Table of Isotopes

Eighth Edition

Volume I

Richard B. Firestone

Virginia S. Shirley
Editor

Coral M. Baglin, S. Y. Frank Chu, and Jean Zipkin
Assistant Editors

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Volume I: A=1–150

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Table of Isotopes
EIGHTH EDITION

To
Mary, Teddy, Robert, and Michael Firestone
and
Dave Shirley

who encouraged and supported us
throughout the production of this book

PREFACE

It has been 60 years since Giorgio Fea published the first compilation of known radionuclides called the *Tabelle Riassuntive E Bibliografia delle Trasmutazioni Artificiali*[1] in Nuovo Cimento. Glenn Seaborg and colleagues published the *Table of Radionuclides*[2] in 1940, and later editions[3,4,5,6], renamed the *Table of Isotopes*, in 1944, 1948, 1953, and 1958. Remarkable historical events paralleled the publication of those editions as the *Table of Isotopes* helped pave our entry into the nuclear age. Some contents of the book were even deleted from publication for several years until the discovery of plutonium could be declassified. Data grew at a remarkable rate despite the prediction of an editor, in 1941, that "the rate at which such radioactivities are discovered may be reduced very considerably and the table would itself become stable." It didn't stabilize and, when Mike Lederer took the helm for the 6th (1967) and 7th (1978) editions[7,8], data compilation was evolving into a specialized discipline. The enormous growth of nuclear data required the development of special expertise to sort through the information, evaluate it, and publish it in a convenient form. Mike Lederer pioneered the use of computers to facilitate the publication of the *Table of Isotopes.* He was one of the first to use word processing techniques, and the 7th edition of the *Table of Isotopes* was an early example of "desktop publishing." However, Mike made one mistake in the last edition. He stated that "the 7th edition of the *Table of Isotopes* will be the last in the series."

While the 7th edition of the *Table of Isotopes* was being prepared, Bruce Ewbank and his colleagues at Oak Ridge National Laboratory were developing the first comprehensive nuclear structure database, the Evaluated Nuclear Structure Data File (ENSDF), with supporting software for producing the *Nuclear Data Sheets.* The Berkeley and Oak Ridge efforts were joined together with groups at Idaho Falls and University of Pennsylvania, under the direction of the National Nuclear Data Center at Brookhaven National Laboratory, to form the U.S. Nuclear Data Network (USNDN). Brookhaven had led similar efforts to advance the compilation of neutron cross section data. Under Sol Pearlstein's direction an international network of nuclear data evaluators was established under the auspices of the IAEA. Nuclear structure and decay data continued expanding at an enormous rate, and it was a challenge even for the large data community to process this information into the ENSDF file and publish it in the *Nuclear Data Sheets*. The editors, Murray Martin and Jagdish Tuli, deserve considerable credit for maintaining the quality of ENSDF and guiding the evaluators through the evaluation and review process. Few other scientific fields have developed such an extensive and efficient data program. In 1986, Edgardo Browne and I were able to use the ENSDF database to prepare the *Table of Radioactive Isotopes*[9], a new book emphasizing radioactive decay data. That effort merged the strengths of an international evaluation program with the publication tradition of the *Table of Isotopes.* In 1991 the National Academy of Sciences Panel on Basic Nuclear Data Compilations, chaired by Jolie Cizewski, requested that we prepare an 8th edition of the *Table of Isotopes.*

I owe an enormous debt of gratitude to my predecessors at Berkeley who began the *Table of Isotopes* and taught me the importance of quality in both the content and presentation of this book. In particular Virginia Shirley, my editor, represented the soul of this effort for over 25 years. Her editing standards were extremely high and accounted for the scarcity of mistakes in the 6th and 7th editions of this book and in the *Table of Radioactive Isotopes.* Virginia passed away shortly before we completed this book and is sorely missed. I regret that she did not see the finished product but, as I completed the final editing, I could sense that she was looking over my shoulder to make sure that we did it right.

Nearly 24,000 references are cited in this edition, and this book would not be possible without the research efforts of thousands of scientists. There have been over 100 nuclear data evaluators whose efforts have directly or indirectly contributed to the book. Some of them are listed on the summary mass chain decay schemes, but many more participated in numerous previous compilations over the past 60 years. Special thanks go to Mulki Bhat for rallying evaluators to update their mass chains in time for this edition. Georges Audi made a special effort to complete his mass evaluation in time for this book. Peter Ekström provided a great deal of advice and criticism throughout the project. Balraj Singh also contributed significantly to the development of this edition and evaluated most of the superdeformed band data. Darleane Hoffman, Glenn Seaborg, and Sigurd Hofmann helped to review and supply up-to-date heavy-element data. Peter Endt, Ron Tilley, and Jean Blachot updated and reviewed much of the data for A<45. Dick Helmer provided prepublication data for the appendix on γ-ray energy and intensity standards. Many evaluators reviewed their contributors to this edition and provided us with additional updated data.

This book would not be possible without the broad support of my colleagues at the Lawrence Berkeley Laboratory. James Symons, director of the Nuclear Science Division, provided advice, support, and encouragement. Jørgen Randrup helped develop and present the original proposals for the 8th edition, Darleane Hoffman continued those efforts, and Janis Dairiki saw to it that we were provided with the critical resources and support necessary to complete this project. Many LBNL scientists provided useful suggestions and reviewed various parts of the book. Special thanks go to the Information and Computer Science Division, under the direction of Stu Loken, for helping us solve many computer and software problems. Particular thanks go to Eric Beals, Marty Gelbaum, Cindy Hertzer, and Lam Wong who kept us up and running. Finally, I gratefully acknowledge the support and encouragement of the U.S. Department of Energy and, in particular, Stan Whetstone and Dick Meyer.

The 8th edition of the *Table of Isotopes* is not the end of this series, but instead the beginning of a new era. Our technology now allows us to update the book automatically from the underlying databases. We have developed this CD-ROM edition of the book to provide considerably more data in a compact format. With space for nearly 100,000 pages of information, we have solved the problem of an ever-expanding database. We look forward to publishing the *Tables of Isotopes* in this CD-ROM format on a much more frequent schedule than was possible for the book. This time we can state that the 8th edition of the *Table of Isotopes* will *not* be the last in this series! We look forward with enthusiasm to preparing the next edition.

Richard B. Firestone

Berkeley, California
August, 1995

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INTRODUCTION

I. General Information

The 8th edition of the *Table of Isotopes* contains nuclear structure and decay data for over 3100 isotopes and isomers with $1 \leq A \leq 272$.

The information in this edition was based primarily on evaluation efforts by the members of the U.S. Nuclear Data Network and the International Atomic Energy Agency's Nuclear Structure and Decay Data Working Group. The detailed evaluations for light mass nuclei ($A \leq 44$) were published in *Nuclear Physics A*, and those for heavier nuclei ($45 \leq A \leq 266$) were published in *Nuclear Data Sheets*. These data are also available in the Evaluated Nuclear Structure Data File (ENSDF)[1], maintained by the National Nuclear Data Center at Brookhaven National Laboratory. We have used the ENSDF file as the starting point for this edition of the *Table of Isotopes.* In most instances, the most recently published evaluation was used but, for some mass chains, we used an updated, prepublication version. Some of the data have been selectively updated by the author from recent literature and/or extensively edited to provide uniform and concise presentation. For more detailed information, the reader is encouraged to consult the ENSDF file or the primary evaluation publications (referenced on the mass chain summary drawings), and the source references given in the tabular data.

In addition to the ENSDF file, data from several other compilations have been incorporated. Nuclear mass and Q-value data were taken from the Audi et al. 1993 mass table[2], neutron cross-section data are from Mughabghab et al.[3], and most spontaneous fission probabilities are from Hoffman et al.[4] Nuclear moment data have been updated, when necessary, from Raghavan[5], and information on fission isomers and superdeformed nuclear band structure has been expanded to include information from Firestone and Singh[6]. The evaluations for $267 \leq A \leq 272$ were prepared by the author because, at this time, none existed in the ENSDF file.

This edition provides greater coverage of nuclear structure properties than previous editions. Adopted data for all known nuclear levels and their de-excitation modes are given. Complete decay data tables are also presented, as in the previous edition but, here, data evaluated from various literature sources have been combined in a single data set. The reaction level schemes of the 7th edition have been superseded by the more extensive level tables. In place of reaction level schemes, we have introduced high-spin nuclear band drawings, emphasizing information of particular importance in high-spin physics. The appendices from the 7th edition have been updated and expanded in this edition, and several new appendices have been added.

II. Organization of the 8th Edition

The 8th edition is organized by mass number (A) and subordered by atomic number (Z). For each mass chain there is an abbreviated summary decay scheme drawing (skeleton scheme) summarizing the ground state and isomeric state(s) half-lives, spin and parity assignments and ground state decay branchings, decay energies, and the proton and neutron separation energies for all known isotopes and isomers of that mass. The isotopes covered include those whose existence has been determined only in nuclear reactions, but whose decay is, as yet, unobserved. Isomers are defined as excited states with half-lives either greater than 1 ms, comparable to the ground-state half-life, or of particular historical interest (e.g., shape isomers).

The skeleton scheme is followed by tabular listings for each isotope, ordered by increasing atomic number (Z); interspersed with these are the decay scheme and band structure drawings. The tables contain general nuclear properties including natural isotopic abundance, mass excess, decay Q-values, proton and neutron separation energies, and neutron capture cross sections. These are followed by an alphabetically coded list of the decay modes and reactions known or expected to populate the isotope, with their associated 6-character reference codes from the Nuclear Science Reference file[7] (NSR). The table continues with an energy-ordered list of level data and γ-ray deexcitation information, adopted from decay and reaction measurements. Adopted level data include spin and parity, isospin, half-life, decay modes and branching itensities, dipole and quadrupole moments, and cross-indexing to the populating reactions and decays in which the level is observed. The data listed for the γ rays include energy, relative photon intensity normalized to 100 for the most intense photon branch from a given level, multipolarity, and mixing ratio. Radioactive decay data tables for the isotope and its isomers follow ech adopted levels table. These provide tables of transition energies, relative intensities, multipolarities, mixing ratios, and absolute intensity normalizations for emitted γ rays, and tables of energies, relative intensities and absolute intensity normalizations for α, p, n, or other particles emitted in decay.

A composite decay scheme drawing summarizes information from all decay modes feeding each daughter isotope. Such drawings show each parent's level energy, spin, parity, half-life, and decay energy. Beta or alpha decay feedings to daughter levels are shown with their associated reduced transition probabilities (log *ft* or HF). All γ rays from the levels populated by decay are shown with their energies, multipolarities, and relative branching intensities from the adopted levels table. Levels identified as having associated collective or high-spin structure are shown in nuclear band drawings. There, bands are drawn side by side and given a short band name if available. In-band γ rays, with their energies rounded to the nearest keV, and transitions to adjacent bands (arrow only) are shown. The existence of additional transition(s) that are not shown is indicated by an arrowhead on the level.

III. General Features of the 8th Edition

A. Uncertainties

Uncertainties are indicated by smaller italic numbers following any value. They represent the uncertainty in the least significant digit(s). For example, 37.2 *22* stands for 37.2±2.2, 15.7^{17}_{5} for 15.7+1.7-0.5, and 4.3 *2*$\times10^{-4}$ for (4.3±0.2)$\times10^{-4}$. Some numbers are indicated as approximate (≈0.15) or as a limit (>10, <0.06). Data from ENSDF for which limits were expressed as ≤ or ≥ have had those limits converted to < or >, respectively, except for quantized values such as spin. Values derived from systematics are indicated either in parentheses, e.g. (123), or as 123 *syst*; calculated values are shown as 1.5 *calc*.

B. Energies

All energies are given in keV. Level energies are shown in boldface type and transition energies in boldface italic type. Level energies are quoted relative to a constant offset (**x, y, z, ..**) as **x** or **0+y**, **1576.5+z**, etc., when their relationship to the ground state is unknown. Some γ-ray energies are given as ***X*** or ***>0*** when the transition is known to exist but its energy is not known. Systematic level energies are given in parentheses. Ground state energies are normally written as **0**, not **0.0.**

C. Reference Codes

Standard reference codes from the Nuclear Science Reference file[7] (NSR), maintained by the National Nuclear Data Center at Brookhaven National Laboratory, are used. These codes follow the general form YYAu%% where the first two characters indicate the reference year, the second two characters are the first two letters of the first author's last name, and the last two characters are arbitrary sequence characters. If the last two characters are numeric, the reference is from a primary source (except for some pre-1969 publications) and, if they are alphabetic, the reference is from a secondary source such as a report, conference proceedings, or private communication. The reference codes are translated into short citations at the end of the main tables. In a few cases, reference codes were unavailable from NSR at the time of publication, so temporary alphabetic sequence numbers were assigned irrespective of whether the source was a primary or secondary one.

D. Masses

Mass excesses, decay Q-values, and proton or neutron separation energies shown in the tables and figures are from the evaluation of Audi and Wapstra[2]. Values extrapolated from systematics are indicated by enclosing them in parentheses and rounding them based on the systematic uncertainty. Isotopes whose masses have not yet been tabulated are displayed on the summary mass chain schemes at their approximate masses estimated from the calculations of Möller, Myers, Swiatecki, and Treiner.[8] These values are presented on the decay scheme drawings in parentheses.

E. Data Evaluation

Data were generally taken directly from the ENSDF file with only minor adjustments to achieve uniform presentation. Updating was primarily limited to the addition of newly discovered isotopes, more complete nuclear band data, and the addition of missing or incomplete nuclear moments from the compilation of Raghavan[5]. Decay energies and proton/neutron separation energies were updated to values provided by Audi and Wapstra[2]. Log*ft* values were recalculated, rounded to the nearest 0.1 unit, and compared with the ENSDF file values for inconsistencies. Decay parent information was compared with relevant adopted daughter level information, and discrepancies were reconciled. Cross-indexing of levels to populating reactions and decays were taken from ENSDF, when available; otherwise, it was assigned on the basis of energy differences, level spins and parities, de-exciting transition energies and multipolarities, reaction ℓ-transfer values, and band assignments. Transition final level assignments are not generally available in ENSDF, so they were deduced from the transition energy with the requirement that transition multipolarity be consistent with initial and final level spin and parity values.

Adopted levels in the tabular data have been extended to include all levels in the decay scheme drawings whether or not the evaluator adopted them. Adopted γ-ray intensities have been renormalized, when necessary, to give 100 for the most intense photon branch from each level. Systematic multipolarities generally are not shown unless they have been used to infer the mixing ratio.

F. Mass-chain Reference

The mass-chain evaluation citations are given in a box on the summary mass-chain decay scheme. The most recent primary reference and subsequent update (if any) are indicated. If a revision date is indicated, an unpublished evaluation which is either a continuous evaluation or a prepublication mass-chain evaluation has been used. The reader is encouraged to refer to the original *Nuclear Physics A* or *Nuclear Data Sheets* publication or the ENSDF file for more detailed information. The evaluator(s) of the most recent evaluation are indicated on the mass-chain skeleton scheme and may also be contacted for additional information. In many instances we have updated selected portions of the mass chains beyond the date indicated on the summary mass-chain decay scheme. This will be evident from the post-evaluation date references included in the tabular data.

IV. Detailed Description of the Tables and Drawings

A. Mass-chain Decay Scheme

The ground-state of each nucleus is represented by a heavy line whose vertical position represents the mass of the nucleus relative to the lightest (most beta-stable) isobar. The square-root energy scale is plotted to the left of the scheme. Isomeric states are represented by heavy lines plotted above the ground state. The positions of these lines only approximate the actual energy to allow room for labels. Dashed lines represent probable isotopes or isomers. Proton or neutron separation energies are plotted as dashed lines near their actual energies. Beta-delayed particle emission is indicated by light lines if only a few discrete levels are populated by the beta decay, or by a cross-hatched band, plotted near the energy region of delayed particle emission, when many levels are populated. The mass, atomic number, and isotope symbol appear below each ground-state line.

Alpha-decay parents are shown at the top of the mass-chain decay scheme, directly above their respective daughters. Their vertical positions are unrelated to the energy scale. Half-lives are printed in large type next to the isotope or isomer lines. Spin and parity assignments are printed above the lines on the left side. Energies of isomeric states are printed above the right hand side of the line. Decay of an isotope is indicated by an arrow, labeled with the decay mode. When several decay processes compete percentage branchings are given when known.

Q-values for β^-, EC (EC+β^+), α, p, and $\beta\beta$ decay modes are given for each isotope; Q_α values are also given for α-decay parents. Q_{EC} is given for all EC+β^+ processes. All Q-values represent the actual mass difference (in units of keV) between neutral atoms, and they are taken from Audi and Wapstra[2]. They are derived from a least-squares fit to measured Q-values for decay and nuclear reactions and data on mass doublets. Systematic values are indicated in parentheses; they have been interpolated or extrapolated from the least-squares fit. The values are rounded, based on experimental or systematic uncertainties, to <25 units in the most significant digit(s). (Systematic uncertainties were also derived from the least-squares fit, but they are not shown here.)

B. Tabulated Data

General isotopic information

Each block of data for an isotope is headed by the isotope label. Immediately below the label are quantities of general interest described as follows.

%: *Natural isotopic abundance* (atom percent basis) for elements as they occur on earth. The values are those adopted by the International Union of Pure and Applied Chemistry[9].

Δ: *Mass excess* ($\equiv$ M-A) on the unified mass scale $\Delta(^{12}C\equiv0)$, in units of keV. All values refer to masses of neutral atoms. Systematic values are given in parentheses.

S_n: *Neutron separation energy* ($M_N - M_{N-1} - M_n$) in units of keV. Systematic values are given in parentheses.

S_p: *Proton separation energy* ($M_Z - M_{Z-1} - M_p$) in units of keV. Systematic values are given in parentheses.

Q_x: *Decay energy* for decay mode x = β^-, EC (EC+β^+), α, or p decay in units of keV. Systematic values are given in parentheses.

σ: *Neutron cross sections* includes values for σ_γ ($\equiv\sigma(n,\gamma)$, the neutron capture cross section), σ_α (n capture cross section for alpha particle emission), σ_p (n capture cross section for proton emission), σ_{abs} ("free" neutron scattering cross section), and σ_f (capture cross section for fission). Cross sections σ are those for thermal neutrons, σ° for 2200 m/sec neutrons, and σ^r for reactor neutrons. Designation of "from" or "to" is followed by the energy of the capture or product nuclear state.

Populating reactions and decay modes

A listing of reactions and decay modes known to populate this isotope. The reaction list is obtained primarily from the compiled datasets, and the decay modes have been supplemented to include populating decays where explicit feeding of specific final levels is not known. A complete list of reference codes used by the evaluator follows each populating reaction or decay mode. Decay modes, sometimes without references, have been added here and the reader is referred to the parent isotope tables for references. When more than one level from a given parent may populate the isotope, the decay modes specify the identifying half-life; if those parent levels have identical half-lives, the decay modes are identified by the parent level energy or spin and parity values. Each entry on this list is preceded by a character which is used to cross-reference this entry to each level populated by the specified reaction or decay.

Adopted level data

The following information about adopted levels is presented.

E: *Energy* in keV. If followed by +x, +y, +z, or some other alphabetic constant, the energy is relative to an unknown excitation energy. Levels whose energy is followed by (?) have questionable existence, and levels with energy in parentheses are systematic.

J^π: *Nuclear spin* (angular momentum) in units of $\hbar$ and *parity*. Isospin *T* or T_Z may also be given. Multiple possible values may be indicated. Spins and/or parities in parentheses are based on less definite information. If the values are separated by "and," the level is presumed to be a doublet. In cases where the spin is presented as J+*x* and *x* is a definite spin value, *x* is the increment in spin relative to some unknown spin value J.

$t_{1/2}$: *Level half-life* (mean-life × ln2). Conventional units are employed: y=year, d=day, h=hour, m=minute, s=second, ms=millisecond (10^{-3} s), μs=microsecond (10^{-6} s), ns=nanosecond (10^{-9} s), ps=picosecond (10^{-12} s), fs=femtosecond (10^{-15} s), and as=attosecond (10^{-18} s). In some instances level width Γ or partial width Γ_x (where x=n, p, γ, ... is the partial decay mode) is given (in eV, keV, or MeV).

Cross-reference codes
Character list indexing the level to the reactions and decay modes that populate it.

Decay modes
Percentage branchings are given for modes denoted by the following symbols:

β^-	Negatron (electron) emission
β^+	Positron emission
EC	Orbital electron capture
α	alpha-particle emission
IT	Isomeric transition (γ ray or conversion electron emission from an excited state)
SF	Spontaneous fission
p	Proton emission
n	Neutron emission
$\beta^-\beta^-$	Double negatron emission
ECEC	Double orbital electron capture
ECx	Electron capture delayed emission of x=p, α, SF (often denoted as ECDF), etc.
β^-x	Negatron delayed emission of x=n, 2n, α, etc.
^{14}C	Emission of ^{14}C nucleus
^{20}Ne	Emission of ^{20}Ne nucleus

In general, decay modes are shown when they have been observed or inferred from experiment or when they are expected to be significant (>0.1%) based on theory. If the percentage is given as "=?," this indicates that the percentage is unknown, and not that the decay mode is uncertain. If the percentage branching is from theory or systematics, the value is indicated as *syst*. When β^+ emission is energetically possible, it is always accompanied by EC decay. In these tables the undivided percentage branching for both modes %EC+%β^+ is given when both modes are possible.

Nuclear moments
The magnetic dipole (μ) and electric quadrupole moment (Q) are taken from the compilation of Raghavan[5] unless the evaluator incorporated a newer value. If several values have been measured, the first value listed in Raghavan's table is the recommended value and that one is reported here. If the measurement led to two possible interpretations, both values are presented separated by the word "or." In cases where the spin is unknown, the "g-factor," *g*, may be shown instead; the magnetic dipole moment μ=*gJ*.

Adopted γ-ray data
The following information on adopted γ rays depopulating the level are presented.

E: *Energy* of the deexciting transition in keV, preceded by γ_{abc} where abc=energy of the level populated by that transition. Transitions with (?) following their energies have uncertain placements.

I_γ, I_e, $I_{e+\gamma}$: *Relative intensity* of photon, conversion electron, or total transition, respectively. Photon intensities are given whenever available, and electron intensities are typically given only for E0 transitions. The transition intensities are usually normalized to 100 for the most intense γ ray emitted from the level.

Multipolarity and mixing ratio (δ): The transition multipolarities and mixing ratio are given when available. If the mixing ratio is inferred from systematic multipolarities, the multipolarities are given in square brackets. The multipolarities are shown as magnetic ($M\lambda$) or electric ($E\lambda$) 2^{λ}-multipole transitions, and as dipole (D, λ=1), quadrupole (Q, λ=2), and octupole (O, λ=3) transitions. Multipolarities in parentheses are determined from weaker evidence, and values reported as M1(+E2) generally infer that the contribution of the second multipolarity is minor. Multipolarities separated by commas represent the list of plausible values not excluded by experiment, and one or more values in the list may be negligible or nonexistent. In some cases, when more than one mixing ratio (δ) may be inferred from the data, multiple values are separated by the word "or". The sign of the mixing ratio (δ) is given explicitly when known, and follows the phase convention of Krane and Steffen[10]. For transitions of the general form $E(M)\lambda_1+M(E)\lambda_2$ ($\lambda_2=\lambda_1+1$), the ratio of the two multipolarity component intensities is $\delta^2= M(E)\lambda_2/E(M)\lambda_1$. The percentage of the second (λ_2) component, as expressed in earlier editions of the *Table of Isotopes*, is $\%E(M)\lambda_2=100\times\delta^2/(1+\delta^2)$.

Quantities for Superdeformation: The following quantities are provided for superdeformed band levels only:

Rotational frequency	$\hbar\omega$ =	$[E_\gamma((J+2)\rightarrow J)+ E_\gamma(J\rightarrow(J-2))]/4$ MeV
Kinetic moment of inertia	$I^{(1)}(J)$ =	$(2J-1)\hbar^2/[E_\gamma(J\rightarrow(J-2))]$ MeV^{-1}
Dynamic moment of inertia	$I^{(2)}(J)$ =	$4\hbar^2/[E_\gamma((J+2)\rightarrow J)- E_\gamma(J\rightarrow(J-2))]$ MeV^{-1}

Decay γ-ray data

Tables of γ-ray energies and intensities from decay are headed by the generic title "*γ (daughter) from parent ($t_{1/2}$) xx decay < for I_γ% multiply by yy>*" where *xx* is the mode of decay and *yy* is the factor required to normalize the γ-ray intensity to units of "per 100 decays of the parent." In some cases the decay is indicated as *from multiple parents* when the data are from a mixed source. The title is followed by an energy-ordered list of transitions, their intensities, multipolarities, and mixing ratios. See the discussion under adopted γ-ray data for a discussion of these quantities. Unplaced γ-ray transitions, not shown in the adopted γ-ray tables, are indicated by (u), following the energy. The γ-ray list typically includes measured values for transitions observed in decay experiments whose energies may vary from their adopted values in the level table. Additional transitions observed in reaction experiments and included in the adopted levels table are excluded from this list. A complete list of γ rays expected from decay can be inferred from the decay scheme drawings (see discussion below).

Decay particle data

Tables of particle emission energies and intensities from decay are headed by the generic title "*x from parent ($t_{1/2}$) x decay <for I_x% multiply by yy>*" where $x=\alpha$, p, n, ... is the emitted particle and *yy* is the normalization factor defined for decay γ rays (see above). Particles are listed in energy order and preceded by x_{abc} where abc is the energy of the level populated in the daughter.

C. Combined Decay-scheme Drawings

Nuclear levels populated by radioactive decay are shown on a detailed combined decay scheme drawing. A single decay scheme for each nucleus summarizes its level structure as observed in the decay of all parent isotopes and isomeric states. All levels populated in radioactive decay, the adopted transitions from these levels, and additional adopted levels fed by the adopted transitions but not observed in decay, are shown on the decay scheme. If the decay scheme is sufficiently complex, it is drawn in several parts divided into regions of level excitation energy populated by the parent. In each part the lower energy levels are omitted from the drawing unless they are fed from above. The following is a description of those properties shown on decay scheme drawings.

Levels are represented as horizontal lines and *transitions* by vertical arrows. Heavy lines denote ground states and isomeric states. Uncertain levels or transitions are indicated by dashed lines. The levels are plotted on a linear energy scale as close to their relative energies as possible; however, a minimum separation is imposed to facilitate legibility. The inner scale of the level drawing has a finer minimum level separation while the outer scale is coarser to allow room for labels. A group of unresolved levels, such as might be populated in delayed particle emission, may be presented as a broad band of lines.

Level energies (keV), in bold type, are located near the right end of a level. These energies are taken from the adopted levels tables.

Spins, parities, and isospin assignments, also in bold type, are located near the left end of a level. These values are from the adopted levels tables.

Half-lives, from the adopted levels tables, are located near the level at various positions as determined by layout considerations. Ground state and isomeric state half-lives are given in larger type than other half-lives.

Relative intensities of γ rays are located immediately above the transition arrow.

γ-Ray energies (keV), in bold type, follow the intensities. An asterisk following the energy denotes a multiply placed γ ray.

Multipolarity of the γ ray follows the energy on the label. The intensity, energy, and multipolarity are from the adopted γ-ray tables.

Particle emission from excited states is indicated by a decay arrow on the left or right side of the level and labeled by the particle decay mode. When delayed particle emission is known to populate specific levels in the particle decay daughter, the relevant levels for that nucleus and the associated particle transitions to those levels are shown in greater detail. Particle decay branchings may be shown on the particle transition lines and final state feedings may be shown on horizontal feeding arrows pointing to the final states.

Parent isotopes are located in the upper corners of the decay scheme: β^- parents to the left, and α or EC+β^+ parents to the right. The parent half-life, energy, spin and parity assignment, decay mode, and decay Q-value are given. A vertical decay arrow points from the parent line to horizontal transition feeding lines (if any) pointing to levels populated in the daughter. If the parent is drawn to scale, a half-bullet on the parent decay arrow marks the energy (Q-value) of the parent on the same internal scale as the levels. Otherwise, a scale break ($\approx$) is drawn through the decay arrow.

Level feedings from α or β decay are usually given on the transition feeding lines in transitions per 100 decays (%) of the parent. In some cases, relative intensities are given, and these are indicated by a † preceding the value. *Log ft values* for β decay are given in italics to the right of the intensity. For unique-forbidden transitions, the uniqueness order is given as a superscript to the *log ft*. *α-Decay hindrance factors* are also given in italics following the α intensity; these values are typically the evaluator's values without revision following the incorporation of the 1993 mass table. In some cases, the transition feeding line is shown bracketed to more than one final level indicating the feeding is the sum of both levels. Dotted transition feeding lines indicate that the population of this level is uncertain.

D. Nuclear Structure Drawings

Decay schemes for families of levels with common collective properties, high-spin structures, or structures of importance in high-spin physics have been drawn. For each nucleus the bands or structures are plotted side by side, with levels drawn at a position nearly proportional to the energy, and labeled by spin and parity on the left and energy on the right. In-band transition arrows are plotted in a compact semistack plot with energies, rounded to the nearest keV, drawn at the end of the arrow. Transitions between adjacent bands are indicated by diagonal arrows but are unlabeled. The existence of other transitions that could not be drawn is indicated by an arrowhead drawn to the right of the level near the energy. Due to layout considerations, some bands may be plotted at a false position relative to other bands.

A band label is drawn beneath each band when that band has been given a definitive name in the literature. Among the common band names used here are:

GS band	The band built on the ground state
Yrast band	Sequence of levels corresponding to the lowest energy for each spin
β band	The band built on the first excited 0^+ state
γ band	The band built on the first excited 2^+ state
Octupole band	The band based on an octupole vibration
$K[Nn_z\Lambda]$	Nilsson configuration
$\pi h_{11/2}$ or $\nu h_{11/2}$	Band based on configuration derived from the proton (π) or neutron (ν) shell model configuration $h_{11/2}$
SD band	Superdeformed band
$\alpha=+1/2$, $\alpha=-1/2$	Favored or unfavored signature band
3 QP	Three quasiparticle band

Sometimes the band label is a compound of more than one of the above forms indicating specific multiparticle configurations or core-particle excitations. Since band labels are somewhat subjective, and labeling has evolved over time, these labels should be considered only as rough descriptions of the more complex nuclear physics underlying their descriptions.

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