ORNL

William H Sullivan

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TRILINEAR CHART OF NUCLIDES

JANUARY 1957

ATOMIC ENERGY COMMISSION
UNITED STATES OF AMERICA

X-847

INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

February 8, 1957

OR-WHS-2159

TO: Recipients of Trilinear Chart

FROM: William H Sullivan

RE: Additional Instructions for Assembly of Trilinear Chart of Nuclides

To obtain a more nearly perfect fit of one sheet to another, remove the Chart sheets from the binder and, after cutting (with razor, scapel, or scissors) the excess material from each sheet as per instructions, align one sheet to the next DRY, using paper clips at top and bottom behind the flap fold. Then raise and moisten the gummed flaps and press into the position already established.

WHS/fh

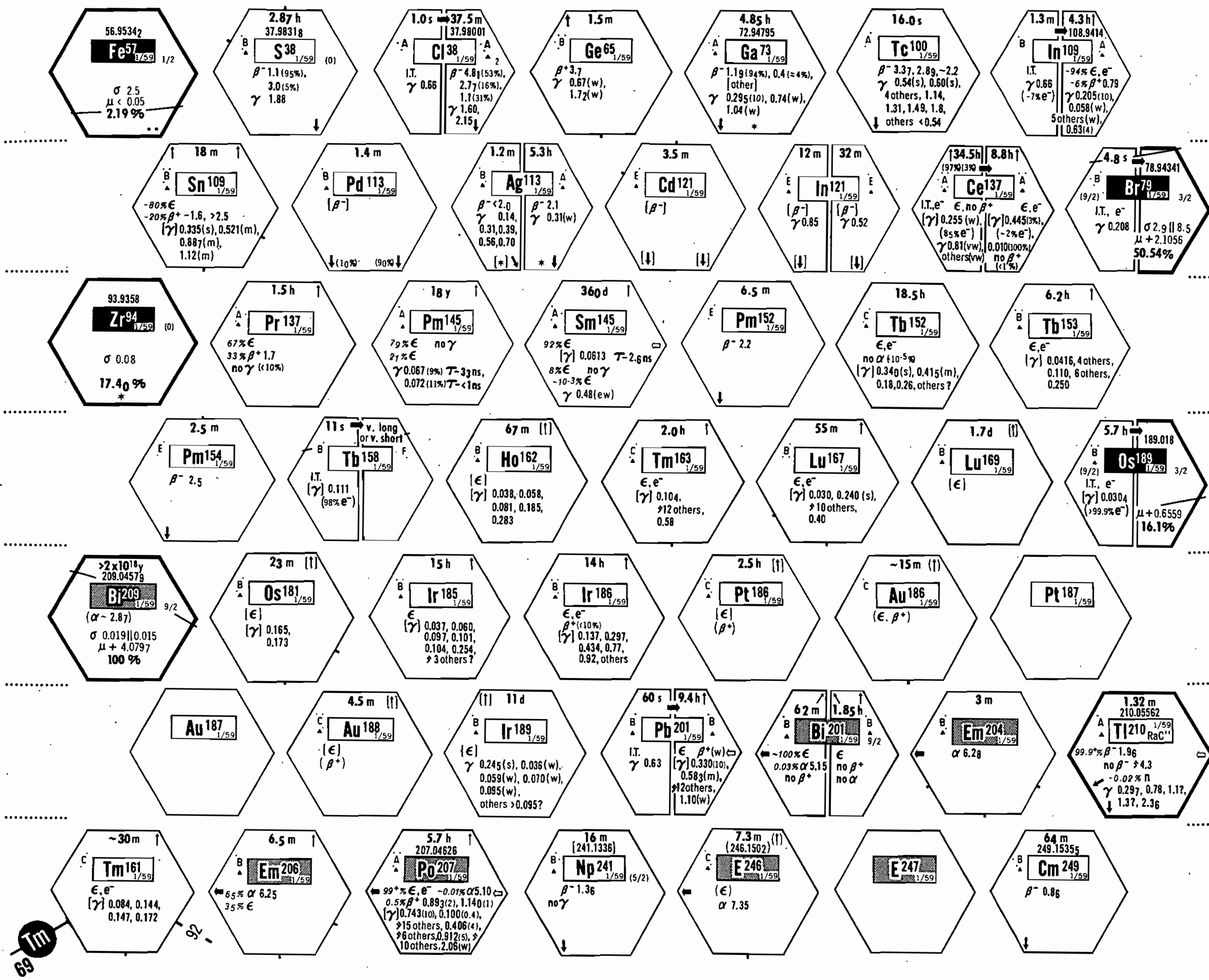
REVISION SHEET FOR THE TRILINEAR CHART OF NUCLIDES

by William H Sullivan
Oak Ridge National Laboratory

ISSUE NO. 3 – JANUARY 1959

INSTRUCTIONS – Cut the seven (horizontal) rows of hexagonal stamps apart as strips (*single cut* between the rows), then cut apart the individual nuclides and affix them, as one affixes postage stamps, to their proper places on the Chart.

MAKE SINGLE CUT BETWEEN HEXAGONS WITHOUT CUTTING INTO BORDERS.



INFORMATION – As with the two previous issues, the stamps on this sheet consist principally of new nuclides or those having significant revisions. Magnetic dipole moment (μ) values, appearing on the gummed stamps, are no longer corrected diamagnetically as were such values on the original Chart. The symbolism ϵ_L means that the energy available for decay is sufficient only for electron capture from the L shells, not the K shell. A person possessing a copy of the Trilinear Chart's Second Printing of this Edition, which has a Table of the Elements, arranged alphabetically by symbol, may correct two typographical errors in the chemical atomic weight values, as follows: Cadmium, 112.41 vs. 122.41, and Chlorine, 35.457 vs. 37.457.

For persons interested in nuclear stability characteristics, a new (since September 1958) and better "atomic weight" for technetium (Tc) is (98) vice (99).

RECOMMENDATION – Readers may find it helpful and useful to cut and paste the strips of INFORMATION, sometimes containing new symbolisms, on the inside back cover of the Chart (or on a sheet of three-hole notebook paper, which can be inserted within the Chart binder).

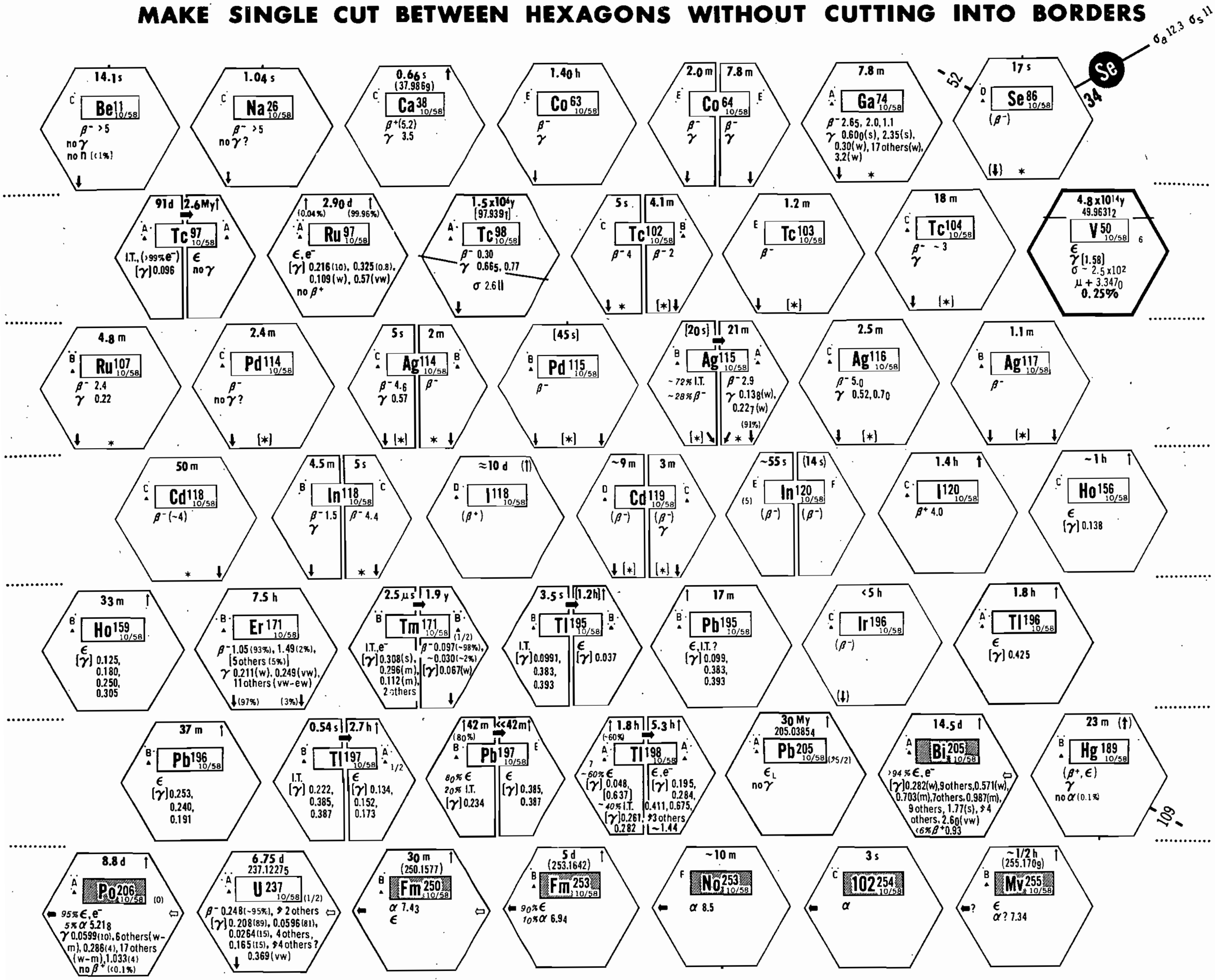
REVISION SHEET FOR THE TRILINEAR CHART OF NUCLIDES

by William H Sullivan
Oak Ridge National Laboratory

ISSUE NO. 2 – OCTOBER 1958

INSTRUCTIONS – Cut the seven (horizontal) rows of hexagonal stamps apart as strips (*single cut* between the rows), then cut apart the individual nuclides and affix them, as one affixes postage stamps, to their proper places on the Chart.

MAKE SINGLE CUT BETWEEN HEXAGONS WITHOUT CUTTING INTO BORDERS



MAKE SINGLE CUT BETWEEN HEXAGONS WITHOUT CUTTING INTO BORDERS

INFORMATION – The stamps on this sheet include (1) new nuclides and (2) nuclides having significant revisions. The stamps for element 102 (No^{253} and 102^{254}) show that its discovery has been reported; however, a controversy still exists concerning proof of the properties of its nuclides. It was named nobelium (No) by the first group reporting discovery. Nuclide Se^{86} does not have a hexagonal area provided on the Chart, but there is ample space for the gummed stamp, with its associated symbol, isotone number, and the σ_a and σ_s values for Se. Nuclides having the symbolism [*], means that they are fission products, but produced by non-thermal nuclear fission reactions.

The numbers below give U^{235} thermal neutron fission chain yield values (see Legend, Part IIB) as errata to the 2nd Edition of the Chart and are to be cut apart and affixed under the proper mass numbers at the top of the Chart.

Mass 72	Mass 73	Mass 77
$1.6x10^{-5}$%	$1.1x10^{-4}$%	$8.3x10^{-3}$%

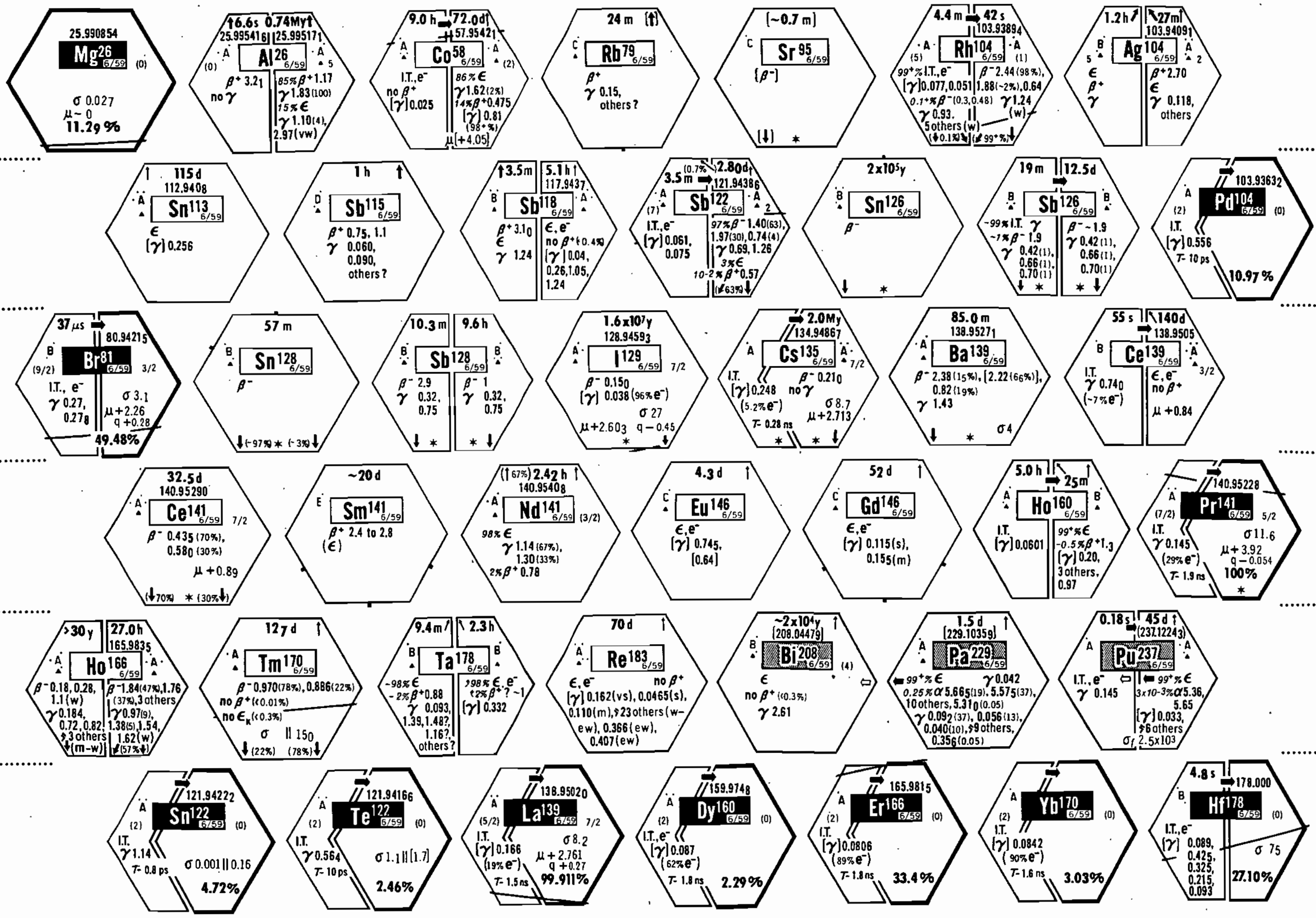
REVISION SHEET FOR THE TRILINEAR CHART OF NUCLIDES

by William H Sullivan
Oak Ridge National Laboratory

ISSUE NO. 4 – JUNE 1959

INSTRUCTIONS – Cut the horizontal rows of hexagonal stamps into six separate strips, then cut apart the individual nuclides and affix them, as one affixes postage stamps, to their proper places on the Chart. Center each stamp carefully.

MAKE SINGLE CUT BETWEEN HEXAGONS WITHOUT CUTTING INTO THE BORDERS



INFORMATION – The stamps on this sheet include (1) new nuclides, (2) nuclides having significant revisions, and/or (3) isobaric diads or triads that have changes important enough to justify the issuance of gummed stamps and which make use of the new "chevron-shape."

The use of a chevron-shape is in keeping with the design principle established in 1946 that each area-shape on the Chart should have a specific meaning and not be repeated. Thus, the chevron is used for isomers of half-life less than a microsecond (10^{-6}s) and with unique characteristics, either as produced by radioactive decay of one or both of the adjoining isobaric nuclides or by its properties. The gamma-radiation in the chevron actually belongs to the longer-lived radionuclide(s) from which it is derived, as shown by the arrows. In many cases, the chevron represents the first excited state of a stable nuclide, e.g., Pd^{104}, Sn^{122}, Te^{122}, La^{139}, Er^{166}, etc., or a long-lived nuclide, e.g., Cs^{135}.

Nuclear electric quadrupole moment values (q) are shown on the gummed stamps whenever possible. They are given for the ground states of nuclides in units of 10^{-24} cm^2, to the right of and, depending on the space available, sometimes beneath the magnetic dipole moment values (μ) in a lightface Gothic type.

The symbol, no ϵ_K, indicates that the disintegration energy is too small for K electron capture but this does not exclude the L electron capture process.

Newer atomic-mass values of stable nuclides are taken from the papers of A. O. Nier and collaborators. When appropriate, the mass values for radionuclides are calculated from these newer values and total disintegration energy data published in *Revs. Mod. Phys.* **29**, 773 (1957) and **30**, 585 (1958).

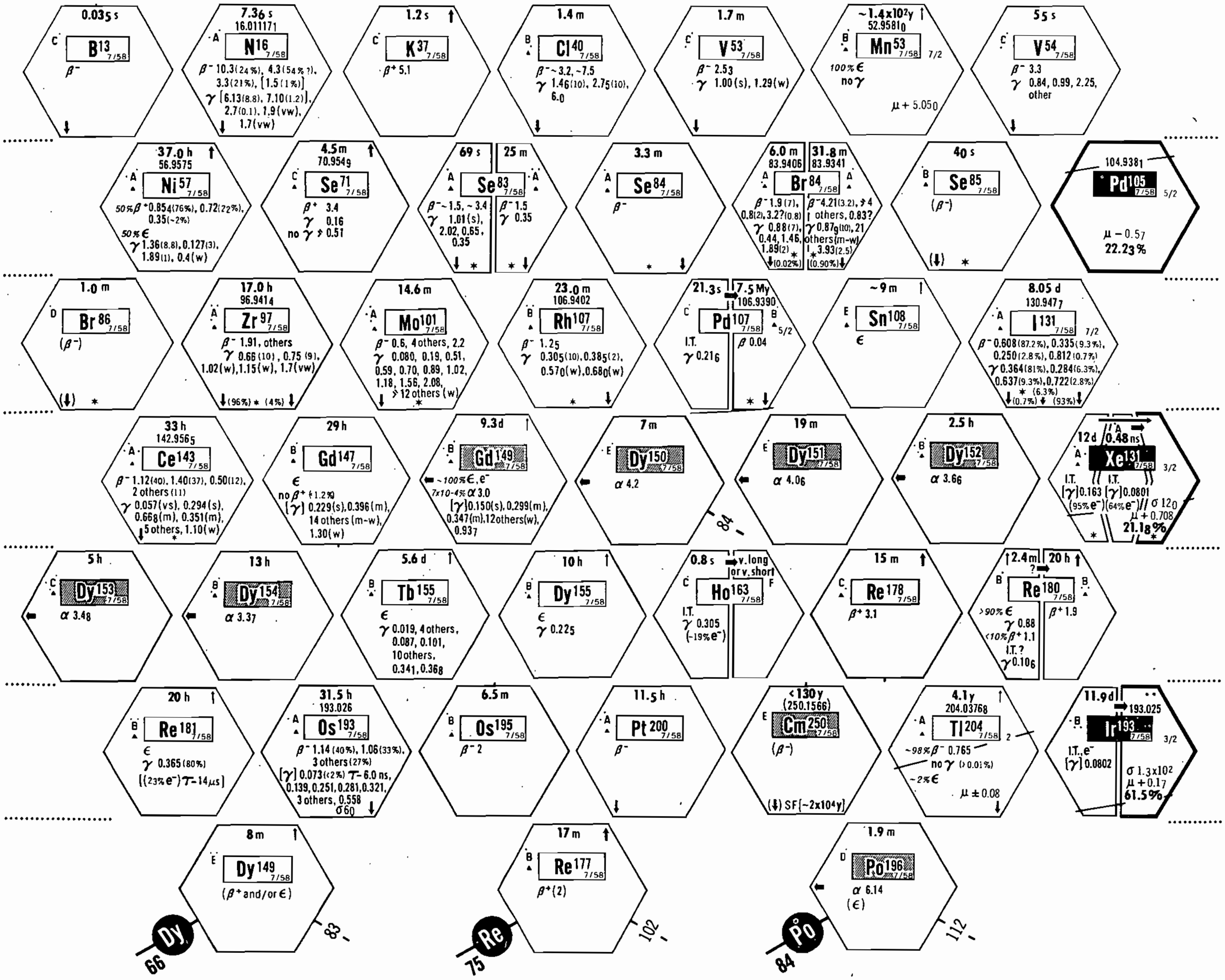
REVISION SHEET FOR THE TRILINEAR CHART OF NUCLIDES

by William H Sullivan
Oak Ridge National Laboratory

ISSUE NO. 1 – JULY 1958

INSTRUCTIONS – Cut the seven (horizontal) rows of hexagonal stamps apart as strips (*single cut* between the rows), then cut apart the individual nuclides and affix them, as one affixes postage stamps, to their proper places on the Chart.

MAKE SINGLE CUT BETWEEN HEXAGONS WITHOUT CUTTING INTO BORDERS



MAKE SINGLE CUT BETWEEN HEXAGONS WITHOUT CUTTING INTO BORDERS

INFORMATION – The stamps on this sheet include (1) new nuclides, (2) nuclides having significant revisions, and/or (3) corrections antedating the second edition "cut-off date" – July 1956. A date (month/year) appearing in the lower right-hand corner of the "nameplate," i.e., rectangle containing element symbol and mass number, gives the issue date for the stamp, which means that all data available prior to this date were reviewed before the stamp was released.

Please note that nuclides Dy^{149}, Re^{177}, and Po^{196} do not have printed hexagonal spaces provided on the Chart, but ample space will be found to place the stamps in their proper positions, together with the element symbols and isotone numbers.

To conserve space and improve clarity, new prefix symbols recommended by the SUN Commission of the IUPAP, for designating very large and very small numbers, will be used: M for 10^6; G, 10^9; T, 10^{12}; n, 10^{-9}; and p for 10^{-12}. For example, 7.5 My = 7.5×10^6 y, 5 Gy = 5×10^9 y, 0.2 Ty = 2×10^{11} y, 22 ns = 2.2×10^{-8} s, and 3.6 ps = 3.6×10^{-12} s.

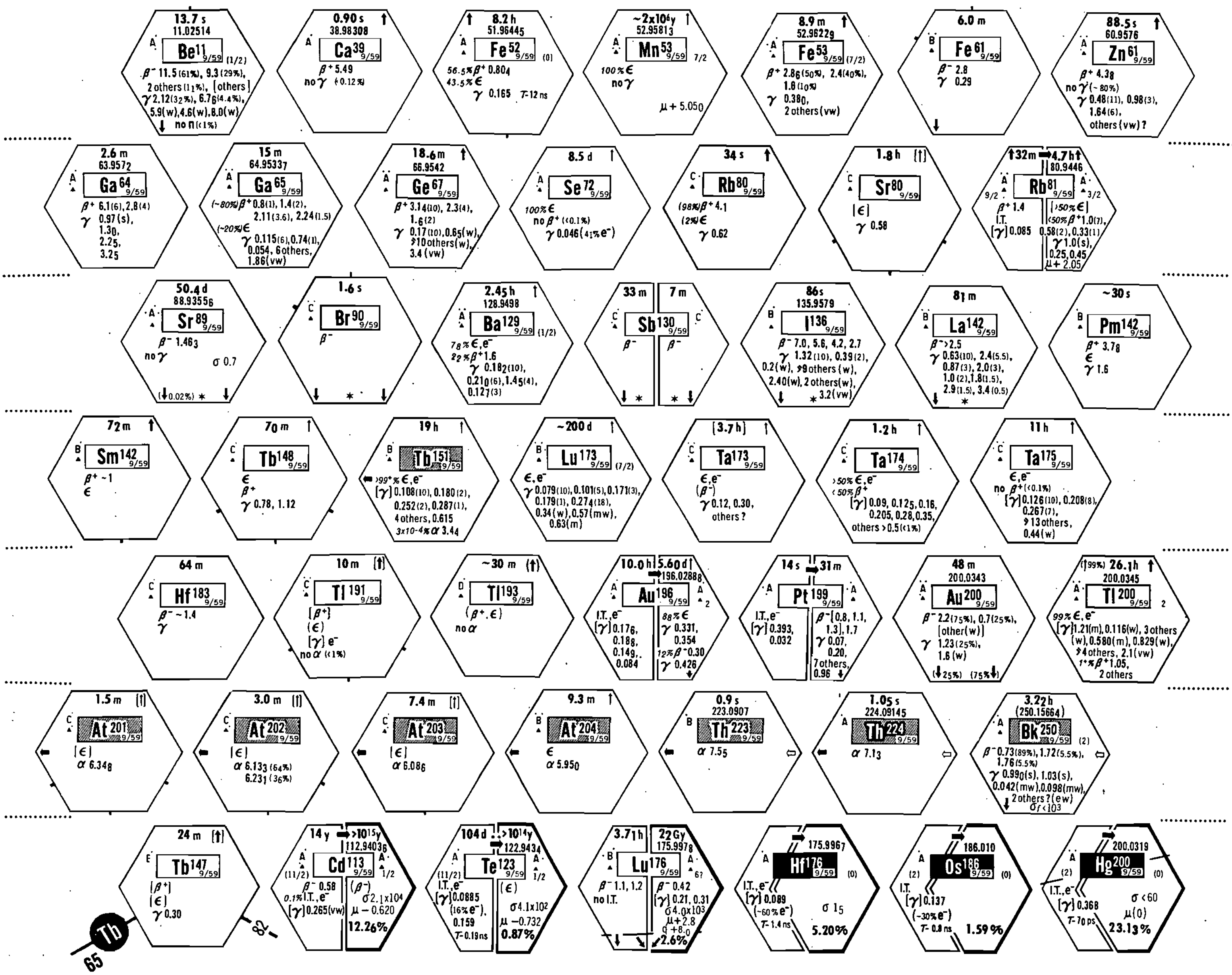
REVISION SHEET FOR THE TRILINEAR CHART OF NUCLIDES

by William H Sullivan
Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA

ISSUE NO. 5 – SEPTEMBER 1959

INSTRUCTIONS – (1) Cut the horizontal rows of hexagonal stamps into seven separate strips. (2) Separate and form individual nuclides (hexagons) by simple diagonal straight-line cuts. (3) Affix the hexagons, as one affixes postage stamps, to their proper places on the Chart, centering each stamp carefully.

MAKE SINGLE CUT BETWEEN HEXAGONS WITHOUT CUTTING INTO THE BORDERS



INFORMATION – The stamps on this sheet include (1) new nuclides, (2) nuclides having significant and useful revisions, and (3) some nuclides making use of the "chevron" shape (see INFORMATION of ISSUE NO. 4, JUNE 1959).

RECOMMENDATIONS – For best results, when replacing an earlier revision stamp with a new one, remove the old stamp first (e.g., Be^{11} or Mn^{53}).

On the Chart, draw a beta arrow ↓ in the lower right-hand corner of Sn^{130} to show β- decay to the ground state, as well as to the excited state.

TRILINEAR CHART OF NUCLIDES

William H Sullivan

This second edition of the Trilinear Chart was sponsored and supported by the Oak Ridge National Laboratory, and the Technical Information Service of the Atomic Energy Commission. Some of the early development work, necessary for converting the Chart from color (first edition) to black and white, was sponsored and supported by the National Research Council, Committee on Nuclear Science, Subcommittee on Nuclear Constants, under a contract with the Office of Naval Research.

Color reproduction was abandoned for this edition, principally for reasons of printing costs. In addition, certain advantages accrue to the reader in improved legibility and greater ease in making use of the Chart. One other design change is that which will permit the issuance of new nuclide data by means of gummed hexagon "stamps," if the demand for such a service is sufficient to justify the time and effort.

The first edition of the Chart in 1949 was published for the Atomic Energy Commission by John Wiley & Sons, Inc.

Revised Artwork by Hildegarde Nemetz from Originals by Kay Benscoter

OAK RIDGE NATIONAL LABORATORY

Operated by the Union Carbide Nuclear Co.

for

UNITED STATES ATOMIC ENERGY COMMISSION

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price $2

ACKNOWLEDGMENTS

The assistance of the following persons, who have reviewed and offered suggestions concerning data on the photoprints for this second edition, is gratefully acknowledged: L. G. Elliott and colleagues of Chalk River, Ontario, for information on work being done there; L. E. Glendenin and E. P. Steinberg, for their efforts to supply the best available data on U^{235} fission product chain yields; J. A. Harvey, for his careful and thorough evaluation of newly published results on neutron cross section values; J. M. Hollander, for offering comments on particular Chart panels; W. M. Manning and affiliates, for much useful information on the transuranic elements; C. L. McGinnis, for reviewing those sections of the Chart in which he has a special interest; A. O. Nier, for critically reviewing the isotope relative abundance data; G. T. Seaborg and associates, for information and for fruitful discussions concerning the heavy nuclides and their systematics; J. R. Stehn, for most helpful assistance in reviewing nuclide properties generally; and H. E. Walchli, for evaluating nuclear spin and magnetic dipole moment data.

May I express my appreciation also to numerous other associates and scientists, both in this country and abroad, who by correspondence and discussion have generously contributed much valuable information.

Especial thanks are due Hildegarde Nemetz, whose patience, perseverance, and diligence in working with the transadhesive material used for the artwork has made possible the presentation of so many data on the Chart. In a like manner, I offer my heart-felt thanks to Anna McNabb who undertook and did in an exemplary manner a difficult assignment on the transadhesive artwork.

To my assistant, Imogene Clayton, I owe a debt of gratitude for invaluable aid in her thorough searching for and assembly of the information embodied in our vast reprint collection, so essential for reviewing the increasingly large amount of original literature in this field of nuclear physics and chemistry. Last but certainly not least, I am greatly indebted to my secretary, Frances Hurley, for the very helpful assistance she has provided in so many ways during the course of this endeavor.

William H Sullivan

July 1956

Issued January 1957

Legend for | Trilinear Chart of Nuclides

PART I

General Design and Coordinate System

A. The Coordinate Grid

The Trilinear Chart of Nuclides when properly assembled presents, on a single continuous 11½-inch-high strip, the systematics of and physical constants data for all experimentally identified nuclides known from information available by approximately July 1956.

The equiangular trilinear coordinate grid was developed from a rectangular plot, having A–Z (number of neutrons) as the ordinate and Z (atomic number) as the abscissa, by compressing the ordinate-abscissa angle to 60°, then rotating the entire graphic plot clockwise 30°. On the resulting triangular grid was superimposed the hexagonal (beehive) pattern with each hexagon representing a single nuclide.

Examination of this graphic arrangement reveals there is a simultaneous plot, with equal emphasis, of A versus Z, A–Z versus Z, and A–Z versus A. Here A is the mass number (number of nucleons in the nucleus). Accordingly, *isotopes* (nuclides having same atomic number) lie along a line inclined at 30° above the horizontal; *isobars* (nuclides having the same mass number) lie in a nearly vertical line; *isotones* (nuclides having the same number of neutrons) lie along a line inclined at 30° below the horizontal; and *isodiapheres* (having same excess number of neutrons, A–2Z) lie on a horizontal line, as shown in the diagram at the beginning of the Chart. Additional information concerning the trilinear coordinate system is given in the J. Chem. Education *24*, 436 (1947).

It will be noted that the actual trilinear coordinate grid is inclined slightly more than the 30° stated above. This arrangement is used so that the entire chart can be presented on a single strip of minimum width. The accordion-fold arrangement was chosen because of the great flexibility in viewing any section of the Chart (35 inches when the alternate page sections are unfolded) with minimum handling.

B. Symbols and Designations

The numbers in the parallelogram-shaped spaces running horizontally at the top and bottom of each page are the mass numbers for each group of isobars. The element symbol (in a circle) and atomic number are placed at either end of each group of isotopes. The number of neutrons in a given nucleus is indicated at either end of a group of isotones.

PART II

General Physical Constants Data

A. Whole Element Cross Section Values

The absorption cross section (σ_a) and scattering cross section (σ_s) values are placed on the coordinate line at the right end of a group of isotopes. These cross section values are given in units of 10^{-24} cm^2 (barns). The scattering cross section for a particular element is that averaged over a Maxwellian distribution. The absorption cross section is for a neutron velocity, v_0, of 2,200 meters per second, corresponding to a neutron energy of 0.0253 ev (electron volt), even though the cross section is often measured with a Maxwellian distribution. It should be remembered that thermal fluxes (nv) are stated for a velocity of 2,200 meters/second (even though the temperature of the Maxwellian distribution may be above room temperature) and hence the cross section at this velocity must be used to compute the reaction rate. In general, the data are taken from report BNL–325 (July 1955), which summarizes the work of the Brookhaven Compilation group.

B. Fission Yield Values

Fission product chain yield values for the slow neutron fission of U^{235} are placed immediately beneath the mass number designations at the top of each page in the region A=72 to A=161. The values given are for the entire isobaric decay chains, as summarized by Steinberg and Glendenin from data in the Proc. Int'l. Conf. Peaceful Uses of Atomic Energy 7, P/614, pp. 3–14 (1955), Can. J. Phys. *33*, 640 (1955), and a compilation by S. Katcoff (private communication, March, 1956). Figures in brackets indicate that the fission yields are derived from the smoothed fission yield curve plotted from data in the references cited above.

C. Line of Stability

For any given mass number, there is an atomic charge number (Z_A), which represents the most stable configuration of neutrons and protons in a nucleus. A plot of this charge number (not usually an integer) against mass number gives a "line of stability" which is indicative of the stability of nuclides against beta decay. The position of this line of stability, shown on the Chart as a frequently interrupted black line, is based upon a knowledge of all naturally-occurring stable nuclides, the decay characteristics of their β-labile isobars and the stability and decay characteristics of radioactive "heavy" nuclides above Z=83. The information and data utilized are reported in Phys. Rev. *73*, 16 (1948); *94* 119 (1954); Rev. Mod. Phys. *26*, 327 (1954); J. Inorg. and Nucl. Chem. *1*, 3 (1955); and Physica *21*, 367, 385, 410 (1955). The dashed line above mass 256 represents the predicted line of stability as derived from the systematics of the "super-heavy" nuclides.

Values of Z_A may be obtained from the Chart by estimating the fractional distance of the line of stability from the center of nuclide Z^A to the center of nuclide $(Z+1)^A$.

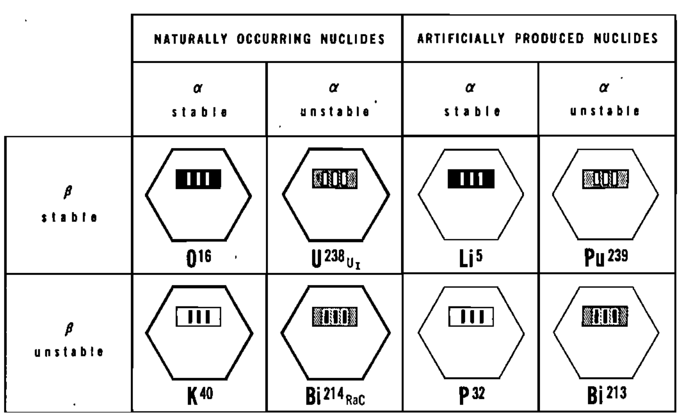
PART III

Types of Nuclides

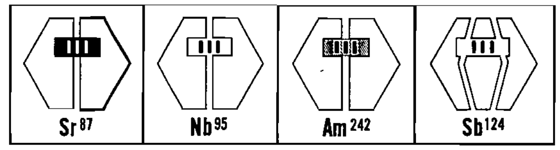
All known nuclides are represented by data within the hexagons on the trilinear coordinate grid. The *heavy border* around the hexagon indicates that a *nuclide occurs in nature* or has been shown to be derived from a radioactive geologically long-lived nuclide. The fact that data appear in a hexagon indicates that information is available concerning it and that the nuclide is produced artifically by one or more different nuclear reactions.

The *rectangular panel* within the hexagon is used: first, to show the *element symbol* and *mass number* of the nuclide; and second, to indicate the nuclide's *alpha* and *beta stability* and *instability*, as based on present direct experimental evidence, deductions from decay energetics data and theoretical and practical considerations. For convenience in reference, the historical symbols for nuclides in the natural radioactivity decay series are placed usually in the lower right-hand corner of the rectangular area for the element symbol and mass number. Where alpha and/or beta decay have been observed, specific symbols and arrows denoting such decay are used. The term beta decay includes negatron and positron emission and orbital electron capture processes.

In simplest terms, *beta instability* is always indicated by *black letters* and *alpha instability* is shown by a *gray background* in the rectangle. The various basic types of nuclides are shown in the following figure.



Isomers are represented within the areas which result from splitting the hexagonal field vertically in half when one isomeric state is shown or in thirds when there are two metastable energy levels, providing space considerations permit. In general, the very short-lived metastable states, for which decay constants are known, are shown to be associated with the longer-lived parent nuclide (see Part IV–E–6). Isomers are generally placed in the order of decreasing energy content from left to right. Typical examples of isomeric nuclides are shown in the sketch below.



PART IV

Physical Constants Data for Individual Nuclides

A. Position

For ease of location, all physical constants for each nuclide are placed when possible in the same relative position within the hexagonal area, even when there are isomers. An additional aid for delineation of data is provided by the use of different type faces for the several kinds of information presented (see Part IV–E).

B. Errors

An attempt to indicate the reliability of the data is made by lowering the position of the last significant figure where the relative probable error is large. The following examples illustrate the rules that are followed:

VALUE ± error	WRITTEN AS
2. 58±<0. 05	2. 58
2. 58±≥0. 05	2. 5_8
2. 58±≥0. 20	2. 6

When "rounding off" numbers, with an error in the last digit of ≥20, the odd-add, even-subtract convention is followed, e. g., 18.5±2.0 becomes 18, 137.5±2.5 becomes 138, and 210.052611±0.000230 becomes 210.0526.

Where the figures and their errors are large, e. g., 55,000±6,000 or 4,800±1,000, the exponential form of presentation is used, with the preceding examples shown as 5.5×10^4 and 4.8×10^3, respectively.

C. Brackets and Parentheses

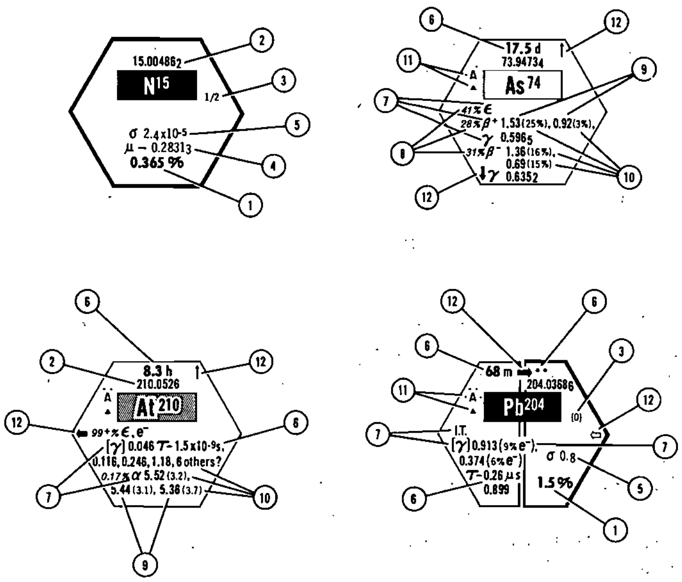
Physical constants or other information derived from related experimental data are enclosed in brackets. Values or information deduced from theory are enclosed in parentheses. Percentage and relative intensity figures, which are easily distinguished, are enclosed in parentheses also.

D. Miscellaneous Symbols

Question marks are used to express doubt as to the certainty of given data. The symbol ~ preceding a numeral indicates that it is an approximation or order-of-magnitude estimate. The symbols >, ≥, ≳, mean greater than, equal to or greater than, and approximately equal to or greater than, respectively. Conversely, the symbols <, ≤, ≲, mean less than, equal to or less than, and approximately equal to or less than, respectively. The abbreviation "g.s." refers to the ground state of a nuclide.

E. Explanation of Symbols and Figures

The specific position and type face for each kind of data, as mentioned in Part IV–A, is shown on the accompanying figure by circled numbers, with pointers, which are keyed to the numbered sections of explanatory material below.



1. *Relative natural isotope abundance* values are expressed as percentage of the total number of atoms. The symbol "var." indicates that the abundance varies significantly with the source.

2. *Atomic mass* values are given for neutral atoms on the physical mass scale. The neutral O^{16} atom is arbitrarily assigned mass 16 exactly. The data are taken mainly from the compilations in Physica *21*, 367, 385, 410 (1955). The errors given in the papers cited are used to round off the atomic mass values, according to the procedure described in Part III–B. For mass-energy conversion the formula, 1 amu (absolute mass unit) = 931.162 Mev, is applicable. See Rev. Mod. Phys. *25*, 691 (1953).

3. *Angular momentum* (*nuclear spin*) values are given in units of $h/2\pi$, where h is Planck's constant (6.62×10^{-27} erg-second). Nuclides having an even number of nucleons (even mass number) have integral spin values, while those of odd mass number have half-integral spin values.

4. *Magnetic dipole moment* values (μ) are given for neutral atoms in nuclear magneton units of $eh/4\pi Mc$, where e is the electronic charge, M the mass of the proton, and c the velocity of light. The values of μ, obtained mainly by resonance methods, are based on a proton moment of 2.792670 n.m. exactly (without diamagnetic correction) and are diamagnetically corrected, as discussed by W. C. Dickinson in the Physical Review *80*, 563 (1950). The sign of the dipole moment is taken as positive when the magnetic and mechanical moments have the same direction.

5. *Slow neutron cross section* values (σ) for nuclides are given in units of 10^{-24} cm^2 for a neutron velocity of 2200 meters per second as described in Part II–A. In a number of cases "pile" (average neutron temperatures vary among reactors but are roughly 100° C) neutron cross section values, as indicated by the symbol $\not\sigma$, are given because no thermal neutron cross sections are available (non-$1/v$ contribution and resonance contribution not known) and such cross sections are useful to nuclear reactor experimenters.

The symbols σ_p, σ_a, and σ_f are used to indicate the thermal neutron cross section values for *np*, *nα*, and *nf* reactions, respectively. The cross section values given are obtained from absorption or activation cross section measurements. Cross section values for isomers are placed on the target nuclide in the same relative positions as the isomers and are shown separated by two vertical lines.

6. *Half-life* values are based, with some exceptions, upon direct experimental determinations, and the following abbreviations are used: y (years), d (days), h (hours), m (minutes), s (seconds), ms (milliseconds, i. e., 10^{-3} s), μs (microseconds, i. e., 10^{-6} s), instant. (instantaneous), est. (estimated), v (very). The partial half-life for any particular mode of decay (i. e. α, β^-, β^+, ϵ, I.T., SF, n) may be calculated from the expression $\lambda_a+\lambda_b+\lambda_c+\ldots$, etc. $=\lambda_{a+b+c}$, etc., when the branching ratios or partial half-lives for individual modes of decay are known or applicable. Here λ_a, λ_b, λ_c refer to the decay constants for the applicable individual modes of branched decay, i. e. α, β^-, β^+, ϵ, I.T., SF, and n.

In nuclides having several metastable (isomeric) states, for which half-lives have been determined, the symbol τ, with a half-life value, is frequently placed behind the prominent gamma ray representing that given metastable state. A clue to the existence of such a metastable state is furnished the user by a *double asterisk* placed in the hexagon, near the *parent nuclide* having the metastable state(s) as the result of radioactive decay. In general, this method for indicating half-life values is used when multiple vertical splitting of the hexagonal spaces would unduly limit the amount of information that could be given.

7. *Modes of disintegration and types of radiation* are shown, using the symbols: α (alpha particle), β^- (negatron), β^+ (positron), ϵ (orbital electron capture), SF (spontaneous fission), n (neutron), γ (gamma ray), [γ] (gamma ray energy measured mainly by observation of internal conversion electrons), e^- (internal conversion electron). When known, and where the space is available, the percentage of internal conversion (total), e. g. (90%e^-), follows the gamma ray energy or intensity percentage value. The decay of the longest-lived metastable state (half-life measurable) is indicated by the symbol "I.T." (isomeric transition). The word no, preceding the symbols γ, β^-, β^+, α, and ϵ, indicates there is no measurable radiation, with the limit expressed in percent if known. Positron annihilation radiation (0.51 Mev) and characteristic X-rays accompanying orbital electron capture are not indicated on the Chart.

8. *Branching ratios* for the different modes of disintegration described in paragraph E–7 above are given in percent. When a nuclide decays to two or more isomeric states, the percentage branching to these isomeric states is indicated when known, by figures placed in parentheses near the decay arrows.

9. *Energy of radiation* in Mev (million electron volts) immediately follows the symbol for mode of decay.

10. *Intensity of radiation* of given energy value is enclosed in parentheses and placed behind the energy value. The stated percentage is based on the fraction of *total* disintegrations of the nuclide except when alpha disintegration is the mode of branched decay. Here percentage figures refer to the relative intensities of alpha, beta, or gamma radiation associated with each separate decay path. Where the disintegration scheme and consequently the exact percentage of each radiation is not known, a relative intensity value may be indicated by enclosing figures behind the energy

value in parentheses or by the use of symbols (vs), very strong; (s), strong; (m), moderate; (w), weak; (vw), very weak; and (ew), extremely weak, with the intensities differing from one another progressively by roughly an order of magnitude (factor of 10).

When many alpha, beta, or gamma rays are present, as much data are included as possible, consistent with the space limitations, and that information excluded is combined and represented by the notation "others," followed by the appropriate percentage figure, if known. Where possible, the number of other alpha, beta, or gamma rays, as determined from present experimental evidence is indicated, e. g., "3 others," "10 others," "24 others."

11. *Degree of certainty of element and mass number assignment* is indicated by the letter symbols:

A. Element and mass number assignment certain.
B. Element certain, mass number probable.
C. Element certain, mass number possible (one of a few).
D. Element certain, no evidence for mass number.
E. Element assignment probable.
F. Evidence insufficient.
G. Data probably in error.

A small, black equilateral triangle, placed beneath the letter indicating certainty of nuclide assignment, denotes the fact that chemistry was performed, establishing the element's identity.

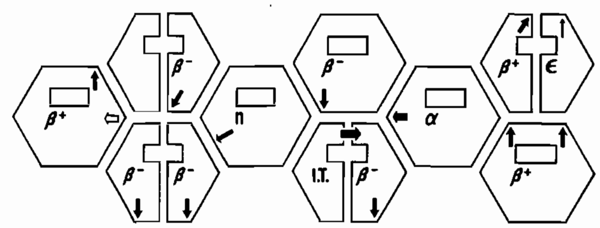
Information concerning experimental or other evidence for certainty of element and mass number assignment is provided by using dots arranged in a hexagonal pattern around the letter symbol. Each dot in its specific position has a particular meaning, according to the following code:

2 . . 3
1 . A . 4
6 . . 5
▲

1. Nuclide is produced by different nuclear reactions so that other mass number assignments are practically eliminated. Simple neutron capture is also shown in this way.
2. Mass number assignment is known to the same degree of certainty as that for the parent or daughter nuclide.
3. Assignment is based on nuclear excitation function and reaction yield data, deductions from the Bohr-Wheeler mass equation, fission yield measurements, or other considerations.
4. Mass spectrograph, spectrometer, or time-of-flight mass separator was used for the separation and identification of nuclide.
5. Assignment was deduced from decay energetics or isomers were identified by the similarity of resonance levels for neutron absorption, excitation thresholds, or reaction yields.
6. Radionuclides were identified through studies with separated stable isotopes.

12. *Genetic relationships* among the disintegrating radionuclides are indicated by arrows. Each type of disintegration is represented by an arrow of particular size and form, and this is placed in a given position within the hexagon, as shown in the accompanying sketch.

In negatron decay the arrows will normally appear in the lower left-hand corner and positron or orbital electron capture arrows, in the upper right-hand corner of the hexagon unless isomers are present, in which case the arrow will be pointed toward the daughter isomer.



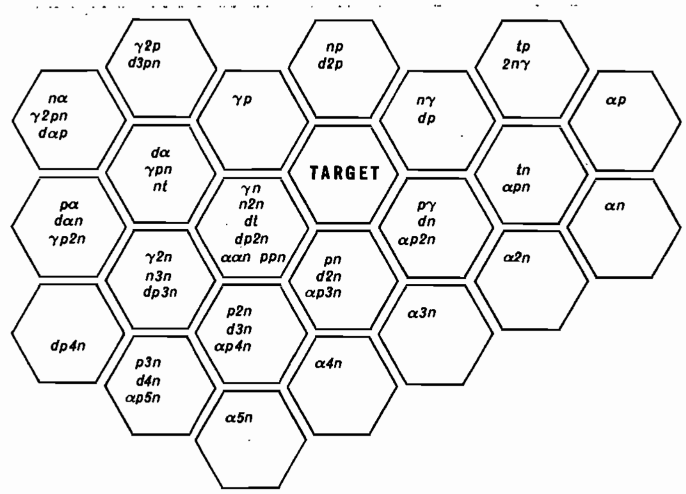
↓ beta (negatron) decay
↑ beta (positron) decay
↑ orbital electron capture
← alpha decay
⇦ nuclide formed by alpha decay
↙ neutron decay
➡ isomeric transition

In all cases, except alpha decay, the daughter nuclides are immediately contiguous to their parents. Alpha decay proceeds horizontally to the left four mass numbers (two isodiapheres).

13. *Fission products* are indicated by an asterisk at the bottom of the hexagon to provide an easy reference for those who are particularly concerned with such material. When stable isotopes are shown to be fission products mass spectrometrically, this fact is shown by the asterisk also.

KEY TO NUCLEAR REACTIONS

To find the product nuclide of the given nuclear reaction relative to the target, the accompanying figure may be used. The reactions shown are representative of those known to occur except there is no attempt to depict fission, spallation, or meson product reactions.



Symbols:

p proton
n neutron
γ gamma radiation
d deuteron
t triton
α alpha particle

Instructions for Assembly of Chart. After cutting the ends of each of the first five sheets of the chart as indicated on the end flaps, moisten the gummed underside of the first flap up to the fold and affix it to the succeeding sheet, taking special care to match the front edge with the first set of isobars on the second sheet so that the space between them is comparable to that between other adjacent sets of isobars. Repeat the same procedure for the remaining four sheets.

U. S. GOVERNMENT PRINTING OFFICE : 1956 O - 389903

TRILINEAR CHART OF NUCLIDES

William H Sullivan

OAK RIDGE NATIONAL LABORATORY

TRILINEAR CHART OF NUCLIDES

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OAK RIDGE NATIONAL LABORATORY

43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88
Cl 17
A 18
K 19
Ca 20
Sc 21
Ti 22
V 23
Cr 24
Mn 25
Fe 26
Co 27
Ni 28
Cu 29
Zn 30
Ga 31
Ge 32
As 33
Se 34
Br 35
Kr 36
Rb 37
Sr 38
Y 39
Zr 40
Nb 41
Mo 42
CUT ON LEFT SIDE OF DOTTED LINE

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133
134
CUT ON LEFT SIDE OF DOTTED LINE


135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180
Sb 51
Te 52
I 53
Xe 54
Cs 55
Ba 56
La 57
Ce 58
Pr 59
Nd 60
Pm 61
Sm 62
Eu 63
Gd 64
Tb 65
Dy 66
Ho 67
Er 68
Tm 69
Yb 70
Lu 71
Hf 72
Ta 73
W 74
Re 75
Os 76
CUT ON LEFT SIDE OF DOTTED LINE

181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226
70 Yb
71 Lu
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Em
87 Fr
88 Ra
89 Ac
90 Th
91 Pa
92 U
93 Np
CUT ON LEFT SIDE OF DOTTED LINE


227
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269
270
Fr 87
Ra 88
Ac 89
Th 90
Pa 91
U 92
Np 93
Pu 94
Am 95
Cm 96
Bk 97
Cf 98
E 99
Fm 100
Mv 101
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107