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NUBASE:
A Database of Nuclear and Decay Properties

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Abstract

A database (NUBASE) containing the main nuclear properties and decay properties of nuclides in their ground- and isomeric-states is being setup. This database has mainly been derived from ENSDF and the Atomic Mass Evaluation but also includes information from recent literature and is meant to cover all experimental data along with their references. When no experimental data are available, trends in the sytematics of neighboring nuclides have been used if possible to derive values (labeled in the database as non-experimental).

1. Introduction

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 intensities, and main decay lines. All the information should be properly referenced in such a database to allow checks on their validity, if desired.

Most of the data are already present in two evaluated files: the Evaluated Nuclear Structure Data Files (ENSDF) [1] and the Atomic Mass Evaluation (AME) [2]. For some of our applications it was useful to combine them in a 'horizontal' structure (which does not exist in ENSDF) and to have as much as possible all the available experimental data included.

One of the applications is the AME which requires clear identification of the states involved in a decay or a reaction. Furthermore, calculations requiring radioactive parameters for nuclear applications (e.g., reactors, waste management, nuclear astrophysics) need to access these basic information on any nuclide. Therefore, a 'horizontal' nuclear experimental database, called NUBASE, is being generated. It can be considered as a critical compilation of the two above mentionned evaluations, AME and ENSDF. In order to be as complete as possible, this compilation is updated on the basis of recent literature. Full references are given for all of the experimental information. When no experimental data exist for a nuclide, values can be estimated from observed trends in the systematics of experimental data; they are clearly labeled with a special symbol.

The contents of NUBASE are described below, along with some of the policies adopted in this work. Updating procedures for the new evaluations from ENSDF and for the new data from the current literature are presented in Section 3. Finally, a display of the contents of NUBASE with a PC-program is described in Section 4.

2. Contents of NUBASE

NUBASE contains experimentaly known nuclear properties together with some values estimated by extrapolation of experimental data for 2923 nuclides. NUBASE also contains data to describe those isomeric states that have half-lives greater than 1 millisecond; there are 631 such nuclides of which 60 have more than one isomeric state.

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. This choice is made for convenience and does not express a preference.

The following quantities have been compiled 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. A sample listing of NUBASE is shown in Table 1 for A=130.

As much as possible, one-standard deviations (1 σ) 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 standard deviations. In not few cases, the uncertainties are not given at all; estimates have been made on the basis of the limitations of the method of measurement.

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. When the further-left significant figure in the uncertainty is larger than 3, values and uncertainties are rounded off, but not to more than tens of keV.

The mass excesses used in NUBASE are those values of the most recent evaluation [2]. By the time the database is published in full, these data will be replaced by the values from the 1995 update [3].

The character # in place of the decimal point means that values and uncertainties are estimated from systematic trends.

In some cases masses give information on nucleon-stability, yielding thus an upper or a lower limit on the half-life.

2.2 Excitation energy

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.

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 the codes given in Table 2 and the numerical value is taken from AME; the rounding policy is the same as for the mass excess. 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 (^{96}Rb^m) or the isomer is proved not to exist (^{184}Lu^m), it is flagged with 'EU' and 'RN' in the origin field, respectively.

In case where the uncertainty σ on the excitation energy E_x is relatively large, the assignment to ground state and isomeric state is uncertain. If $\sigma > E_x/2$ a flag is added in NUBASE (e.g., ^{130}In and ^{130}In^m in Table 1).

As a result of this work, the ordering of the ground- and isomeric-states have been reversed for the following nuclides compared to ENSDF: ^{58}Mn, ^{87}Nb, ^{108}Rh, ^{119}Ag, ^{138}Pm, ^{156}Tb, ^{147}Er, ^{152}Tm, ^{187}Hg, ^{187}Pb, and ^{188,198}Bi, and we found evidence for a state below the adopted ENSDF ground-state for the following nuclides: ^{94}Ag, ^{127}La, ^{137}Pm, ^{151,153}Lu, ^{181,189}Pb, ^{184}Au, and ^{257}Db. Whereas, compared to AME [2], the following cases have been reversed: ^{84}Y, ^{99}Rh, ^{130}Sb, ^{148}Pr, and ^{248}Bk, as also done in the AME update [3].

2.3 Half-life

The half-live values originate from ENSDF and the literature (492 updates). For some light nuclei, the half-life ($T_{1/2}$) is deduced from the level total width (Γ_{cm}) by the equation $\Gamma_{cm}\, T_{1/2} \simeq \hbar \ln 2$:

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

There are approximatively 60 cases (40 from ENSDF and 20 from the literature) where the uncertainties are given asymmetrically T^{+a}_{-b}. If these uncertainties are used in some applications, they need to be symmetrized. We have provisionally adopted the same method as in the AME: 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 of this relatively simple procedure needs to be assessed further before being fully accepted. An alternative method would be to define T as the central value and symmetrize only the uncertainties as $(a + b)/2$; however, this approach is not particularly attractive since T might be smaller than $(a + b)/2$. Table 3 illustrates the results from both of these methods. The symmetrized data are flagged in NUBASE.

Some measurements are reported as a range of values with most probable lower and upper limits. A uniform distribution of probabilities has been assumed which yields a value at the middle of the range and an uncertainty of 29% of that range [4].

New half-life measurements in the literature are not used in NUBASE if their accuracy is not three times better than the ENSDF-value. These new data are stored separately and made available to the users.

For some nuclides identified by using a time-of-flight spectrometer, an upper or a lower limit on the half-life is given following the characteristics of the experimental setup.

The half-life units used in NUBASE include seconds (s), minutes (m), hours (h), days (d), and years (y); all sub-units are given in Table 4. Conversion between years and seconds is given by 1 year (tropical year 1900) = 31 556 925.974 7 s.

2.4 Spin and parity

Spins and parities are mostly taken from ENSDF, and have also been updated by 96 sets of experimental data from the literature.

As in ENSDF, values are presented without and with parentheses based upon strong and weak arguments, respectively (see the introductory pages of reference [5]). If no experimental spin and parity data exist, in some cases (mostly for odd-A nuclides) they are estimated from systematic trends in neighboring nuclides with the same odd-N or odd-Z numbers, and flagged with the '#' symbol.

2.5 Decay modes and intensities

The decay modes have been updated for 113 nuclides on the basis of the recent literature, including evaluations of delayed-neutrons [6] and spontaneous fission [7] intensities.

Table 5 lists the decay modes and their symbols. Clear distinction is made between a decay mode allowed energetically but not observed (represented by a question mark alone) and an observed decay mode but for which the intensity was not measured (represented by '=?'). As in ENSDF, no corrections are made to normalize the primary intensities to 100%.

For delayed-emissions, decay intensities have to be considered carefully because the given intensities correspond to the emitted radiations or the emitted particles. In terms of daughter nuclides, the intensities are different. For example, if the (A,Z) nuclide has a decay described by 'B–=100; B–N=20', this means that for 100 decays of the parent nuclide 100 β^- and 20 delayed-neutrons are emitted, but that, after decay, 80 (A,Z+1) and 20 (A–1,Z+1) daughter nuclides are produced. This also holds for more complex delayed emissions.

2.6 Isotopic abundances

Isotopic abundances are taken from reference [8], and are listed in the decay field with the symbol IS.

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 [9], followed by a one letter code which specifies the added or modified physical quantity (T for half-life, J for spin or parity, E for the isomer excitation energy, D for decay mode and/or intensity, and I for identification). In cases where more than one quantity is updated for the same nuclide (e.g., ^{130}In in Table 1), the NSR key number for the next letters in the code are listed in a special file available for the users. No reference is given for systematic values. A few re-interpretations of the data by the present authors are denoted by the ABBW key.

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. Programs have been developed [10] 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.

From Figure 1, which presents the ENSDF status, one can see that some data are relatively old. Therefore, NUBASE has to be updated from the literature (including annual reports, conference proceedings, and theses). As above, the scanning of the literature is undertaken independently and 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. Display of NUBASE in a PC-program

NUBASE may be used in conjonction with a PC-program called NUCLEUS [11], whose main purpose is to display the nuclear properties contained in various databases, and also to draw a chart of nuclides according to the considered database. Figure 2 gives the display for the ^{101}Rh data from NUBASE, together with the decay and separation energies from AME. An extension of NUBASE presently under development for selecting the main α, EC, γ, and X-lines is also shown. Full references to the displayed data are available to the user through the 'Reference' option.

5. Conclusions

A 'horizontal' database (NUBASE) has been developed which contains several 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 on the basis of recent 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.

NUBASE will be published in full and made available through the electronic highways.

Acknowledgements

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Table 1. Sampling listing of NUBASE for A=130. In column 3 the isomeric excitation energy is followed by its origin code and by the symbol '*' if the assignment is uncertain (see text). The symbol '#' means that the associated value is derived from trends in systematics.

Nuclide	Mass excess (keV)		Isomer excitation energy (keV)			Half-life			Spin Parity	Decay modes and intensities (%)	Reference
130Cd	-61600#	500#				200	ms	40	0+	B-=100;B-N AP 4	90
130In	-69990	50			*	278	ms	3	1-	B-=100;B-N=1.01 22	90 85RE.ATD
130Inm	-69940	50	50	50	BD*	550	ms	10	(10-)	B-=100;B-N=1.65 18	90 93RU01D
130Inn	-69590	60	400	60	BD	550	ms	10	(5+)	B-=100;B-N=1.65 18	90 93RU01D
130Sn	-80242	28				3.72	m	0.04	0+	B-=100	90
130Snm	-78296	28	1946.88	.10		1.7	m	0.1	7-	B-=100	90
130Sb	-82393	25				39.5	m	0.8	(8-)	B-=100	90
130Sbm	-82388	25	5.1	.2		6.3	m	0.2	(5)+	B-=100	90 94WA.AE
130Te	-87352.8	1.9				<1.25	Zy		0+	IS=33.80 2;B-=100	90
130I	-86932	3				12.36	h	0.03	5+	B-=100	90
130Ixm	-86892	3	39.9525	.0013		9.0	m	0.1	2+	IT=84 2;B-=16 2	90
130Xe	-89880.9	1.1				stbl			0+	IS=4.1 1	90
130Cs	-86898	8				29.21	m	0.04	1+	EC+B+=98.4;B-=1.6	90
130Csm	-86735	8	163.25	.11		3.46	m	0.06	5-	IT=99.84 2;EC+B+=0.16 2	90
130Ba	-87271	7				stbl			0+	IS=0.106 2	90
130Bam	-84796	7	2475.12	.18		11	ms	2	8-	IT=100	90
130La	-81670#	210#				8.7	m	0.1	3(+)	EC+B+=100	90
130Ce	-79470#	210#				25	m	2	0+	EC+B+=100	90
130Pr	-71370#	300#				40.0	s	0.4		EC+B+=100	90
130Nd	-66340#	700#				28	s	3	0+	EC+B+=100	90
130Pm	-55470#	800#				2.2	s	0.5		EC+B+=100;B+P GT 0	90
130Sm	-47700#	900#							0+		

Table 2. Symbols used in NUBASE for the origin of excitation energies for the isomers.

Symbol	Experimental method
MD	Mass doublet
RQ	Reaction energy difference
AD	α energy difference
BD	β energy difference
p	proton decay

Table 3. Treatment of asymmetric uncertainties in half-lifes. Method 1 is the method used in the AME. Method 2 keeps the central value and symmetrizes only the uncertainties.

Nuclide	Original $T_{1/2}$			Method 1	Method 2
^{65}As	190	+110-70	ms	210 ± 90	190 ± 90
^{222}U	1.0	+10-4	μs	1.3 ± 0.7	1.0 ± 0.7
^{264}Hn	80	+400-40	μs	260 ± 220	80 ± 220
^{266}Mt	3.4	+61-13	ms	5.8 ± 3.7	3.4 ± 3.7

Table 4. Half-life sub-units used in NUBASE.

ms	:	10^{-3} s	millisecond	ky	:	10^{3} y	kiloyear
μs	:	10^{-6} s	microsecond	My	:	10^{6} y	megayear
ns	:	10^{-9} s	nanosecond	Gy	:	10^{9} y	gigayear
ps	:	10^{-12} s	picosecond	Ty	:	10^{12} y	terayear
fs	:	10^{-15} s	femtosecond	Py	:	10^{15} y	petayear
as	:	10^{-18} s	attosecond	Ey	:	10^{18} y	exayear
zs	:	10^{-21} s	zeptosecond	Zy	:	10^{21} y	zettayear
ys	:	10^{-24} s	yoctosecond	Yy	:	10^{24} y	yottayear

Table 5. Symbols for the decay modes.

Symbol	Decay mode
B-	β^- decay
2B-	double β^- decay
B+	β^+ decay
EC	electron capture
EC+B+	electron capture and β^+ decay
IT	internal transition
N	neutron emission
B-N	β^- delayed neutron emission
B-2N	β^- delayed 2-neutron emission
P	proton emission
B+P	β^+ delayed proton emission
B+2P	β^+ delayed 2-proton emission
ECP	electron capture delayed proton emission
2P	2-proton emission
A	α emission
B-A	β^- delayed α emission
B-3A	β^- delayed 3-α emission
B+A	β^+ delayed α emission
ECA	electron capture delayed α emission
SF	spontaneous fission
^{24}Ne...	heavy cluster emission

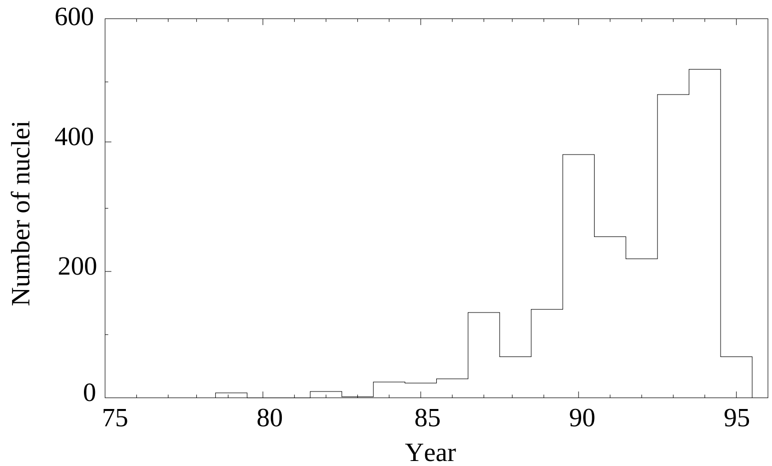

Figure 1. ENSDF status (total number of nuclei = 2347).

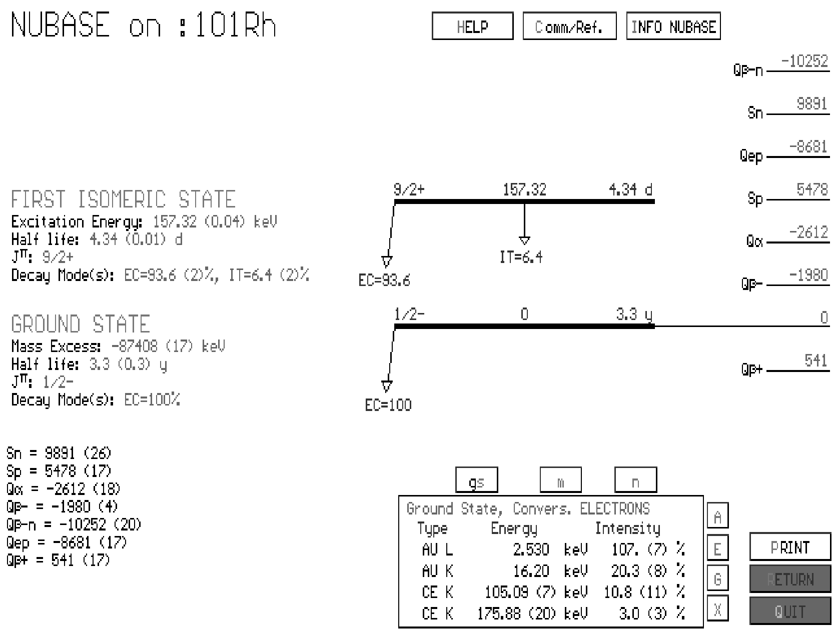

Figure 2. Screen image of the display for ^{101}Rh from the PC-program NUCLEUS. Data are from NUBASE and AME.