995 (AME'95) [2]. The demand above could be thus partially fulfilled by combining them in a 'horizontal' structure (which exists in the AME, but not in ENSDF). NUBASE is therefore, at a first level, a critical compilation of these two evaluations.

In making this, we found it necessary to examine the literature, firstly, to revise several of the collected results and insure that the mentioned data are presented in a more unique way; secondly, to have as much as possible all the available experimental data included, not only the recent ones (updating requirement), but also those missed in ENSDF and/or in AME (completeness requirement). This implied some evaluation work, which appears in the remarks added in the NUBASE table and in the discussions below. Full references are given for all of the added experimental information (cf. 2.7. References).

The cut-off date for the data from literature used in the present NUBASE'97 evaluation was December 31, 1996. Some post cut-off date work were also included, but only in remarks to the relevant data.

The contents of NUBASE are described below, along with some of the policies adopted in this work. Updating procedures of NUBASE are presented in Section 3. Finally, the electronic distribution of NUBASE and an interactive display of its contents with a World-Wide Web Java program or with a PC-program is described in Section 4.

2. Contents of NUBASE

NUBASE contains experimentally known nuclear properties together with some values estimated by extrapolation of experimental data for 3001 nuclides. NUBASE also contains data on those isomeric states that have half-lives greater than 1 millisecond; there are 669 such nuclides of which 58 have more than one isomeric state.

The following quantities have been compiled, and when necessary evaluated, for each nuclide (A,Z) and for each state (ground or isomeric): mass excess, excitation energy of the isomeric states, half-life, spin and parity, decay modes and intensities for each mode, isotopic abundances of the stable nuclei, and references for all experimental values of the above items.

In the description below, references to works that are also quoted in the NUBASE table are given with the same Nuclear Structure Reference key number style [3]. They are listed at the end of the main table.

The names and the chemical symbols of the elements 104 to 109 as recommended recently by the Commission on Nomenclature of Inorganic Chemistry of the International Union of Pure and Applied Chemistry (IUPAC) were used: 104 dubnium (Db), 105 joliotium (Jl), 106 rutherfordium (Rf), 107 bohrium (Bh), 108 hahnium (Hn), and 109 meitnerium (Mt), while the provisional symbols Xa and Xb were used for the elements 110 and 111. It is known to the present authors that a new set of suggestions has been made. The choice mentioned above is made for convenience and does not express a preference.

As in the AME'95 evaluation, we took care in having continuity of the set of nuclides that we consider in N, in Z, in A and in $N-Z$.

As much as possible, one-standard deviations ($1\,\sigma$) are given to represent the uncertainties connected with the experimental values. Unfortunately, experimentalists do not always define the meaning of the uncertainties that they quote; under such circumstances, the uncertainties are assumed to be one standard deviations. In not a few cases, the uncertainties are not given at all; we then estimated them on the basis of the limitations of the method of measurement.

Values and errors that are given in the NUBASE table have been rounded, even if unrounded values were found in ENSDF or in the literature. In cases where the two furthest-left significant digit in the error were larger than a given limit (30 for the energies, to maintain strict identity with AME'95, and 25 for all other quantites), values and errors were rounded off (examples: $2345.67 \pm 2.28 \rightarrow 2345.7 \pm 2.3$, $2345.67 \pm 4.68 \rightarrow 2346 \pm 5$, $2346.67 \pm 46.82 \rightarrow 2350 \pm 50$, $2345.6789 \pm 0.0068 \rightarrow 2345.679 \pm 0.007$). When we felt it necessary, and to allow traceability, we added a remark with the original value.

When no experimental data exist for a nuclide, values can often be estimated from observed trends in the systematics of experimental data. In the AME'95, masses estimated from systematic trends were already flagged with the symbol '#'. The use of this symbol is being extended in the present work to all other quantities and has the same meaning of indicating non-experimental information.

2.1. Mass excess

The mass excess is defined as the difference between the atomic mass (in mass units) and the mass number, and is given in keV for each nuclear state together with its one standard deviation uncertainty. The mass excesses values given in NUBASE are those of the AME'95 evaluation [2]. No values were changed here, since a new evaluation of masses would have required a considerable extra effort.

It sometimes happen that knowledge on masses can yield information on the decay modes, in particular regarding nucleon-stability. Such information has been used here, as can be seen in the table for ^{10}He, ^{19}Na, ^{39}Sc, ^{62}As or ^{63}As.

Figure 1 complements the main table in allowing to display the precisions on the masses, in a color-coded chart, directly as a function of N and Z. NUBASE includes nuclides that were not in the AME'95. They appear in light grey in figure 1, and no mass values are given in the table.

2.2. Isomers

For this first version of NUBASE we have adopted a simple definition for the isomers: they are excited states that live longer than 1 millisecond. Isomers are given in order of increasing excitation energy and identified by appending 'm' or 'n' to the nuclide name, e.g., ^{122}Cs for the ground-state, ^{122}Cs^m for the first isomeric state, and ^{122}Cs^n for the second isomeric state. It was not necessary to give a notation for more isomers, except that for one nuclide, ^{178}Ta, three isomers are known to exist. For this nuclide we give then, in a remark to ^{178}Ta^n (the second isomer), the available data for this third isomer.

The excitation energy can be derived from a number of different experimental methods. When this energy is derived from a method other than γ-ray spectrometry, the origin is indicated by a two letters code and the numerical value is taken from AME. Otherwise, the code is left blank and the numerical value is taken from ENSDF or from literature update.

When the existence of an isomer is under discussion (e.g., ^{96}Rb^m) it is flagged with 'EU' in the origin field to mean "existence uncertain". A comment is generally added to indicate why its existence is questioned, or where this matter has been discussed. Depending on the degree of our confidence in this existence, we can still give a mass excess value and an excitation energy, or omit them altogether. In the latter case, the mention "non-existent" appears in place of that excitation energy.

When an isomer has been reported, and later proved not to exist (e.g., ^{184}Lu^m), it is flagged with 'RN' in the origin field. In such case we give of course no mass excess value and no excitation energy, and, as in the case of the 'EU's above, they are replaced by the same mention "non-existent".

The definition of isomers as excited states that live longer than one millisecond is a simple one, but does not go without drawbacks, particularly for alpha and proton decaying nuclides. For β-decay a limit of one millisecond is acceptable, since the shortest-lived known β-decaying nuclide (^{35}Na) has a half-life of 1.5 millisecond. But for alpha or proton decay, several cases are known where an isomer lives longer than a ground-state with half-life below 1 millisecond. In a future version, NUBASE will certainly amend the rule above, but here we decided not to accept more than a few exceptions. One of them is the newly discovered proton emitter ^{185}Bi^m with 44 μs half-life; the ground-state of ^{185}Bi is yet unknown, with estimated 2 seconds half-life. Another exception is ^{187}Bi^m with a half-life of 0.8(0.6) millisecond compatible with the 1 millisecond limit.

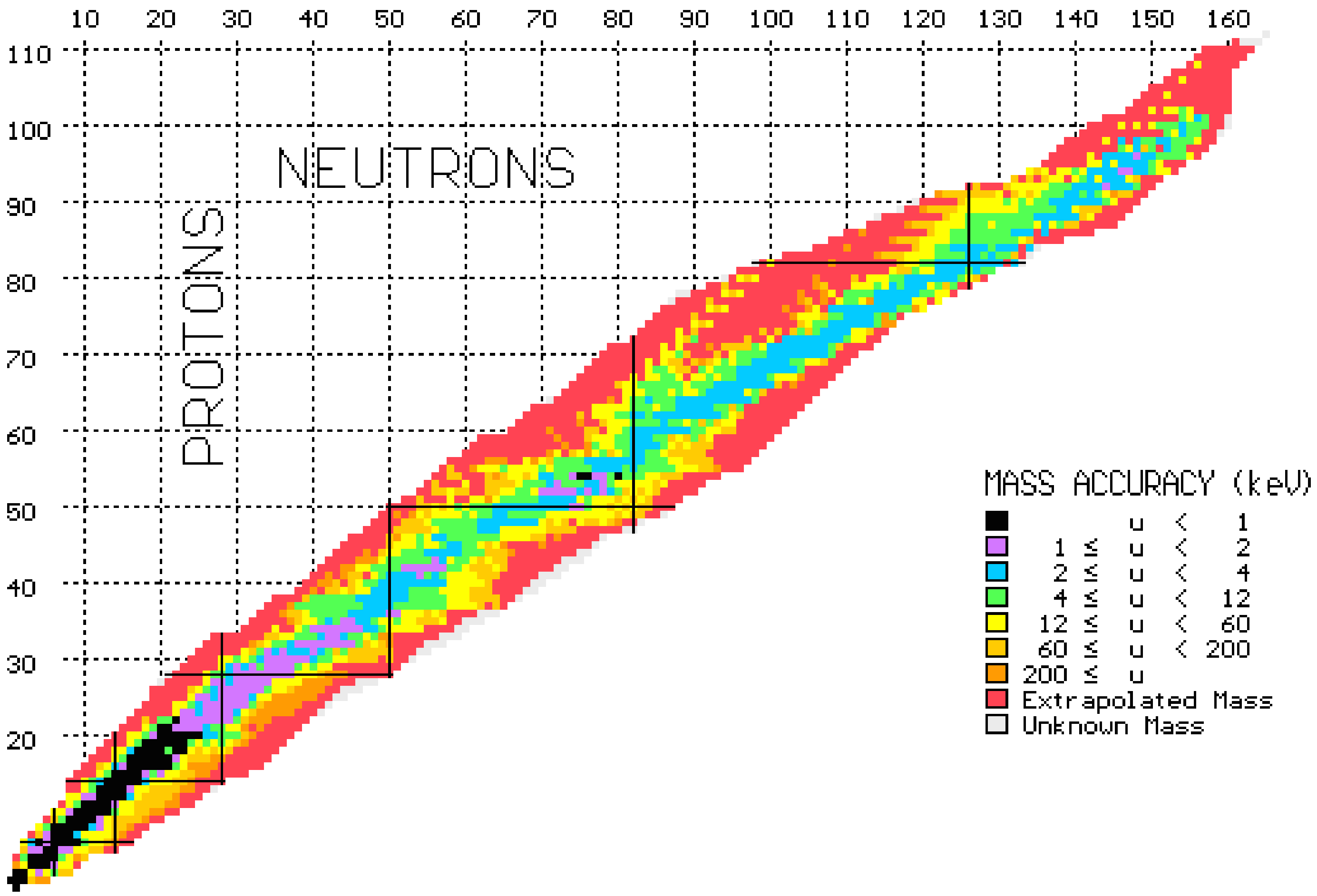

Figure 1: Chart of the nuclides for half-lives.

In several cases ENSDF gives a lower and a higher limit for an isomeric excitation energy. A uniform distribution of probabilities has been assumed which yields a value at the middle of the range and a 1σ uncertainty of 29% of that range [4]. An example is ^{136}La for which it is known that the isomer lies above the level at 230.1 keV, but, as explained in ENSDF, there are good experimental indications that the difference between these two level cannot exceed 22 keV. We presented this information as $E = 241(7)$ keV. However, if that difference would have been derived from theory or from systematics, the resulting E would have been considered as non-experimental and the value flagged with the '#' symbol.

In case where the uncertainty σ on the excitation energy E is relatively large compared with the value, the assignment to ground state and isomeric state is uncertain. If $\sigma > E/2$ a flag is added in the NUBASE table.

As a result of this work, the orderings of several ground-states and isomeric-states have been reversed compared to the ones in ENSDF. They are flagged in the NUBASE table with the '&' symbol. In several cases we found evidence for a state below the adopted ENSDF ground-state. Also, in many other cases, the systematics of nuclides with same parities in N and Z strongly suggest that such a lower state should exist. They have been added in the NUBASE table and can be located easily, since they are also flagged with the '&' symbol. In a few cases, new information on masses can also lead to reverse the level ordering. However, following the policy defined above for this first release of NUBASE, in maintaining strict compatibilty with AME'95, the exchange of the two levels has then not been made. Instead, the information is given in an added remark.

News on isomeric excitation energies

Interestingly, the rather new technique of investigating proton decay of very proton-rich nuclides has given new information on isomeric excitation energies. Thus, such work on ^{167}Ir [97Da07] now showed that it has an isomeric excitation energy $E = 172(15)$ rather than the AME'95 value 220#(90#). In addition, study of the alpha-decay series of these activities not only showed that a number of alpha lines earlier assigned to ground-states belong in reality to isomers, but also allowed to derive values for their excitation energies. Notes in the table refer to several of these cases.

Another case of such a change is ^{181}Pb. The α decay half-life that was assigned to ^{181}Pb^m in AME'95 is now assigned to the ground-state, following the work of [96To01] who showed, first, that contrary to a previous work, there is no α line at higher energy than the one just mentioned, second, that the observed α is in correlation with the decay of the daughter ^{177}Hg, which is most probably also a $5/2^-$ state.

2.3. Half-life

For some light nuclei, the half-life ($T_{1/2}$) is deduced from the level total width (Γ_{cm}) by the equation $\Gamma_{cm}\, T_{1/2} \simeq \hbar \ln 2$:

$$T_{1/2}\,(s) \simeq 4.562\,10^{-22}/\Gamma_{cm}\,(MeV).$$

Quite often uncertainties for half-lives are given asymmetrically T^{+a}_{-b}. If these uncertainties are used in some applications, they need to be symmetrized. In AME'95 a simple rough symmetrization was used: take the central value to be the mid-value between the upper and lower 1σ-equivalent limits $T + (a - b)/2$, and define the uncertainty to be the average of the two uncertainties $(a + b)/2$. The validity [5] of this relatively simple procedure was further investigated and we found, from a more strict statistical derivation (see Appendix), that a better approximation for the central value is obtained by using $T + 0.64 \times (a - b)$. The expression for the uncertainty is more complex.

In the case of experiments in which extremely rare events are observed [84Sc13], and where the results are very asymmetric, we did not average directly the half-lives derived from different works, but instead, when the information given in the papers was sufficient (e.g., ^{264}Hn or ^{267}Hn), we combined the delay times of the individual events.

Some measurements are reported as a range of values with most probable lower and upper limits. They were treated, as above (cf. 2.2. Excitation energy), as a uniform distribution of probabilities with a value at the middle of the range and a 1σ uncertainty of 29% of that range.

For some nuclides identified by using a time-of-flight spectrometer, an upper or a lower limit on the half-life is given. For observed species, we just used for lower limit the time-of-flight of the nuclides in the spectrometer. Upper limits for undetected nuclides have been evaluated for NUBASE by [93Po.A], based on the time-of-flight of the experimental setup and the yields expected from the trends in neighboring nuclides.

When half-lives for nuclides with same parities in Z and N are found to vary smoothly (see Fig. 2), interpolation or extrapolation is used to obtain reasonable estimates.

2.4. Spin and parity

As in ENSDF, values are presented without and with parentheses based upon strong and weak assignment arguments, respectively (see the introductory pages of reference [6]). The latter include estimates from systematics or theory. Where we could distinguish them, we used parentheses if the so-called "weak" argument was an experimental one, but the symbol '#' in the other cases. The survey might have not

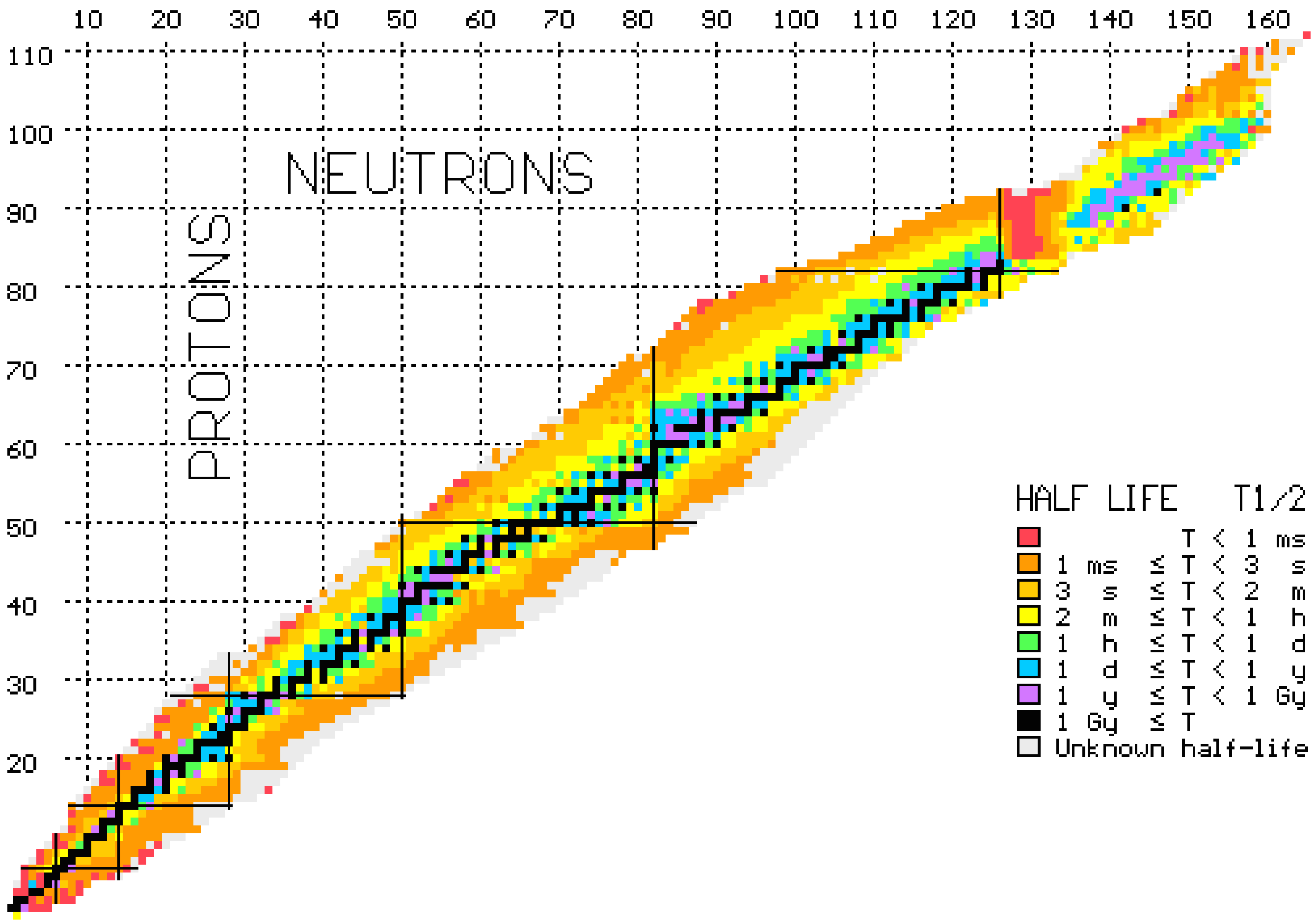

Figure 2: Chart of the nuclides for half-lives.

been complete, and the reader might still find non-flagged non-experimental cases (the authors gratefuly acknowledge mention of such cases that will help improve future versions of NUBASE).

If spin and parity are not known from experiment, they can be estimated, in some cases, from systematic trends in neighboring nuclides with the same parities in N and Z. This is often true for odd-A nuclides (see Fig. 3 and Fig. 4), but also, not so rarely, for odd-odd ones, as can be seen in Fig. 5. These estimated values are also flagged with the '#' symbol. In several cases we replaced the ENSDF systematics by our own.

The review of nuclear radii and moments of Otten [89Ot.1], in which the spins were compiled, was used to check and complete the spin values in our table.

2.5. Decay modes and intensities

The most important policy, from our point of view, in coding the information for the decay modes, is in establishing a very clear distinction between a decay mode that is energetically allowed but not experimentally observed (represented by a question mark alone, which thus refer to the decay mode itself), and a decay mode that is actually observed but for which no intensity could be determined (represented by '=?', the question mark refering here to the quantity after the equal sign).

As in ENSDF, no corrections have been made to normalize the primary intensities to 100%.

Besides direct updates from literature, we also made use of partial evaluations by other authors (with proper quotation). They are mentioned below, when discussing some particular decay modes.

The β^+ decay

In the course of our work we refined some definitions and notations for the β^+ decay, in order to present more clearly the available information. We denote β^+ the decay process that include both electron capture, denoted ϵ, and the decay by positron emission, denoted e^+. As is well known, for an available energy below 1022 keV, only electron capture is allowed; above that value both processes compete. This notation is **not** the same as the one implicitely used in ENSDF, where the combination of both modes is denoted "EC+B+".

When both modes compete, the separated intensities are not always available from experiment. Most of the time, separated values in ENSDF are calculated ones. In continuation of one of our general policies in which we retain whenever possible only experimental information, we decided not to retain ENSDF's calculated separated values (which are scarce and moreover not always updated). Only in some very particular cases the distinction is of importance, like in the case of rare or extremely

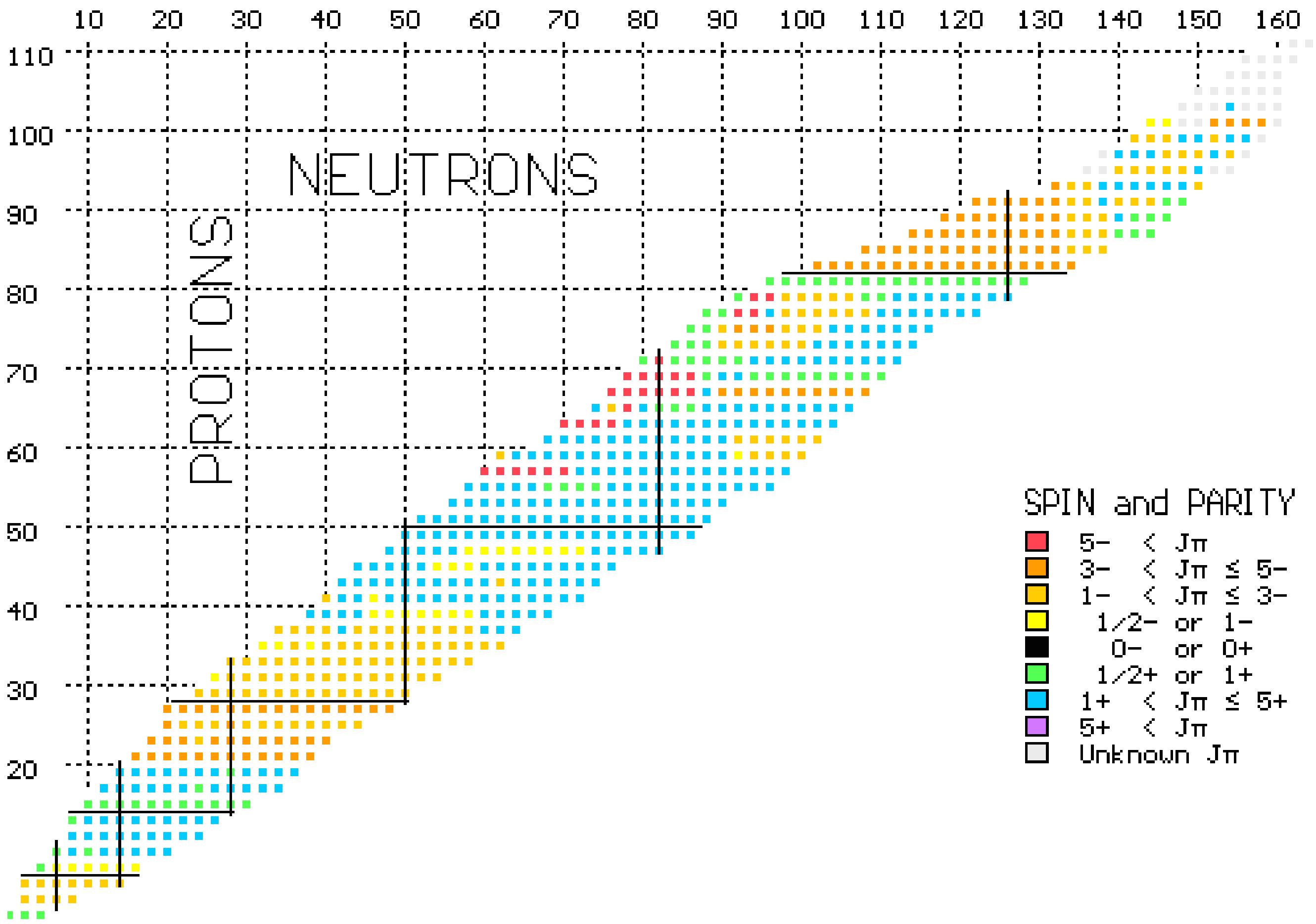

Figure 3: Chart of the nuclides for spins and parities. Shown are only the odd-Z even-N nuclides.

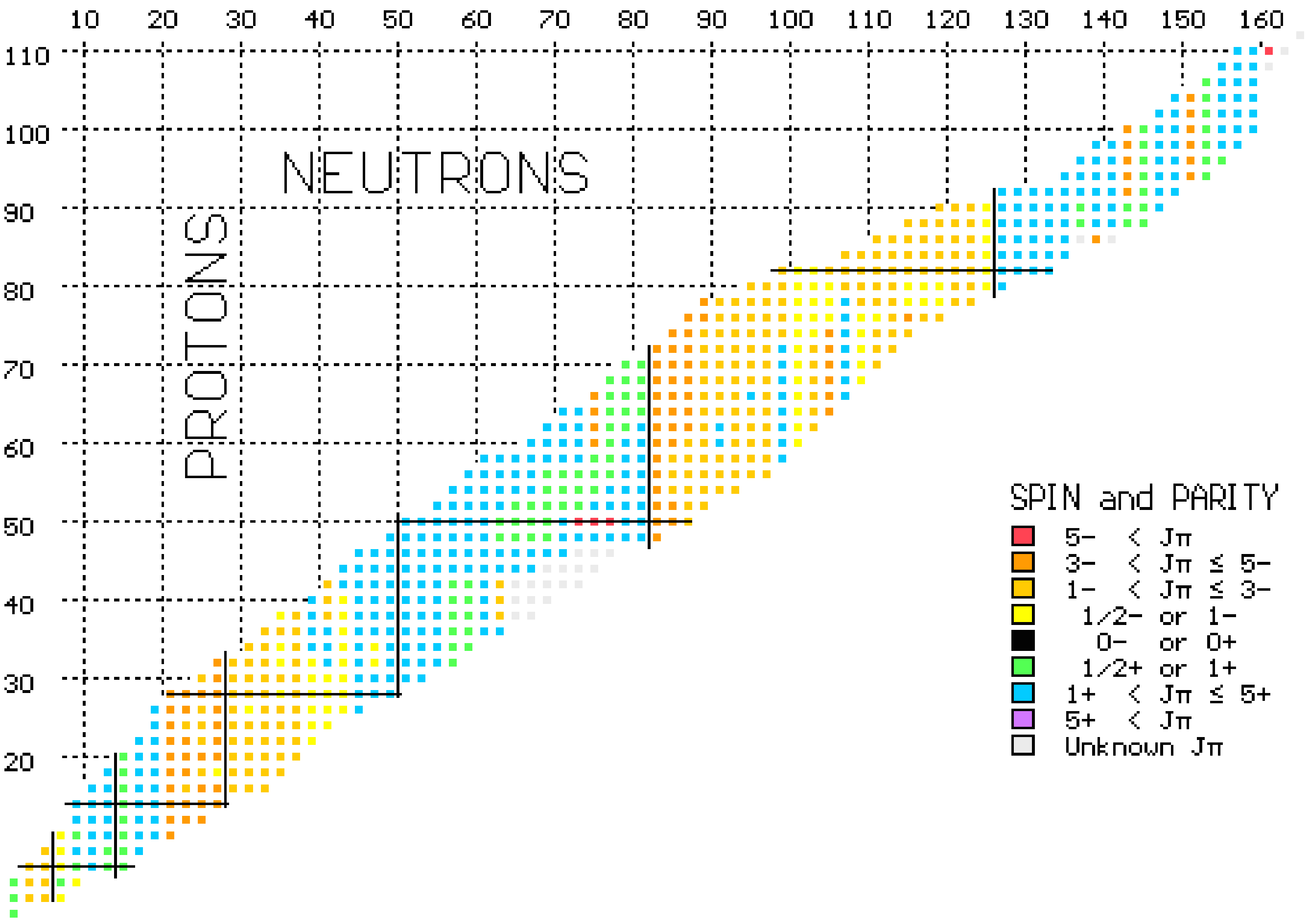

Figure 4: Chart of the nuclides for spins and parities. Shown are only the even-Z odd-N nuclides.

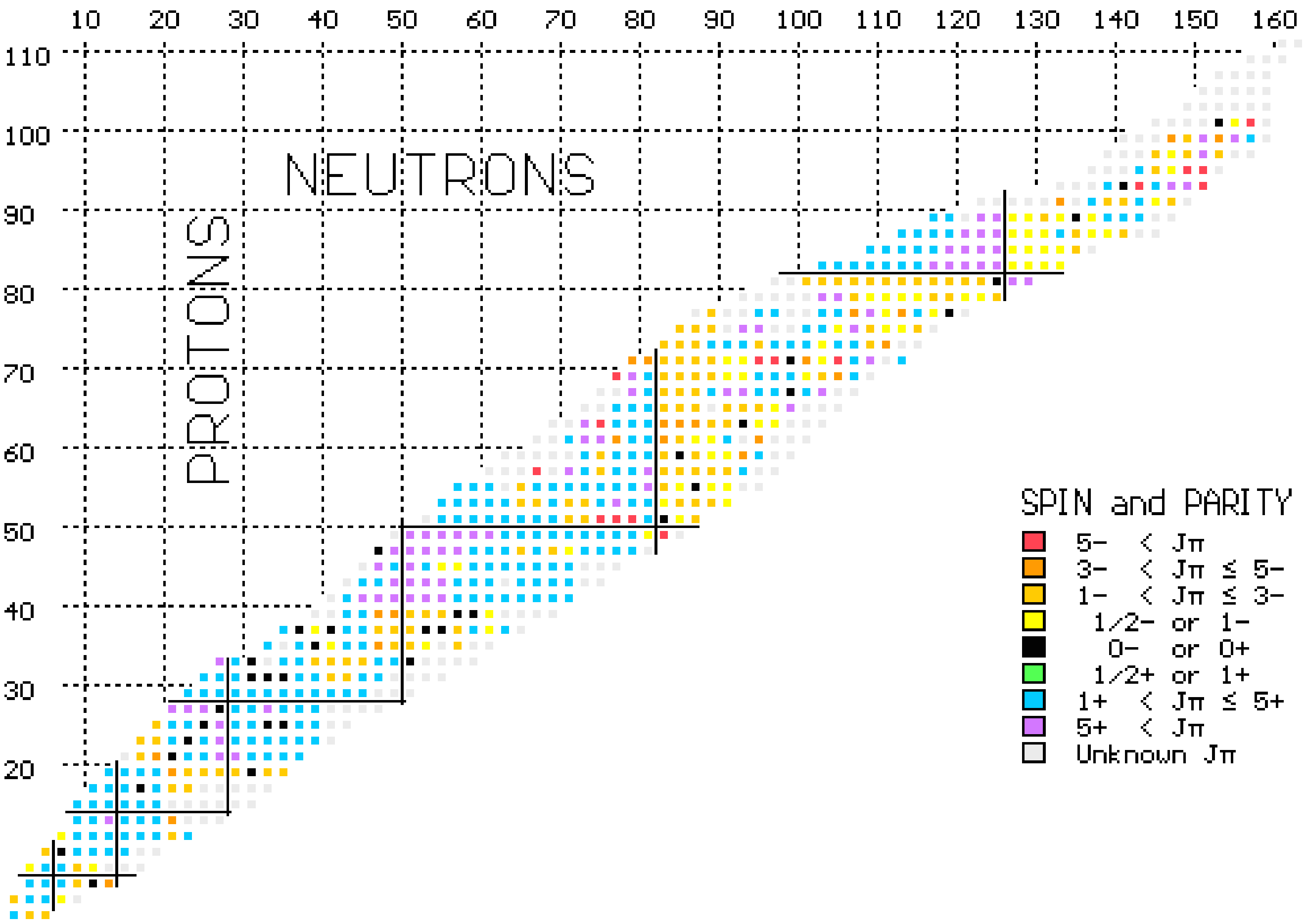

Figure 5: Chart of the nuclides for spins and parities. Shown are only the even-Z odd-N nuclides.

rare processes (e.g., ^{91}Nb, ^{54}Mn). Then, the use of our notation is usefull.

Similarly, we give both electron capture ϵ-delayed fission and the positron e^+-delayed fission with the same symbol β^+SF.

The double-β decay

In the course of our work we found that half-lives for double-β decay were not always given in a consistent way in ENSDF. For NUBASE we decided to give only half-live values or upper-limits related to the dominant process, which is in general the 2 neutrino gs-gs transition (one exception may be ^{98}Mo, for which the neutrinoless decay is predicted to be faster, see [95Tr07]). No attempt was made to convert to the same statistical confidence level (CL) upper limit results given by different authors.

The excellent recent compilation of Tretyak and Zdesenko [95Tr07] was of great help in this part of our work.

β-delayed decays

For delayed decays, intensities have to be considered carefully. By definition, the intensity of a decay mode is the percentage of decaying nuclei in that mode. But traditionally, the intensities of the pure β decay and of those of the delayed ones are summed to give an intensity that is assigned to the pure decay. For example, if the (A,Z) nuclide has a decay described, according to the tradition, by 'β^-=100; β^-n=20', this means that for 100 decays of the parent 80 $(A,Z{+}1)$ and 20 $(A{-}1,Z{+}1)$ daughter nuclei are produced and that 100 electrons and 20 delayed-neutrons are emitted. A strict notation would have been in this case 'β^-=80; β^-n=20'. However we decided to follow the long-lived tradition and give also 'β^-=100; β^-n=20'.

This also holds for more complex delayed emissions. A decay described by: 'β^-=100; β^-n=30; β^-2n=20; $\beta^-\alpha$=10' corresponds to the emission of 100 electrons, 70 delayed-neutrons and 10 delayed-α particles; and in terms of residual nuclides, to 40 $(A,Z{+}1)$, 30 $(A{-}1,Z{+}1)$, 20 $(A{-}2,Z{+}1)$ and 10 $(A{-}4,Z{-}1)$. More generally, P_n, the probability for the neutron emission, can be written:

$$P_n = \sum_i i \times \beta^-_{in};$$

(and similar expressions for α or proton emission). The number of residual β daughter $(A,Z{+}1)$ is:

$$\beta^- - \sum_i \beta^-_{in} - \sum_j \beta^-_{j\alpha} - \dots$$

Another special remark concerns the intensity of a particular β-delayed mode. The primary β decay populates several excited states in the β-daughter, that will further decay by particle emission. However, in the case where the daughter's ground state also decays by the same particle emission, some authors included its decay in the value for the concerned β-delayed intensity. We decided not to do so for two reasons. Firstly, because the energies of the particles emitted from the excited states are generally much higher than that from the ground-state, implying different subsequent processes. Secondly, because the characteristic times for the decays of the excited states are related to the parent, whereas those for the decays of the daughter's ground state are due to the daughter. For example ^{9}C decays through β^{+} mode with an intensity of 100% of which 12% and 11% to 2 excited p-emitting states in ^{9}B, and 17% to an α-emitting state. We give thus β^{+}p=23% and $\beta^{+}\alpha$=17%, from which the user of our table can derive a 60% direct feeding of the ground-state of ^{9}B. In a slightly different example, ^{8}B decays only to 2 excited states in ^{8}Be which in turn decay by α and γ emission, but not to the ^{8}Be ground-state. We write thus β^{+}=100% and $\beta^{+}\alpha$=100%, the difference of which leave 0% for the feeding of the daughter's ground state.

Finally, we want to draw to the attention of the user of our table that the percentages are, by definition, related to 100 decaying nuclei, not to the primary beta-decay fraction. An illustrative example is given by the decay of ^{228}Np, for which the delayed-fission probability is given in the original paper as 0.020(9)% [94Kr13], but this number is relative to the ϵ process, the intensity of which is 59(7)%. We thus renormalized the delayed-fission intensity to 0.012(6)% of the total decay.

In collecting the delayed proton and α activities, the remarkable work of Hardy and Hagberg [89Ha.1] in which this physics was reviewed and discussed was an appreciable help in our work. The review of Honkanen, Äystö and Eskola [7] on delayed-protons has also been checked.

Similarly, the review of delayed neutron emission of Hansen and Jonson [89Ha.2] was carefully examined and used in our table, as well as the evaluation of Rudstam, Aleklett and Sihver [93Ru01].

Spontaneous fission

The evaluation of Lorenz [86Lo.A] for spontaneous fission intensities has been used here.

^{6}H and multi-neutron emission

In the very special case of ^{6}H, we mention as possible decay channels 3 neutrons and 4 neutrons emissions. The reason is that, based on the observed mass values, both its S_n and S_{2n} separation energies are positive, which makes it stable against 1 neutron and 2 neutron emission, but **not** against 3n or 4n emission. ^{6}H decays with a half-life of 320(60) yoctoseconds. Its mass value is derived from two ^{7}Li(^{7}Li,^{8}B) experiments and one ^{9}Be(^{11}B,^{14}O). If this mass value is confirmed, ^{6}H would be a unique laboratory for searching for simultaneous 3n or 4n emission.

2.6. Isotopic abundances

Isotopic abundances are taken from reference [8] and are listed in the decay field with the symbol IS. They are displayed as given in the compilation of Holden, i.e. we did not even apply our rounding policy.

2.7. References

The year of the archival file is indicated for the nuclides evaluated in ENSDF; otherwise, this entry is left blank.

References for all of the experimental updates are given by the NSR key number [3], followed by a one letter code which specifies the added or modified physical quantity (see the Explanation of Table). In cases where more than one reference is needed to describe the updates, they are given in a remark. No reference is given for systematic values. The ABBW reference key is used in cases where it may not appear unambiguously that re-interpretations of the data were made by the present authors.

3. Updating procedure

NUBASE is updated via two routes: from ENSDF after each new A-chain evaluation and directly from the literature.

ENSDF files are retrieved from NNDC using the on-line service [1] and transfered through Internet. Two of the present authors [9] developped programs to successively:
• check that each Z in the A-chain has an 'adopted levels' data set; if not, a corresponding data set is generated from the 'decay' or 'reaction' data set,
• extract the 'adopted levels' data sets from ENSDF,
• extract from these data sets the required physical quantities, and convert them into a format similar to the NUBASE format.

The processed data are used to update manually the previous version of NUBASE. This step is done separately by the four authors and cross-checked until full agreement is reached.

The ENSDF is updated generally by A-chains, and, more recently, also by individual nuclides. Its contents however is very large, since it encompasses all the complex nuclear structure and decay properties. This is a huge effort, and it is no wonder that some older data (including annual reports, conference proceedings, and theses)

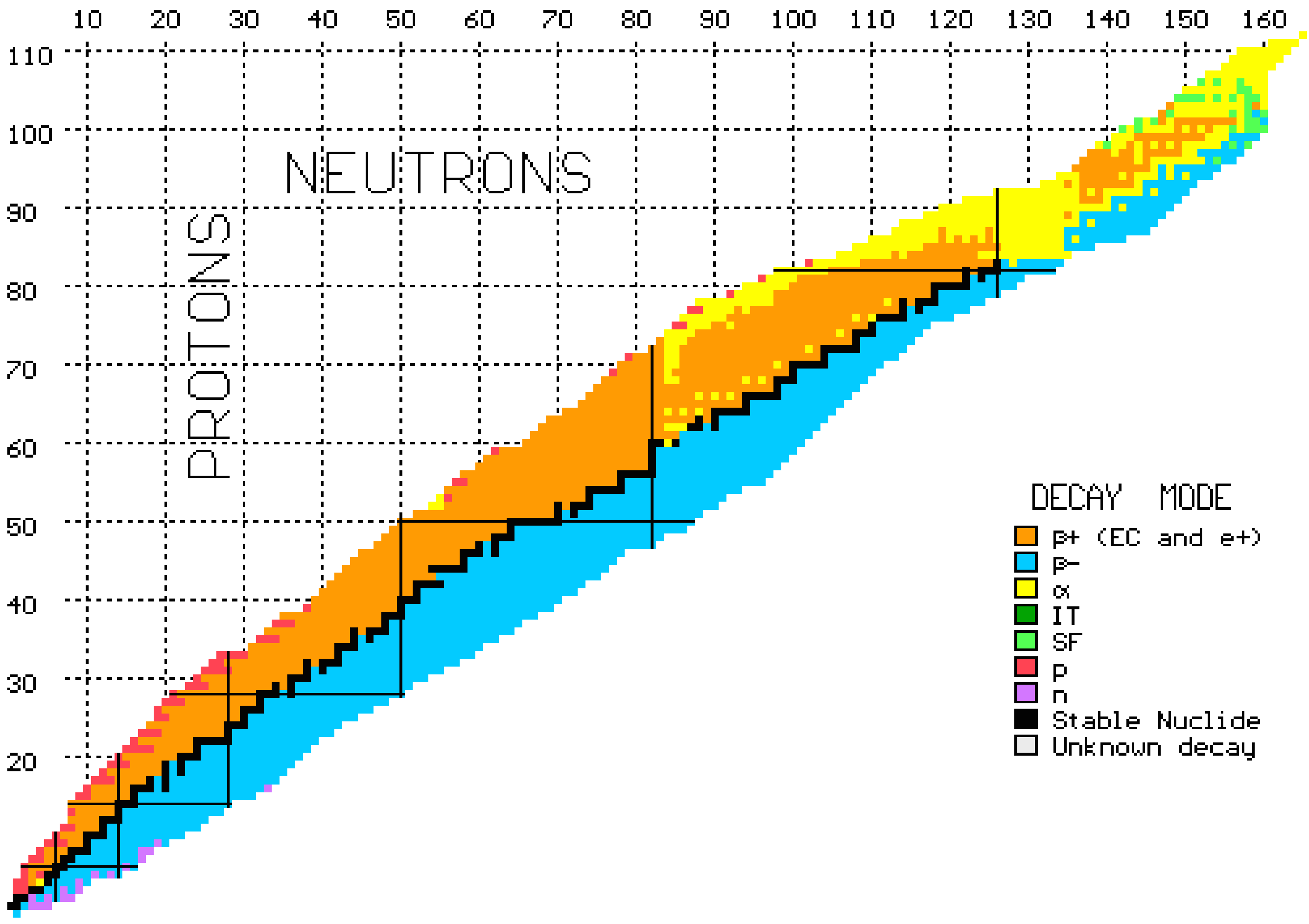

Figure 6: Chart of the nuclides for decay modes.

are missing, and that some recent data have not yet been included. Where we notice such missing data, they are analyzed and evaluated, as above, independently by the four authors and the proposed updatings are compared. Most often these new data are included in the next ENSDF evaluation and the corresponding references can be removed from the NUBASE database.

4. Distribution and displays of NUBASE

An electronic ASCII file for the NUBASE table is distributed by the Atomic Mass Data Center (AMDC) [10] through anonymous *ftp* and through the *Word Wide Web*. This file will **not** be updated, to allow stable reference data for calculations. Any work using that file should make reference to the present paper and not to the electronic file.

The contents of NUBASE can be displayed by a Java program JVNUBASE [11] through the *World-Wide Web* and also with a PC-program called "Nucleus" [12]. Both can be accessed or downloaded from the AMDC. They will be updated regularly to allow the user to check for the latest available information in NUBASE.

5. Conclusions

A 'horizontal' evaluated database has been developed which contains some of the main properties of the nuclides in their ground and isomeric states, . These data originate from critical compilations of two evaluated datasets (ENSDF and AME) updated and completed from the literature. The guidelines in setting up this database was to cover as completely as possible all the experimental data, and to provide proper reference for those used in NUBASE and not already included in ENSDF; this traceability allows any user to check the recommended data and, if necessary, undertake a re-evaluation.

As a result of this 'horizontal' work, a greater homogeneity in data handling and presentation has been obtained for all of the nuclides. Furthermore, isomeric assignments and excitation energies have been reconsidered on a firmer basis and their data improved.

It is expected to follow up this first version of NUBASE with improved treatments. Among them, we plan to extend of the definition of isomer to states not limited by the 1 millisecond half-life condition in order to better take into account isomers in nuclides decaying by α or proton emission. Also, isomers with half-life as short as 1 microsecond are produced together with longer lived ones in experiments at the large scale facilities. Another foreseable implementation would be to provide at the same the main decay lines for each nuclide. NUBASE could also be extended to other nuclear properties: radii, moments... An interesting feature that is already implemented, but not yet checked sufficiently to be included here, is to give for each nuclide, in ground or isomeric-state, the year of its discovery.

Acknowledgements

We wish to thank our many colleagues who answered our questions about their experiments and those who sent us preprints of their papers. Continuous interest, discussions and suggestions of C. Thibault were highly appreciated. Our thanks to F. Pougheon, C. Borcea, A. Gizon and C.F. Liang for enlightening discussions. We appreciate the help provided by M. Martin and J.K. Tuli in solving some of the puzzles we encountered. The help of the NNDC at Brookhaven laboratories is highly appreciated, more particularly from T.W. Burrows regarding the ENSDF library. Our thanks to F. Bouvot and S. Audi for preparing the color figures in this paper. A.H.W. expresses his gratitude to the NIKHEF laboratory and J.B. to the ISN-Grenoble, DRFMC-Grenoble and CSNSM-Orsay laboratories for the permission to use their facilities.

Appendix: Symmetrization of asymmetric uncertainties

Experimental data are sometimes given with asymmetric uncertainties, X^{+a}_{-b}. If these data are to be used with other ones in some applications, these uncertainties may need to be symmetrized. A simple method (Method 1) consisted in taking the central value to be the mid-value between the upper and lower $1\,\sigma$-equivalent limits $X+(a-b)/2$, and define the uncertainty to be the average of the two uncertainties $(a+b)/2$.

An alternative method (Method 2) is to consider the random variable x associated with the measured quantity. For this random variable, we assume the probabilty density function to be an asymmetric normal distribution having a modal (most probable) value of $x = X$, a standard deviation b for $x < X$, and a standard deviation a for $x > X$ (Fig.7). Then the average value of this distribution is

$$\langle x \rangle = X + \sqrt{2/\pi}\,(a-b),$$

with variance

$$\sigma^2 = (1-2/\pi)\,(a-b)^2 + ab, \qquad (1)$$

The median value m which divides the distribution into two equal areas is given, for $a > b$, by

$$\mathrm{erf}\left(\frac{m-X}{\sqrt{2}\,a}\right) = \frac{a-b}{2\,a}, \qquad (2)$$

and by a similar expression for $b > a$.

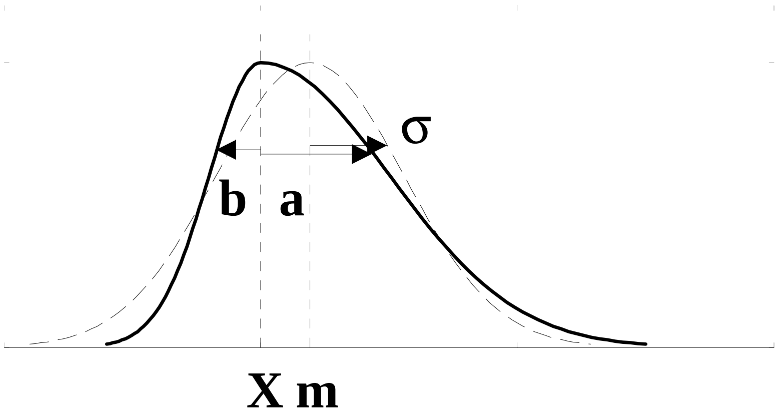

Figure 7: Simulated asymmetric probability density function (heavy solid line) and the equivalent symmetric one (dashed line).

Table A: Examples of treatment of asymmetric uncertainties for half-lives. Method 1 is the classical method as used in AME'95, and in the present work for masses and excitation energies. Method 2 is the one developed here and used for half-lives and intensities of the decay modes.

Nuclide	Original $T_{1/2}$	Method 1	Method 2
^{65}As	190+110–70ms	210 ± 90	220 ± 90
^{222}U	1.0+1.0–0.4μs	1.3 ± 0.7	1.4 ± 0.7
^{264}Hn	80+400–40 μs	260 ± 220	310 ± 250
^{266}Mt	3.4+61–13 ms	5.8 ± 3.7	6.5 ± 4.0

We define the equivalent symmetric normal distribution we are looking for as a distribution having a mean value equal to the median value m of the previous distribution with same variance σ.

If the shift $m - X$ of the central value is small compared to a or b, expression (2) can be written [13]:

$$m - X \simeq \sqrt{\pi/8}\,(a - b) \simeq 0.6267\,(a - b).$$

In order to allow for a small non-linearity that appear for higher values of $m - X$, we adopt for Method 2 the relation

$$m - X = 0.64\,(a - b).$$

Table A illustrates the results from both methods. In NUBASE, Method 2 is used for the symmetrization of asymmetric half-lives and of asymmetric decay intensities.

References

References such as 86Lo.A, 89Ha.1 or 96To01 are listed [9] under "References to the NUBASE *table"(p.110).*

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[9] O. Bersillon and J. Blachot, NEANDC(E) 246/L, INDC(FR) 071/L, September 1991.

[10] The NUBASE file in the electronic distribution can be retreived from the Atomic Mass Data Center by *anonymous ftp* to: csnftp.in2p3.fr, in directory /pub/AMDC, or through the *Web* at the address http://csnwww.in2p3.fr/amdc/.

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