APPENDIX C

NUCLIDES AND ISOTOPES

ACCOMPANYING THE CHART OF THE NUCLIDES
REVISED 1969 BY DR. NORMAN E. HOLDEN AND F. WILLIAM WALKER
KNOLLS ATOMIC POWER LABORATORY, SCHENECTADY, N.Y.

INTRODUCTION

The earliest discussion of the atomic hypothesis is attributed to the ancient Greek philosophers who speculated about the mysteries of nature. In the fifth century B.C., Democritus believed that elementary substances (earth, water, fire, and air) were formed by minute individual particles called atoms. This vague philosophical speculation was given reality when John Dalton, between 1803 and 1808, showed how to determine the weights of different atoms relative to one another.

In 1816, William Prout believed (based on the few atomic weights known) that all atomic weights were whole numbers and integral multiples of the atomic weight of hydrogen. He thought that all elements might be built up from hydrogen. His concept lost favor when elements such as chlorine were definitely shown to have noninteger atomic weights.

PERIODIC PROPERTIES OF ELEMENTS

In 1869, Dmitri Mendeleev published a short note on the periodic regularity of chemical elements. He arranged the elements in rows according to the magnitude of their atomic weights, beginning with the smallest weight. Elements that appeared in the same vertical column showed a remarkable similarity in their chemical properties. Mendeleev hypothesized that deviations from the expected periodicity were due to chemists' failure to discover some elements in nature. He predicted the properties of gallium, scandium, and germanium, which were subsequently discovered. Pairs of elements (for example, nickel and cobalt) that did not fit the periodic properties of their columns were interchanged so that they would correspond. He argued that the atomic weight measurements for these elements must be in error. It is now known that the atomic number (see page 2), rather than the atomic weight, is the correct basis for the periodicity in the chemical properties of the elements. By coincidence, the list of elements ordered by atomic weight usually agrees with the list ordered by atomic number, except for the few cases observed by Mendeleev.

NEW PHENOMENA

Toward the end of the nineteenth century, the successes in chemistry, together with those of classical mechanics and electromagnetic theory, convinced some individuals that classical physics was a "closed book" and that workers in the field would henceforth merely advance existing knowledge to the next decimal place. This attitude changed in 1895 when Wilhelm Roentgen discovered X-rays and in 1896 when A. Henri Becquerel discovered natural radioactivity. Since such phenomena could not be explained by existing theories of matter, they created great interest.

In 1902, Ernest Rutherford and Frederick Soddy, in their theory of radioactive disintegration, proposed that radioactivity involves changes occurring within the atom. Their view met strong opposition because it was considered contrary to the established view on the permanency of the atom.

EARLY MODELS OF ATOMIC STRUCTURE

Early experiments in the investigation of atomic structure disclosed three different types of radioactivity, called alpha, beta, and gamma radiation. Alpha rays were found to be positively charged helium ions; beta rays were found to be negatively charged electrons; and gamma rays were high-energy electromagnetic waves. In a magnetic field, the alpha rays were deflected in one direction, the beta rays deflected in the opposite direction, and the gamma rays not deflected at all.

The discovery of radioactivity and Sir Joseph Thomson's proof of the independent existence of the electron were the starting points for theories of atomic structure. Thomson proposed one of the first models of the atom. His "plum pudding" model of internal structure depicted the atom as a homogeneous sphere of positive electric fluid (the pudding) in which were imbedded the negatively charged electrons (the plums). In this model the negatively charged electrons, which repel each other and which are attracted to the positive charge, assume certain stable positions inside the atom. If the electron distribution is disturbed by an external force, e.g., the violent collisions between atoms in a hot gas, the electrons vibrate about their equilibrium positions and emit electromagnetic radiation.

The homogeneous-atom concept was proved incorrect when Rutherford performed a series of experiments with a beam of high-speed alpha particles fired at a very thin metal foil. Most of the alpha particles passed straight through the foil or were scattered or deflected only slightly from their original paths. A small percentage of alpha particles were significantly deflected, however, with some alphas reversing their directions.

The Thomson model, in which the positive charge was uniformly distributed throughout the atom, would never permit a sufficiently large concentration of this charge in one region to affect the alpha particles significantly. Rutherford thought that "it (the experimental result) was about as credible as if you had fired a 15-inch shell at a piece of tissue paper and it came back and hit you."

To explain these results, Rutherford postulated that the atom does not consist of a uniform sphere of positive electrification, but that the positive charge is concentrated in a small region called the nucleus, at the center of the atom. In his dynamic planetary model, the nucleus plays the role of the sun and the electrons correspond to individual planets of the solar system revolving about the sun. This model, along with the classical physical laws of electricity and mechanics, provided an adequate explanation of the alpha particle's scattering. Subsequent experiments performed on seven different scattering materials and at different alpha energies verified Rutherford's theory.

Electromagnetic theory demands that an oscillating or revolving electric charge emit electromagnetic waves. Such emission results in the loss of energy by the emitting particle. Applied to Rutherford's electrons, this energy loss would cause a steady contraction of the system since the electrons would spiral into the central nucleus as their rotational energy was dissipated. This process would occur very rapidly and would directly contradict the permanent existence of atoms. Also, if the radiation pattern produced by the atom were related to the energy radiated by its moving electron, this radiant energy would be changing with the radius of curvature of the electron's path. The pattern would consist of a continuous range of wavelengths instead of the well-defined discrete wavelengths that are characteristic of each element.

BOHR ATOM

Since the known stability of atomic systems could not be reconciled with classical principles of mechanics and electrodynamics, Niels Bohr in 1913 reasoned that classical physics laws must be wrong when applied to the motion of the electron in the atom. Max Planck revealed an essential limitation in the theories of classical physics in 1901 when he introduced the concept of discrete amounts of energy (the energy quantum) in his quantum theory of heat radiation. Albert Einstein had applied this concept to light in 1905, when he described the photoelectric effect. The quantum theory states that electromagnetic radiation (of which light is one form) must be emitted or absorbed in integral multiples of these energy quanta. Bohr coupled Rutherford's atom with the quantum theory to produce his quantum theory of atomic structure.

Since a body that spins about its own axis or revolves in an orbit about a central point possesses angular momentum, Bohr assumed that the electron's angular momentum was restricted to certain values (he quantized the angular momentum). Each of the restricted values, which was described by a principal quantum number, n, would specify a particular circular orbit. An atomic system, whose electrons were in given orbits, would not emit electromagnetic radiation even though the particles were accelerating. The whole atom was said to be in a stationary state. Such an assumption is contrary to classical electrodynamics as mentioned earlier. Electromagnetic radiation would be emitted or absorbed only when an electron changed from one allowed orbit to another allowed orbit. The energy difference between the two states would be emitted or absorbed in the form of a single quantum of radiant energy, producing a radiation pattern of a definite frequency ν, related to the energy E by the relation $E = h\nu$ already postulated by Planck and Einstein.

QUANTUM NUMBERS

The quantum theory was further refined in 1916 when Arnold Sommerfeld introduced an azimuthal quantum number, l, where $l = n - 1$, which permitted discrete elliptical orbits for electrons, in addition to the circular orbits. This change permitted the Bohr model to account for detailed structure in the pattern of radiation emitted by hydrogen and other atoms. To account for the change in the emitted radiation pattern when an atom is exposed to a magnetic field, a magnetic quantum number m (with permitted integral values from $-l$ to $+l$) was added. This quantum number designates different projections of the possible circular or elliptical orbits along the magnetic field direction in space. Finally, a spin quantum number for the electron was postulated by Samuel Goudsmit and George Uhlenbeck to account for the close grouping of two or more spectral lines. An electron was considered to have an angular momentum about its own axis; in mechanical terms, this motion can be thought of as spin. In a magnetic field, the spin axis can have two directions relative to the field.

The orbits in which the electrons move can be described by specifying a set of these four quantum numbers. All electrons with principal quantum number $n = 1$ are in the innermost orbit, called the K shell. All electrons with $n = 2$ fall into a second group, called the L shell. The total number of electrons in a shell is limited by the various possible combinations of the other three quantum numbers. When an electron shell is filled, the atom is in a stable configuration (the noble gas configuration) and does not easily undergo chemical reactions. If only one or two electrons are in the last unfilled shell, it is relatively easy for the atom to lose these electrons to another atom whose last unfilled shell has one or two vacancies. The first of these two atoms becomes positively charged (because of the loss of electrons); the second becomes negatively charged (because of the gain of electrons). These atoms can now attract each other and form a compound (ionic bonding).

The periodicity or repetitive structure of the Mendeleev chart is now understood to be due to the number of electrons in the atom. In a neutral atom the number of electrons is balanced by the equal number of protons (hydrogen nuclei with a positive charge and a mass of about 1836 electron masses) in the nucleus of the atom. Note that the atomic number of an element is equal to the number of unit positive charges carried by the nucleus and is not the same as the atomic weight. In 1913,

Henry G. J. Moseley determined the magnitude of the nuclear charge by comparing the characteristic X-ray wavelengths of elements. Identification of the atomic number of an element from its high-frequency spectrum provided a rule for fitting newly discovered elements into vacant places on the Mendeleev chart.

In 1923, Louis DeBroglie postulated that, in analogy with light having both a wave and a particle nature, matter should have a wave as well as a particle nature. The wavelength that he predicted for a particle was inversely proportional to the particles' momentum. Clinton J. Davisson and Lester H. Germer experimented with the scattering of electrons from a crystal. They showed that electrons definitely had wave properties with a wavelength corresponding to the value predicted by DeBroglie.

The mechanical picture offered for the classification of stationary states of atoms by the Bohr theory, and its subsequent modification, was handicapped by its reliance on many *ad hoc* postulates and by an inability to explain the intensities of radiation patterns emitted by atoms. A new departure was provided in 1926 by Erwin Schrödinger's establishment of wave-mechanics,* in which stationary states are conceived as proper solutions of a fundamental wave equation. In advanced theories, the mechanical models are no longer used.

ISOTOPES

Experimental investigations in nuclear physics began to require specialized instruments. One of the first of these instruments was the mass spectrograph developed by Francis W. Aston to measure the relative mass of the atoms of an element. This device directed positive ions of an ionized (electrically charged) gas at a photographic plate. The ions were deflected by electric and magnetic fields, working at right angles, so that all particles having the same mass were brought to a focus at a fine line. Heavier ions, having more inertia, were deflected less than were the lighter ions.

With the use of the mass spectrograph, it was discovered that some chemical elements have two or more components, each with its own mass. Natural chlorine, whose atomic weight is fractional (about 35.5), produced two lines on the photographic plate corresponding to masses very close to 35 and 37. No particle was found with a fractional mass (within the experimental error). Components of the same chemical element with different mass numbers are called isotopes. Most elements in their natural state consist of two or more isotopes, although 20 elements have only one isotope: for example, aluminum, cobalt, and gold. Modifying Prout's hypothesis, Aston proposed the whole-number rule which states that all atomic masses are close to integers and that fractional atomic weights are due to the presence of two or more isotopes, each of which has an approximately integral value. On the carbon-12 scale now used, where the atomic weight of carbon-12 is exactly 12 units, all other isotopes have atomic weights close to integers.

* Wave-mechanics is equivalent to the matrix mechanics developed by Werner Heisenberg in 1925.

With the problem of fractional atomic weights solved, physicists at first believed that nuclei consisted of electrons and protons. A nucleus with an atomic number Z and an atomic mass A would consist of A protons, to account for the total mass, and A minus Z electrons to balance the excess positive charge of the protons. This view of the structure of the nucleus was altered in 1932 when James Chadwick discovered the neutron. This particle has no electric charge and has approximately the same mass as the proton.

It is now believed that neutral atoms consist of N neutrons, Z protons, and Z orbital electrons, with $A = N + Z$. Isotopes are nuclides with the same Z but different N. For example, natural hydrogen consists almost entirely of atoms that contain one proton and one electron. However, a small amount (about 0.015 percent) of deuterium (heavy hydrogen) is present in nature; deuterium consists of one proton, one neutron, and one electron. In general, the situation becomes more complex as the heavier elements are encountered. Natural tin, which has atomic number 50, consists of 10 isotopes of masses 112, 114, 115, 116, 117, 118, 119, 120, 122, and 124. These isotopes differ from one another because, although each has 50 protons and 50 electrons, each contains a different number of neutrons (ranging from 62 to 74).

The nucleus is held together by attractive forces between the neutrons and protons. These attractive forces are not completely understood, but it is known that they must be strong enough to overcome the electrostatic repulsion between the protons. Because of this repulsion, however, the ratio of neutrons to protons increases for stable isotopes as the atomic number increases. Among light elements in nature, there is approximately one proton for every neutron. Among heavy stable isotopes, for every two protons there are approximately three neutrons.

As previously mentioned, Aston found that the atomic masses were approximately integers. More accurate measurements indicate that the total mass of a nucleus is always less than the sum of the proton and neutron masses of which the nucleus is composed. In 1905, Einstein had shown that mass, m, was another form of energy, E, expressed by his relationship $E = mc^2$, where c is the velocity of light. The mass deficiency of the nucleus is expressed as the nuclear binding energy. The binding energy represents the amount of energy required to break the nucleus into its constituent nucleons. The ratio of the binding energy to the number of particles in the nucleus varies among the stable elements. It is greater for elements with mass numbers between 30 and 120 than it is for very light or very heavy stable elements.

ARTIFICIAL RADIOACTIVITY

In 1919, Rutherford's discovery of artificial radioactivity achieved the feat vainly sought by the ancient alchemists, that is, changing one element into another. Rutherford bombarded nitrogen gas with a stream of alpha particles. Some of the alpha particles were absorbed by the nitrogen, protons were emitted, and a different element, oxygen, was formed. The physicist uses symbolic language

to represent the transformation as follows:

$$^{14}_{7}N + {}^{4}_{2}He \rightarrow {}^{17}_{8}O + {}^{1}_{1}H.$$

The superscripts denote the total number of nucleons (number of protons plus neutrons), and the subscripts denote the atomic number (number of protons) in each element. Note that the superscripts on one side of the arrow balance those on the other side. The same is true for the subscripts. The balance represents the conservation of the number of protons and neutrons separately.

This initial discovery has been followed by the construction of large machines designed to accelerate charged particles such as protons and alpha particles to higher energies so that they may be used to bombard nuclei. Among these machines are the Van de Graaff generator, the cyclotron, the betatron, the linear accelerator (linac), and others. Beams of high-energy neutrons can also be produced. Since the neutron is electrically neutral, however, there is no electrostatic repulsion between bombarding neutrons and the positively charged target nuclei. Even thermal neutrons could be used for nuclear reaction studies (thermal neutrons have energies that correspond to the most probable energy for a group of neutrons at 68°F, that is, energies in the neighborhood of 0.025 eV).

NEUTRON FISSION

During the investigation of neutron-produced reactions in various target elements, Enrico Fermi and his associates discovered different beta activities (distinguished by half-life) when uranium was used as a target. They assumed that a transuranium element had been produced (that is, an element whose atomic number was greater than 92). In 1938, Otto Hahn and Fritz Strassman, repeating the experiments, discovered part of the activity to be due to barium (atomic number 56). Lise Meitner and Otto Frisch suggested that the uranium nucleus had split into two roughly equal parts, barium and krypton (the latter, atomic number 36), when the uranium captured the incident neutron. This reaction Frisch termed "fission," after the term used to describe the division of cells in a living organism. Since the mass defect (or binding energy) per particle is greater for the residual nuclei, barium and krypton, than for the uranium, neutron fission is accompanied by a large energy release.

For nuclear reactions other than fission, Fig. 1 illustrates the many combinations of incident (or bombarding) and emitted particles, and how each combination changes the original nucleus. This figure is copied from the lower right corner of the chart. A special type of shorthand is used on this diagram to identify the data represented. An example is (p,n) which denotes a reaction in which the nucleus absorbs a proton and emits a neutron. The symbols used are:

n	neutron	t	triton (hydrogen-3 nucleus)
d	deuteron	α	alpha particle
p	proton	γ	gamma ray
^{3}He	helium-3 nucleus		

Using these reactions, nuclear physicists have produced far more artificially radioactive isotopes than the stable or radioactive isotopes that occur in nature. The term "nuclide" was proposed by Truman P. Kohman for a species of atom characterized by the number of neutrons and protons that the atom contains. The term is used in this booklet in this general sense to encompass both stable and radioactive species. At present, there are 1675 nuclides known, of which 264 are stable forms of the natural elements. In addition, 65 of the unstable nuclides are found in nature, mainly among the heaviest elements. Active nuclear research, which is conducted in many laboratories throughout the world, causes additions and changes in the list of nuclides. Since the last edition of the chart was published (1966), 8 nuclides, which had been misassigned, have been removed, and 180 new nuclides have been added.

CHART OF THE NUCLIDES

(Data revised to December 1968; occasional data to June 1969)

The general arrangement of the Chart is similar to that suggested by Emilio Segrè and followed in previous editions. Because of its size, the Chart is presented in three overlapping sections. The numbers along the left-hand side, marking the horizontal rows, represent the atomic number Z (the number of protons in each nucleus of that row). Each horizontal row represents one element; the filled spaces indicate the known isotopes of that element. The numbers at the bottom of the vertical columns represent the number of neutrons in each nucleus of that column; the number is designated by N.

Heavy lines on the Chart occur for Z or N equal to 2, 8, 20, 28, 50, 82, and 126. These are the so-called "magic numbers", i.e., the numbers of neutrons (protons) present when a neutron (proton) shell is closed. In analogy with the electron shell model of the atom, a nuclear shell model has been developed for the neutrons and protons within a nucleus. Filled shells represent the most stable configurations. Nuclides having either a closed neutron shell, or a closed proton shell, or both, are most stable.

Spaces shaded in gray represent isotopes that occur in nature and that are generally considered stable. A black rectangular area at the top of a

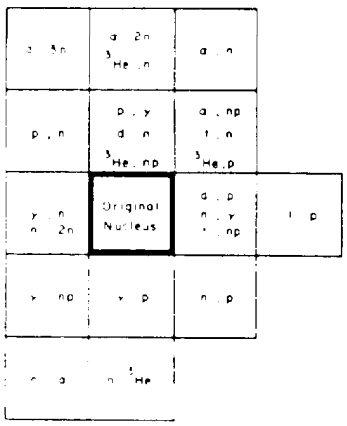


Fig. 1 Changes Produced by Various Nuclear Reactions

white square indicates a radioactive isotope that is found in nature. Examples of such isotopes are (1) an unstable nuclide having a lifetime sufficiently long to have prevented the loss by disintegration of all atoms of that particular nuclide that were available at the time the elements were formed, and (2) a short-lived nuclide that is a disintegration product of such a long-lived nuclide. Occasionally one nuclide has both the gray shading and the black top. This indicates an isotope found in nature, such as rubidium-87, that is radioactive with a very long half-life. Squares with smaller black rectangular areas near the top represent members of one of the naturally radioactive decay chains (see page 8). The old symbolic name is inserted in this smaller black area. White squares represent artificially produced radioactive nuclides.

The heavily bordered space at the left side of each horizontal row gives properties of the element as found in nature, including the chemical atomic weight (on a mass scale where the neutral atom of carbon-12 = 12.00000) and the thermal neutron absorption cross section (see page 6).

Each of the other occupied spaces carries the chemical symbol (a list of these symbols is given on page 7 along with the atomic weights) and the mass number of the nuclide indicated. The mass number, designated by A, is the sum of the number of neutrons and protons in the nucleus. The number of neutrons N is equal to the difference between the mass number and the atomic number, that is, A minus Z.

STABLE NUCLIDES

Classifying the 264 stable nuclides by the even- or oddness of Z and N gives four possible categories. The first category contains an even number of protons and an even number of neutrons (so called even-even nuclei). The other categories are even-odd, odd-even, and odd-odd. Table 1 shows the number of stable nuclides that fall in each category.

Table 1. Distribution of Stable Nuclides

A	Z	N	Number of Stable Nuclides
Even	Even	Even	157
Odd	Even	Odd	53
Odd	Odd	Even	50
Even	Odd	Odd	4
			264

Table 1 shows that for the odd A nuclides there are approximately as many nuclides with an even number of protons (even Z) as with an even number of neutrons (even N). This is evidence that the nuclear force between two nucleons is independent of whether the nucleons are protons or neutrons. Odd-odd stable nuclides are scarce, and they are found only among the lightest nuclides. Their scarcity is due to a "pairing energy" between particles in the same shell. The condition of being in the same shell increases the binding energy of these particles, making them more stable than particles in different shells. An odd-odd nuclide contains at least one unpaired proton and one unpaired neutron which are usually in different shells and hence contribute weakly to the binding. For the lightest nuclei, however, the unpaired neutron and proton are in the same shell.

Diagonals running from upper left to lower right connect nuclides of different elements, which have the same mass numbers. For example, one line could connect calcium-40, which has 20 protons and 20 neutrons, with argon-40, which has 18 protons and 22 neutrons. Nuclides of the same mass number are called isobars; nuclides with the same number of neutrons are called isotones.

DATA DISPLAY

The manner of displaying data is explained in the lower right corner of the chart. For stable nuclides, the first line contains the chemical symbol and mass number; the second line presents the atom percent of the natural element that this isotope represents (known as the absolute isotopic abundance); the third line contains the thermal neutron cross section (see page 6); and the fourth line presents the isotopic mass of the neutral atom (the mass of the nucleus and its surrounding electrons). This mass is given in atomic mass units where carbon-12 is assigned a mass of 12.00000.

For long-lived, naturally occurring radioactive nuclides, the first line contains the chemical symbol and mass number, the second line presents the absolute isotopic abundance, and the third line contains the half-life. The half-life is the period of time in which half of the nuclei initially present in a given sample disintegrate. Additional lines present the decay modes (or types) and energies of decay, and the isotopic mass of the nuclide. Energies are given in millions of electron volts (MeV). When more than one mode of decay occurs, the most prominent mode appears first (above, or to the left of, the other modes). When gamma radiation is emitted in more than one decay mode, or if several gamma rays are emitted in one mode, the gamma rays are separated and presented below (or to the right of) their associated decay mode(s).

For radioactive nuclides that are not of the long-lived, naturally occurring type, the same information is presented except that the isotopic abundance is omitted and the last line of the pertinent square contains the beta-decay energy instead of the isotopic mass. For the heavy elements, where the major mode of decay is alpha-particle emission, the isotopic mass is retained in the last line. In many squares, a small black triangle appears in the lower right corner to indicate that the nuclide has been formed as a product in the thermal-neutron fission of uranium-235.

METASTABLE STATES

Note that certain squares are divided, for example, the square for aluminum-26. Such divisions occur when a nuclide has one or more isomeric states, that is, when a nuclide has the same mass number and atomic number, but possesses different radioactive properties in different long-lived energy states. On the chart, a long-lived state is arbitrarily defined as a state whose half-life is one microsecond (one-millionth of a second) or longer. The lower energy state is generally referred to as the ground state, the higher state as the isomeric state. Frequently, the ground state is a stable nuclide. If one metastable state exists, it is shown on the left. If two exist, the higher energy state is shown on the

left, the lower below it or to the right of it, and the ground state to the right of both.

A mode of decay and the decay energy shown in parentheses indicate that the decay results from a short-lived daughter that accompanies its parent. (In a radioactive decay, the original nuclide is called the parent or precursor; the resultant nuclide is called the daughter.) For example, nitrogen-17, with a half-life of 4.14 seconds, decays by negative beta emission (symbol β^-) into an exceedingly short-lived state of oxygen-17, which in turn emits a neutron. Thus nitrogen-17 emits "delayed neutrons" with a half-life of 4.14 seconds.

Another example is 17-day palladium-103, which decays by K-electron capture mainly to the 57-minute rhodium-103 and, statistically less often, to stable rhodium-103. (K-electron capture occurs when the nucleus captures an electron from the K shell; the symbol is ε.) The 57-minute rhodium emits a gamma ray or an internal-conversion electron that corresponds to an isomeric transition of 0.040 MeV. (An internal-conversion process involves the direct transfer of energy from the nucleus to one of the orbital electrons, and the electron is ejected from the atom; the symbol used is e^-.) On the chart, the delayed gamma ray is assigned to the parent; inclusion of the energy in parentheses indicates that the gamma ray comes from the daughter, but continues to last as long as the disintegrating parent is still present.

A further example is provided by a standard laboratory radionuclide, 30.2-year cesium-137. This long-lived parent decays directly to a short-lived daughter, 2.551-minute barium-137, by negative beta emission. The 6.616-MeV gamma ray which is emitted by the barium is included in parentheses on the cesium square.

THERMAL NEUTRON CROSS SECTIONS

The Greek letter σ with various subscripts is used to identify the thermal neutron cross sections. The neutron cross section measures the probability of interaction of a neutron with matter. The cross section can be most easily visualized as a cross-sectional target area presented to the neutron by the nucleus. The cross section depends upon the type of interaction involved and the energy of the neutron. At thermal energies, a number of reaction types are possible. The thermal neutron absorption cross section (symbol σ_a) is the sum of the cross sections for all reactions except scattering of the neutron. Cross sections are usually measured in units of barns per atom. A barn is the area of a square a millionth of a millionth of a centimeter on each side (10^{-24} square centimeters). The most probable reaction (that is, the reaction with the largest cross section) is generally the neutron capture reaction (symbol σ_γ) in which the absorption of the neutron by the nucleus is accompanied by high-energy gamma-ray emission. Occasionally, a proton or an alpha particle may be emitted, or the nucleus may fission upon neutron absorption (symbols σ_p, σ_α and σ_f). Examples of these cross sections are found on the squares of beryllium-7, boron-10, and thorium-227, respectively.

A given nuclide might undergo two or more interactions, and its square would then contain two or more of these cross-section values. When neutron capture can lead to a metastable state as well as to the ground state, more than one value will appear beside the capture cross section for that nuclide. The cross-section value for metastable state formation is listed on the left and that for direct ground state formation on the right. For two metastable states, the higher of the two states is on the left. For example, indium-113 has an indicated capture cross section σ_γ of (2.8 · 5.0 · 3), which means that the cross section for formation of 44-millisecond indium-114 is 2.8 barns, the cross section for the direct formation of 50.0-day indium-114 is 5.0 barns, and the cross section for formation of 71.9-second indium-114 is 3 barns.

The designation mb or μb following the cross-section value indicates that the units of the cross section are millibarns per atom (10^{-27} cm^2 atom) or mircobarns per atom (10^{-30} cm^2 atom), respectively. When no mb or μb appears on the chart square, the units of the cross section are barns per atom.

SPINS AND PARITIES

In the upper right corner of the square for the ground state of a nuclide, and in the upper left corner of the isomeric state, are shown the spin and parity of the corresponding energy level. Each neutron and proton has an intrinsic angular momentum of $\frac{1}{2}$ (in units of $h/2\pi$, where h is Planck's constant), similar to that of the electron, which combines with their orbital angular momentum to produce a resultant angular momentum called the nuclear spin. Since the orbital angular momentum is always zero or an integral multiple of $h/2\pi$, the nuclear spin (in units of $h/2\pi$) is always integer or half-odd-integer, depending upon whether the nucleus has an even or an odd number of nucleons. The concept of parity was introduced by the mathematical formalism of quantum theory and has no classical analogue. A system in a given state may have even parity (symbol +) or odd parity (symbol −). For aluminum-27 the spin and parity are shown as 5 +, where the 2 in the denominator of 5/2 has been removed to improve the readability of the chart. The ground states of all even-even nuclides are known to have spin and parity 0 +; so 0 + has been omitted.

The arguments for the assignment of spin and parity to nuclear states can be divided into two classes: strong arguments such as measuring values directly, and weak arguments such as inferring values indirectly. On the chart, the absence of parentheses indicates spins and or parities based on strong arguments; the presence of parentheses indicates spins and or parities based on weak arguments. When the spins of both the ground state and an isomeric state are given for a particular nuclide, it is interesting to observe that these spins usually differ by two or more units of $h/2\pi$. The large angular momentum (spin) change is required for the gamma-ray transition between the states. Combining this spin change with the small energy differences (a few hundred keV) leads to a relatively long lifetime (metastable state).

RADIOACTIVE DECAY CHAINS

As nuclear processes occur, whether in natural radioactivity or under artificially induced conditions, the nuclides change in accordance with the scheme shown in Fig. 2. To understand the use of this scheme more fully, consider the uranium-238 decay chain (one of three such chains found in nature). On the chart we start with the parent uranium-238 which emits an alpha particle. The daughter nucleus is in the second space diagonally down to the left (see Fig. 2). This square represents the isotope thorium-234. (This nuclide is also identified by the old symbol uranium X_1, which is the historic name given it before it was identified as thorium.)

Thorium-234 in turn emits a negative electron; so the loss of mass is not appreciable. However, there is a loss of one negative charge, which means that the atomic number Z increases by one. In effect, one neutron has changed into a proton. The move one space up and one space to the left (see Fig. 2) leads to protactinium-234 which has isomeric states. Each of these states undergoes negative beta emission; so another move diagonally upward to the left leads to uranium-234.

Uranium-234 emits an alpha particle ending at thorium-230. Another alpha decay yields radium-226. Three further alpha decays result first in radon-222, then in polonium-218, and finally in lead-214. However, this isotope of lead is unstable and emits a negative electron producing bismuth-214. A beta decay to polonium-214 is followed by an alpha decay to lead-210. An alternate route from bismuth-214 to lead-210 is taken in a small fraction of the disintegrations since bismuth-214 can also emit an alpha particle and the resulting thallium-210 beta-decays to lead-210.

In either case, lead-210 beta-decays to bismuth-210. Another beta decay produces polonium-210 which alpha-decays to the stable isotope lead-206. At this point the chain ends. Incidentally, in many of the above steps, gamma rays and conversion electrons are also emitted.

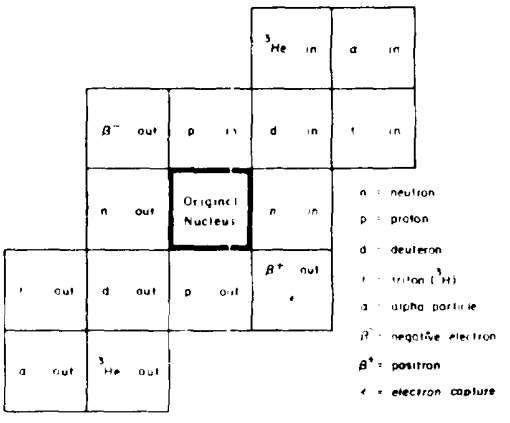


Fig. 2. Relative Locations of the Products of Various Nuclear Processes

Similarly, the two other natural radioactive sequences may be traced. One is the actinium series which starts with uranium-235 and ends with lead-207. The other is the thorium series, which goes from thorium-232 to lead-208. A fourth, or neptunium, series is also known. However, the half-life of the parent, neptunium-237, is only about two million years. Since the age of the earth is five or ten billion years, most of the neptunium-237 present when the earth was younger has already decayed, and the series is not found in nature.

Since the naturally radioactive decay chains end at stable isotopes of lead, the isotopic composition of lead ore will be variable depending upon its source and its past history. Elements such as lithium and boron also have variable compositions that are affected by reactions that their samples have previously undergone. In a similar manner, scientists examining the isotopic compositions of samples recently brought back from the moon have already obtained an estimate of the age of the samples from the relative amounts of potassium and argon-40 present. A comparison of the isotopic composition of elements on the moon with those on earth might provide scientists with some solutions to the problem of the origin of the universe.

Errata

(Chart of the Nuclides, Tenth Edition)

The absorption cross sections for oxygen and sodium should read as follows:

Oxygen σ_a .27 mb

Sodium σ_a .534

The atomic weight for praseodymium should read 140.908.

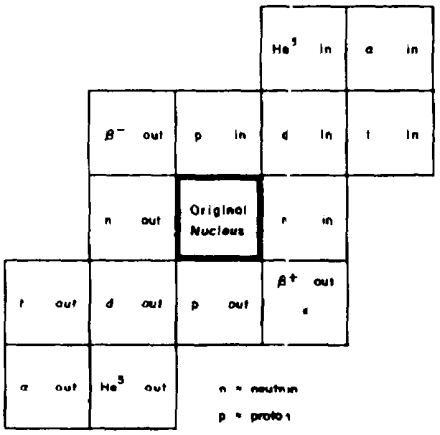
ACKNOWLEDGMENTS

The authors thank the large number of persons who by correspondence and in discussions contributed generously of their time and information. It is not possible to acknowledge specifically in this limited space everyone who sent his experimental results in advance of publication and whose assistance was needed in the comparison of the various experimental data. Special thanks are due to John R. Stehn of the Brookhaven National Laboratory, Geoffrey C. Hanna of the Chalk River Laboratory, David T. Goldman of the National Bureau of Standards, Earl K. Hyde and Albert Ghiorso of the Lawrence Radiation Laboratory, Arve Kjelberg of CERN, Jere D. Knight of Los Alamos Scientific Laboratory, W. Bruce Ewbank of the Nuclear Data Project at Oak Ridge National Laboratory, R. Van Lieshout of the Instituut Voor Kernphysisch Onderzoek, and T. Leo Collins, Jr., and the mass spectrometry group at KAPL, for their assistance in various stages of the preparation of the accompanying Chart of the Nuclides.

LIST OF ELEMENTS

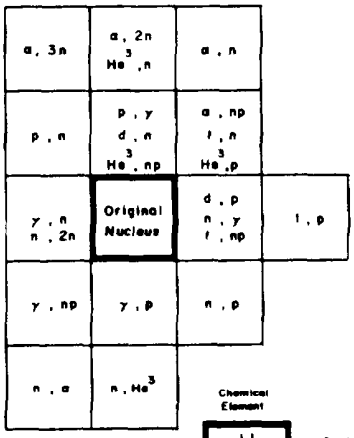
ATOMIC NUMBER	SYMBOL	NAME	ATOMIC WEIGHT	ATOMIC NUMBER	SYMBOL	NAME	ATOMIC WEIGHT
0	n	neutron	.....	52	Te	tellurium	127.60
1	H	hydrogen	1.00797	53	I	iodine	126.9044
2	He	helium	4.0026	54	Xe	xenon	131.30
3	Li	lithium	6.940	55	Cs	cesium	132.905
4	Be	beryllium	9.0122	56	Ba	barium	137.34
5	B	boron	10.811	57	La	lanthanum	138.91
6	C	carbon	12.01115	58	Ce	cerium	140.12
7	N	nitrogen	14.0067	59	Pr	praseodymium	140.908
8	O	oxygen	15.9994	60	Nd	neodymium	144.24
9	F	fluorine	18.9984	61	Pm	promethium	.....
10	Ne	neon	20.179	62	Sm	samarium	150.35
11	Na	sodium	22.9898	63	Eu	europium	151.96
12	Mg	magnesium	24.305	64	Gd	gadolinium	157.25
13	Al	aluminum	26.9815	65	Tb	terbium	158.924
14	Si	silicon	28.086	66	Dy	dysprosium	162.50
15	P	phosphorus	30.9738	67	Ho	holmium	164.930
16	S	sulfur	32.064	68	Er	erbium	167.26
17	Cl	chlorine	35.453	69	Tm	thulium	168.934
18	Ar	argon	39.948	70	Yb	ytterbium	173.04
19	K	potassium	39.102	71	Lu	lutetium	174.97
20	Ca	calcium	40.08	72	Hf	hafnium	178.49
21	Sc	scandium	44.956	73	Ta	tantalum	180.948
22	Ti	titanium	47.90	74	W	tungsten	183.85
23	V	vanadium	50.942	75	Re	rhenium	186.2
24	Cr	chromium	51.996	76	Os	osmium	190.2
25	Mn	manganese	54.9380	77	Ir	iridium	192.2
26	Fe	iron	55.847	78	Pt	platinum	195.09
27	Co	cobalt	58.9332	79	Au	gold	196.967
28	Ni	nickel	58.71	80	Hg	mercury	200.59
29	Cu	copper	63.546	81	Tl	thallium	204.37
30	Zn	zinc	65.37	82	Pb	lead	207.19
31	Ga	gallium	69.72	83	Bi	bismuth	208.980
32	Ge	germanium	72.59	84	Po	polonium	.....
33	As	arsenic	74.9216	85	At	astatine	.....
34	Se	selenium	78.96	86	Rn	radon	.....
35	Br	bromine	79.904	87	Fr	francium	.....
36	Kr	krypton	83.80	88	Ra	radium	.....
37	Rb	rubidium	85.47	89	Ac	actinium	.....
38	Sr	strontium	87.62	90	Th	thorium	232.038
39	Y	yttrium	88.905	91	Pa	protactinium	.....
40	Zr	zirconium	91.22	92	U	uranium	238.03
41	Nb	niobium	92.906	93	Np	neptunium	.....
42	Mo	molybdenum	95.94	94	Pu	plutonium	.....
43	Tc	technetium	.....	95	Am	americium	.....
44	Ru	ruthenium	101.07	96	Cm	curium	.....
45	Rh	rhodium	102.905	97	Bk	berkelium	.....
46	Pd	palladium	106.4	98	Cf	californium	.....
47	Ag	silver	107.868	99	Es	einsteinium	.....
48	Cd	cadmium	112.40	100	Fm	fermium	.....
49	In	indium	114.82	101	Md	mendelevium	.....
50	Sn	tin	118.69	102	No	nobelium	.....
51	Sb	antimony	121.75	103	Lr	lawrencium	.....

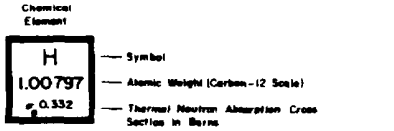
Relative Locations of the Products of Various Nuclear Processes

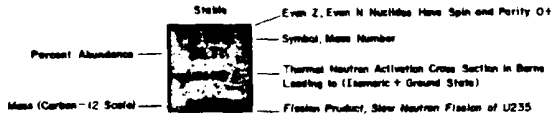


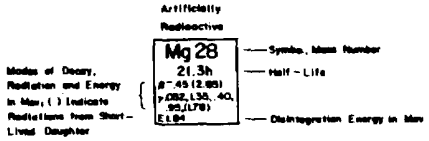
n = neutron
p = proton
d = deuteron
t = tritium (H^3)
α = alpha particle
β^- = negative electron
β^+ = positron
ε = electron capture

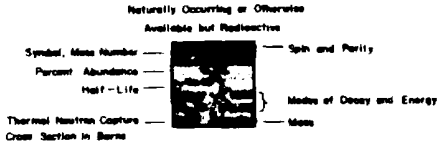
Displacements Caused by Nuclear Bombardment Reactions

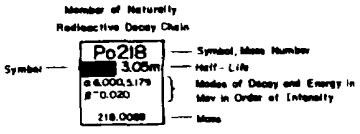


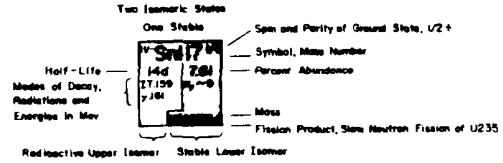


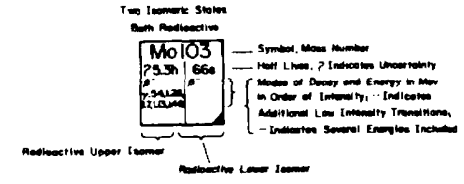












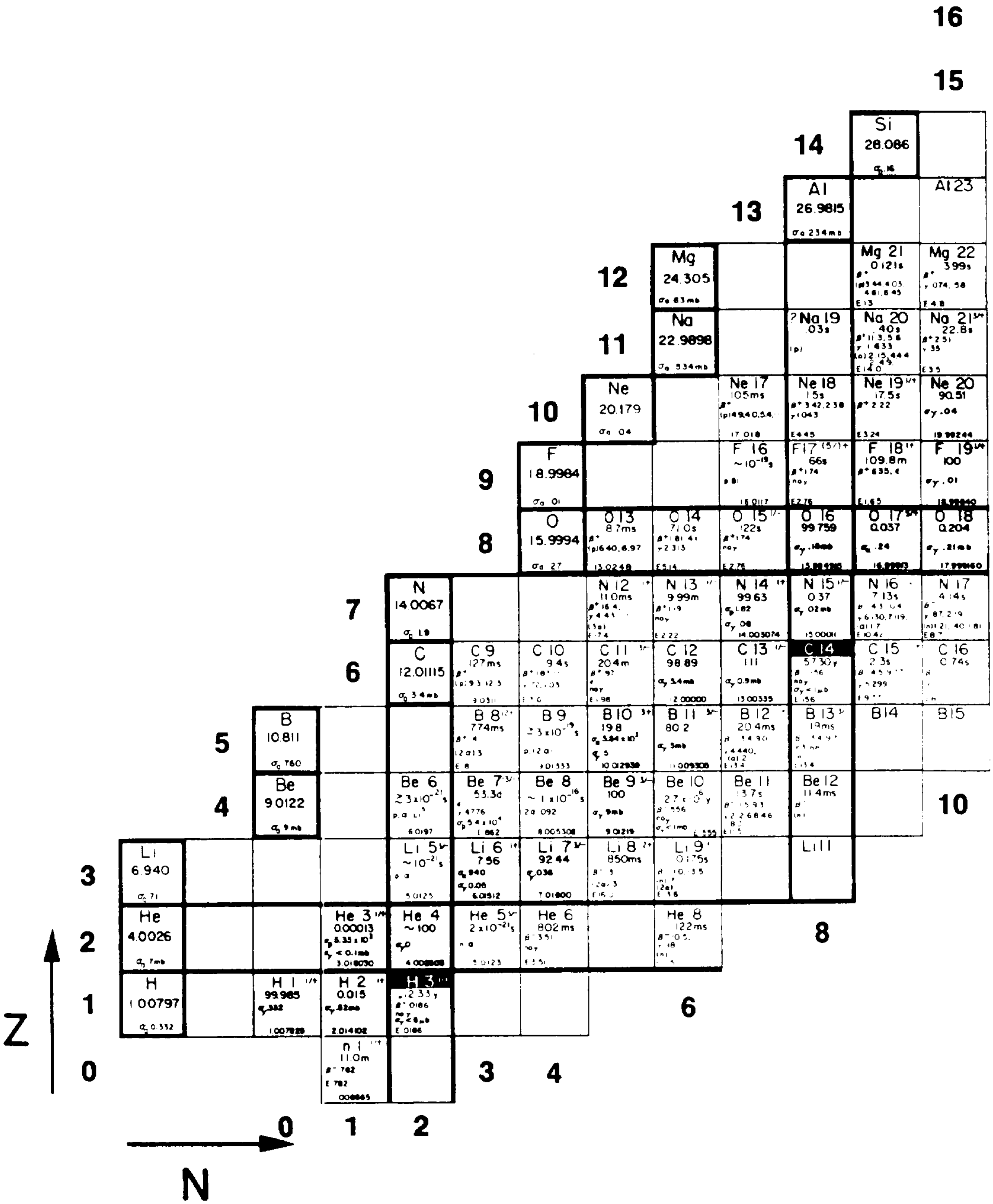
SYMBOLS

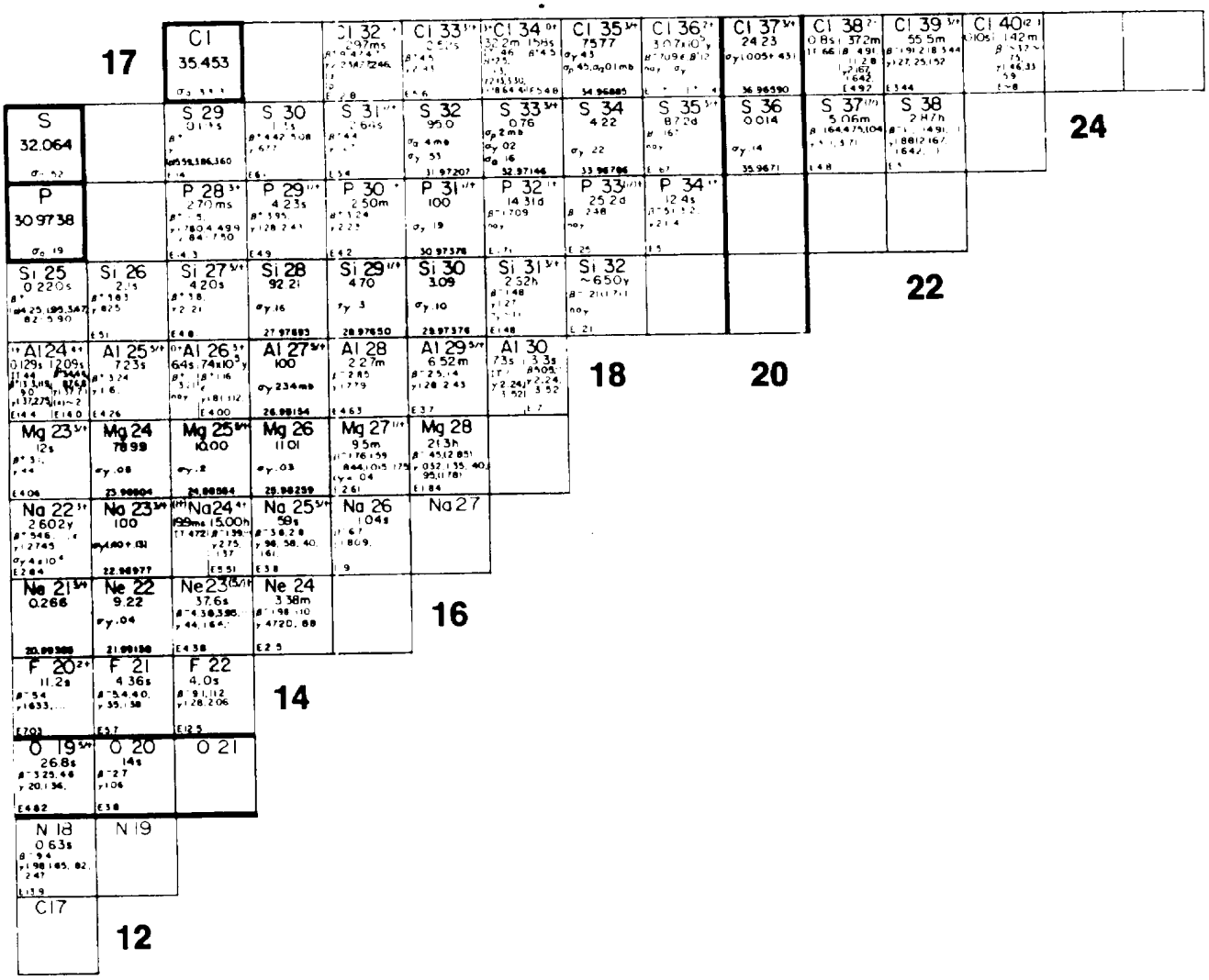
RADIATIONS AND DECAY

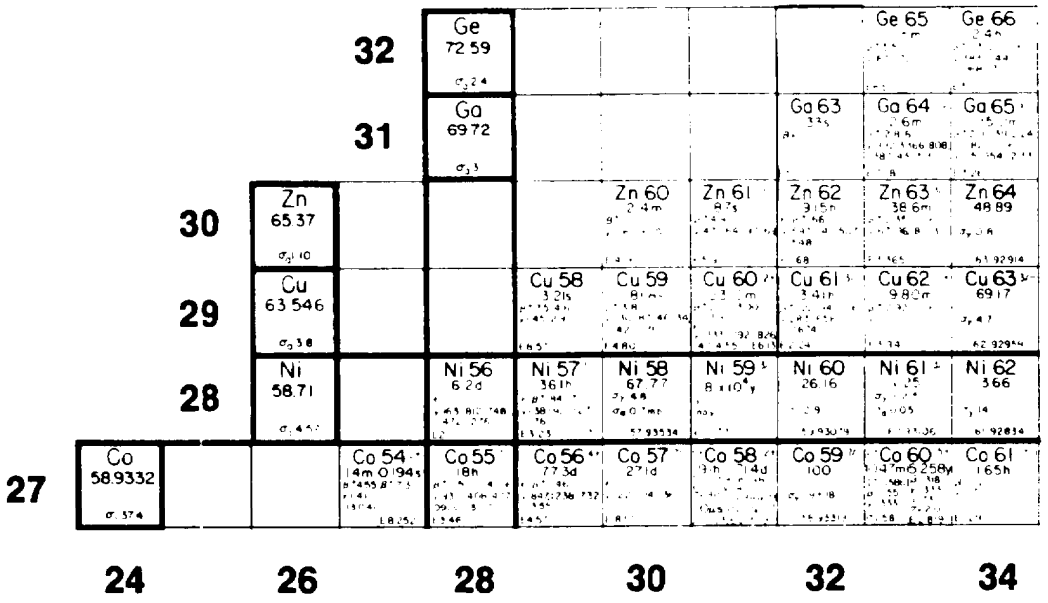
α	alpha particle
β^-	negative electron
β^+	positron
γ	gamma ray
n	neutron
p	proton
ε	electron capture
IT	isomeric transition
D	radiation delayed
SF	spontaneous fission
E	disintegration energy
e^-	conversion electron

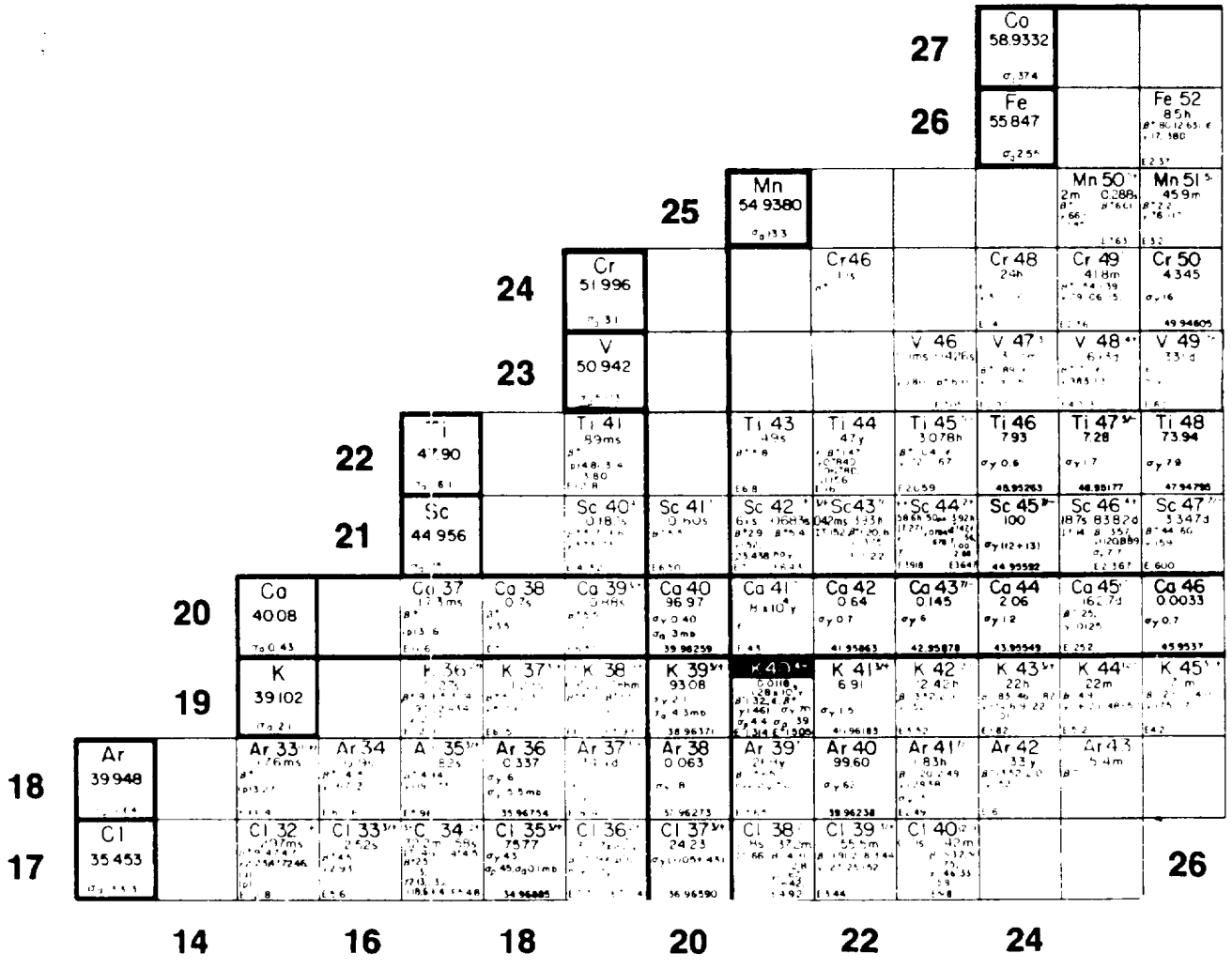
TIME

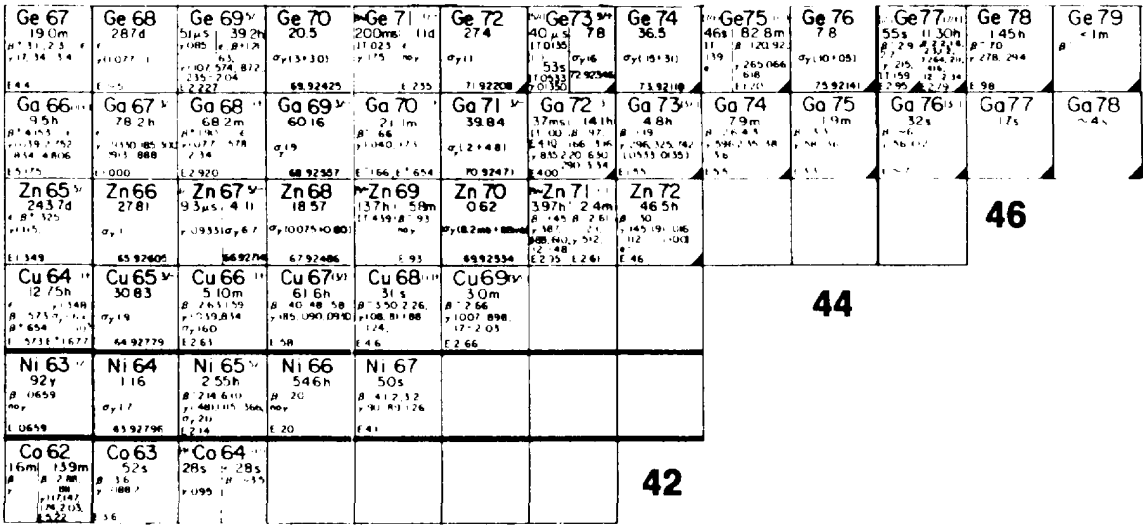
ms	milliseconds (10^{-3} s)
μs	microseconds (10^{-6} s)
s	seconds
m	minutes
h	hours
d	days
y	years

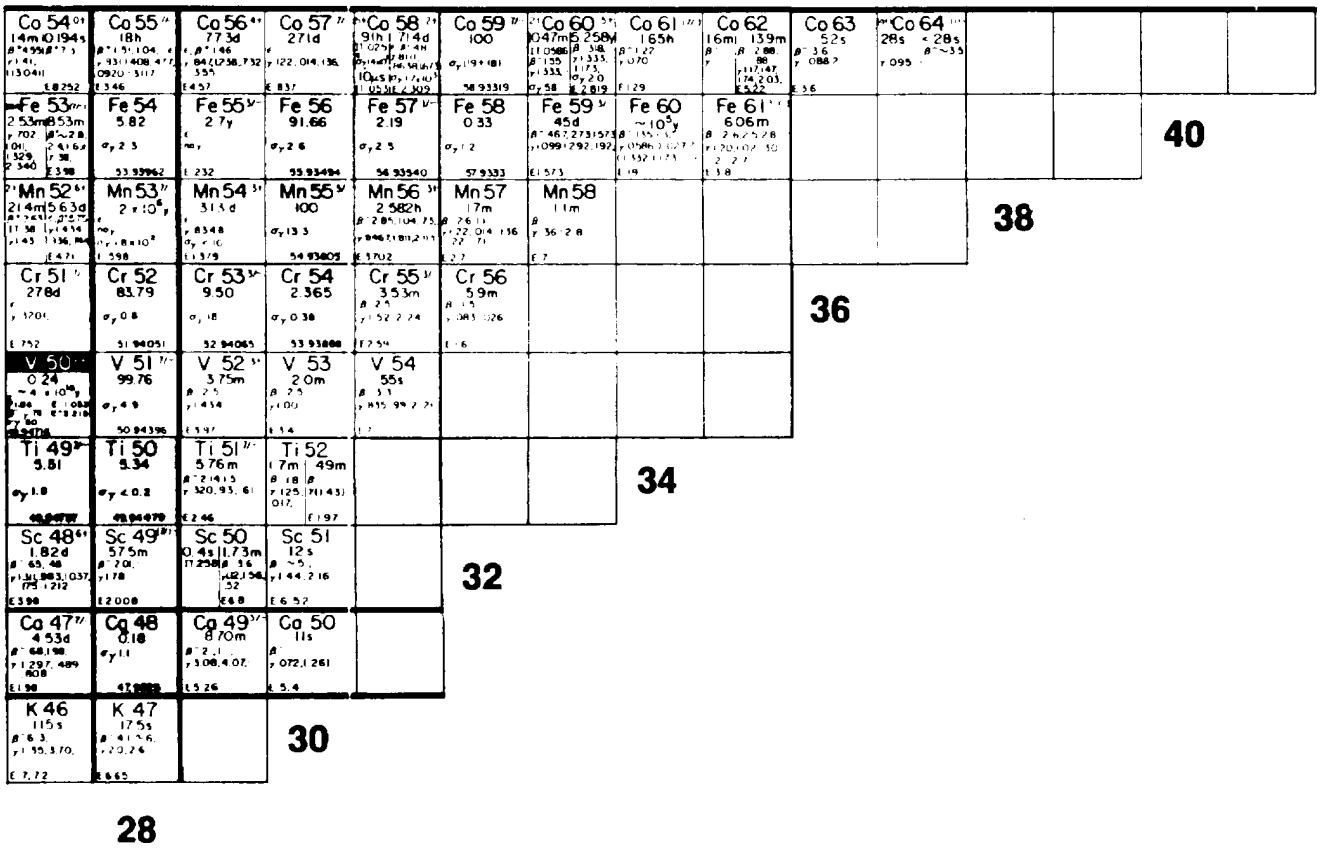

Z
N
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
H
1.00797
He
4.0026
Li
6.940
Be
9.0122
B
10.811
C
12.01115
N
14.0067
O
15.9994
F
18.9984
Ne
20.179
Na
22.9898
Mg
24.305
Al
26.9815
Si
28.086
n 1
11.0m
H 1
99.985
H 2
0.015
H 3
12.33y
He 3
0.00013
He 4
~100
He 5
He 6
802ms
He 8
122ms
Li 5
Li 6
7.56
Li 7
92.44
Li 8
850ms
Li 9
0.175s
Li 11
Be 6
Be 7
53.3d
Be 8
Be 9
100
Be 10
Be 11
13.7s
Be 12
11.4ms
B 8
774ms
B 9
B 10
19.8
B 11
80.2
B 12
20.4ms
B 13
19ms
B 14
B 15
C 9
127ms
C 10
19.4s
C 11
20.4m
C 12
98.89
C 13
1.11
C 14
5730y
C 15
2.3s
C 16
0.74s
N 12
11.0ms
N 13
9.99m
N 14
99.63
N 15
0.37
N 16
7.13s
N 17
4.14s
O 13
8.7ms
O 14
71.0s
O 15
122s
O 16
99.759
O 17
0.037
O 18
0.204
F 16
F 17
66s
F 18
109.8m
F 19
100
Ne 17
105ms
Ne 18
1.5s
Ne 19
17.5s
Ne 20
90.51
?Na 19
.03s
Na 20
.40s
Na 21
22.8s
Mg 21
0.121s
Mg 22
3.99s
Al 23


17
Cl 35.453
S 32.064
P 30.9738
18
20
22
24
16
14
12


32
31
30
29
28
27
Ge 72.59
Ga 69.72
Zn 65.37
Cu 63.546
Ni 58.71
Co 58.9332
Ge 65
Ge 66
Ga 63
Ga 64
Ga 65
Zn 60
Zn 61
Zn 62
Zn 63
Zn 64
Cu 58
Cu 59
Cu 60
Cu 61
Cu 62
Cu 63
Ni 56
Ni 57
Ni 58
Ni 59
Ni 60
Ni 61
Ni 62
Co 54
Co 55
Co 56
Co 57
Co 58
Co 59
Co 60
Co 61
24
26
28
30
32
34

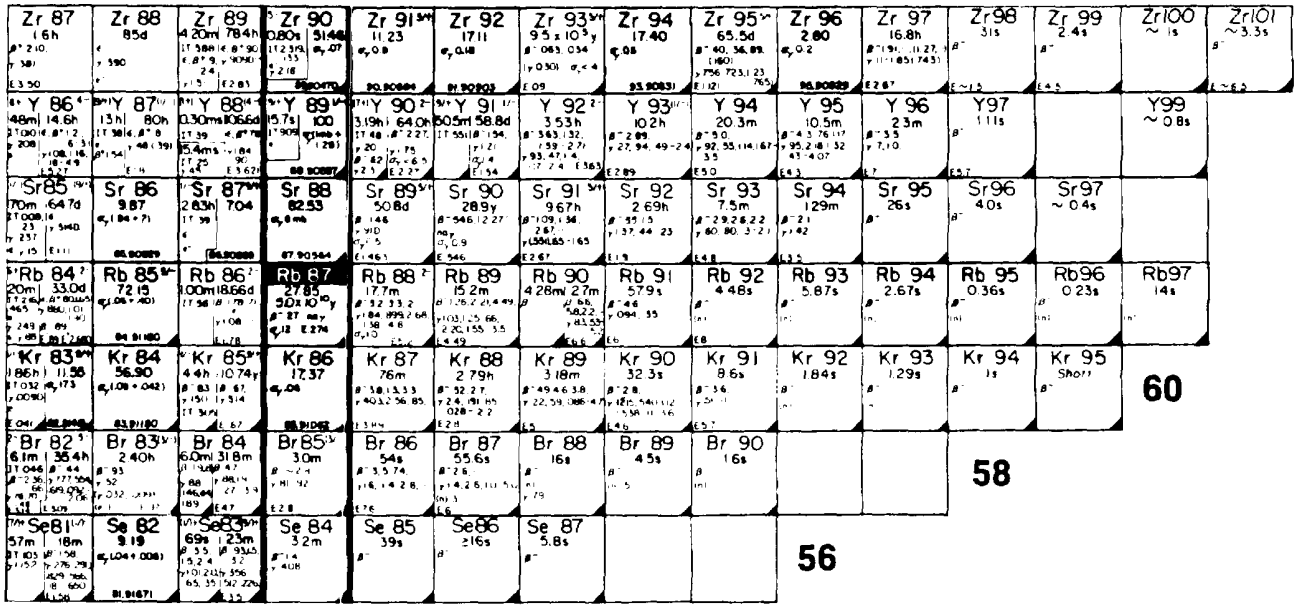

27
26
25
24
23
22
21
20
19
18
17
Co 58.9332
Fe 55.847
Mn 54.9380
Cr 51.996
V 50.942
Sc 44.956
Ca 40.08
K 39.102
Ar 39.948
Cl 35.453
Fe 52
Mn 50
Mn 51
Cr 46
Cr 48
Cr 49
Cr 50
V 46
V 47
V 48
V 49
Ti 41
Ti 43
Ti 44
Ti 45
Ti 46
Ti 47
Ti 48
Sc 40
Sc 41
Sc 42
Sc 43
Sc 44
Sc 45
Sc 46
Sc 47
Ca 37
Ca 38
Ca 39
Ca 40
Ca 41
Ca 42
Ca 43
Ca 44
Ca 45
Ca 46
K 37
K 38
K 39
K 40
K 41
K 42
K 43
K 44
K 45
Ar 33
Ar 34
Ar 35
Ar 36
Ar 37
Ar 38
Ar 39
Ar 40
Ar 41
Ar 42
Ar 43
Cl 32
Cl 33
Cl 34
Cl 35
Cl 36
Cl 37
Cl 38
Cl 39
Cl 40
26
14
16
18
20
22
24

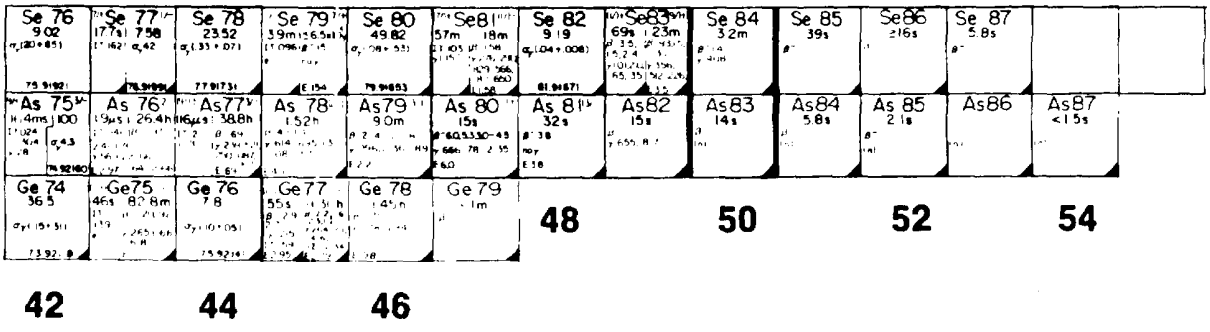

Ge 67
19.0m
Ge 68
287d
Ge 69
39.2h
Ge 70
20.5
Ge 71
11d
Ge 72
27.4
Ge 73
7.8
Ge 74
36.5
Ge 75
82.8m
Ge 76
7.8
Ge 77
11.30h
Ge 78
1.45h
Ge 79
< 1m
Ga 66
9.5h
Ga 67
78.2h
Ga 68
68.2m
Ga 69
60.16
Ga 70
21.1m
Ga 71
39.84
Ga 72
14.1h
Ga 73
4.8h
Ga 74
7.9m
Ga 75
1.9m
Ga 76
32s
Ga 77
17s
Ga 78
~4s
Zn 65
243.7d
Zn 66
27.81
Zn 67
Zn 68
18.57
Zn 69
Zn 70
0.62
Zn 71
3.97h
Zn 72
46.5h
46
Cu 64
12.75h
Cu 65
30.83
Cu 66
5.10m
Cu 67
61.6h
Cu 68
31s
Cu 69
3.0m
44
Ni 63
92y
Ni 64
1.16
Ni 65
2.55h
Ni 66
54.6h
Ni 67
50s
Co 62
1.6m
Co 63
52s
Co 64
28s
42
36
38
40

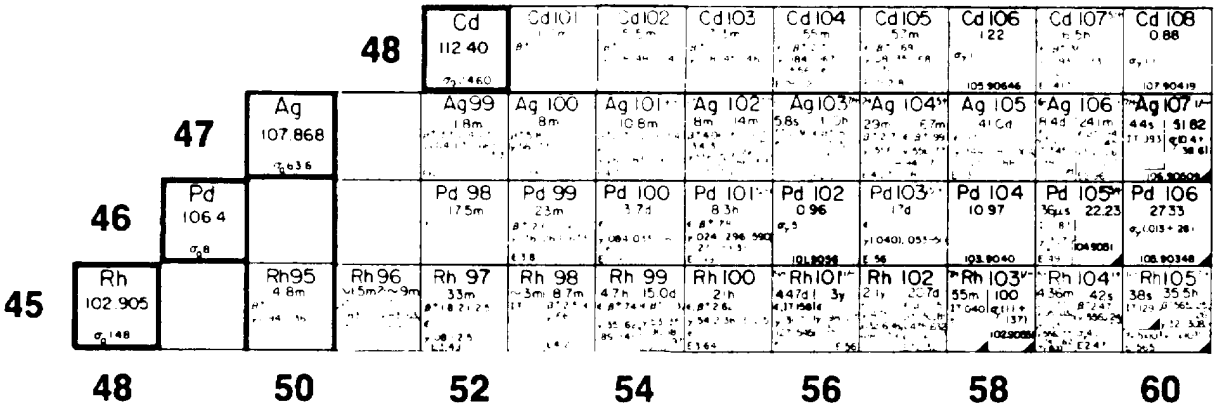

Co 54
1.4m
Co 55
18h
Co 56
77.3d
Co 57
271d
Co 58
9.1h
Co 59
100
Co 60
1.047m
5.258y
Co 61
1.65h
Co 62
1.6m
Co 63
52s
Co 64
28s
Fe 53
2.53m
Fe 54
5.82
Fe 55
2.7y
Fe 56
91.66
Fe 57
2.19
Fe 58
0.33
Fe 59
45d
Fe 60
~10^5y
Fe 61
6.06m
40
Mn 52
21.4m
Mn 53
2 x 10^6y
Mn 54
313d
Mn 55
100
Mn 56
2.582h
Mn 57
1.7m
Mn 58
1.1m
38
Cr 51
27.8d
Cr 52
83.79
Cr 53
9.50
Cr 54
2.365
Cr 55
3.53m
Cr 56
5.9m
36
V 50
0.24
V 51
99.76
V 52
3.75m
V 53
2.0m
V 54
55s
Ti 49
5.81
Ti 50
5.34
Ti 51
5.76m
Ti 52
1.7m
49m
34
Sc 48
1.82d
Sc 49
57.5m
Sc 50
0.4s
1.73m
Sc 51
12s
32
Ca 47
4.53d
Ca 48
0.18
Ca 49
8.70m
Ca 50
11s
K 46
11.5s
K 47
17.5s
30
28

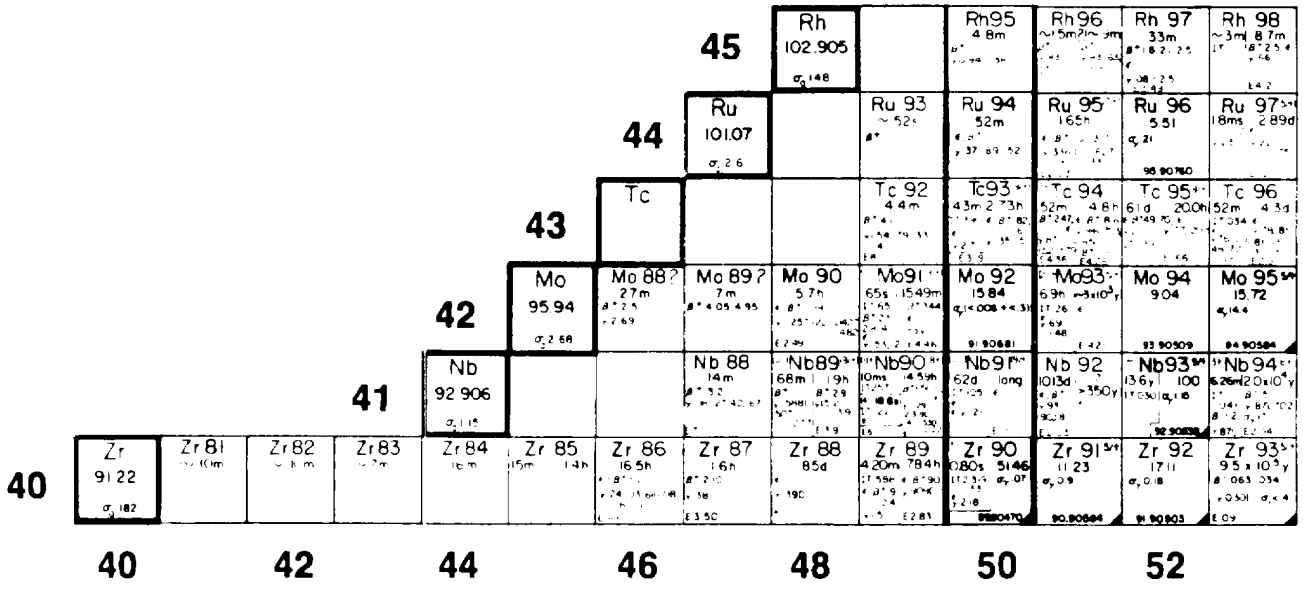

40
39
38
37
36
35
34
Zr 91.22
Zr 81 ~10m
Zr 82
Zr 83 ~7m
Zr 84 6m
Zr 85 15m 4h
Zr 86 16.5h
Y 88.905
Y 82 2m
Y 83 7.5m
Y 84 4.1m
Y 85 2.7h 5.0h
Sr 87.62
Sr 80 7h
Sr 81 29m
Sr 82 25d
Sr 83 32.4h
Sr 84 0.56
Rb 85.47
Rb77
Rb78 6m
Rb79 23m
Rb 80 34s
Rb 81 32m 4.7h
Rb 82 6.4h 1.25m
Rb83 8.6s 83d
Kr 83.80
Kr 74 16m
Kr 75 ~5m
Kr 76 14.8h
Kr 77 2h
Kr 78 0.354
Kr 79 50s 34.9h
Kr 80 2.27
Kr 81 2.1×10^5 y
Kr 82 11.56
Br 79.904
Br 70? 23s
Br 74 4m 36m
Br 75 97m
Br 76 16h
Br 77 57h
Br 78 125ms 6.4m
Br 79 4.84s 50.69
Br 80 4.42h 17.6m
Br 81 37.6s 49.31
Se 78.96
Se 70 39m
Se 71 4.5m
Se 72 8.5d
Se73 42m 7.1h
Se 74 0.87
Se 75 120.4d
Se 76 9.02
Se 77 17.5s 7.58
Se 78 23.52
Se 79 3.9m 1.1×10^6 y
Se 80 49.82
34
36
38
40
42
44
46

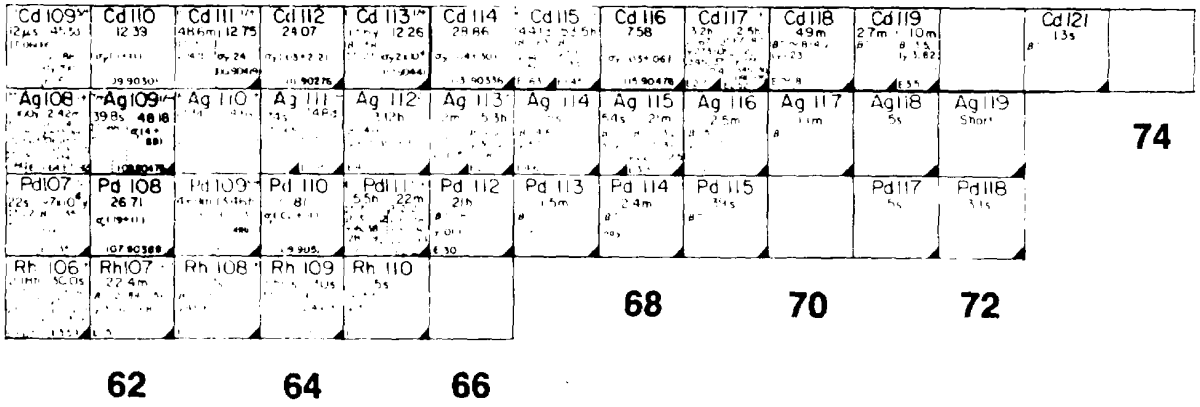
34
33
32
Se 78.96
Se 70 39m
Se 71 4.5m
Se 72 8.5d
Se73 42m 7.1h
Se 74 0.87
Se 75 120.4d
As 74.9216
As 68? ~7m
As 69 15m
As 70 52.5m
As 71 64h
As 72 26h
As73 76d
As 74 17.7d
Ge 72.59
Ge 65
Ge 66 2.4h
Ge 67 9.1m
Ge 68 287d
Ge 69
Ge 70 20.5
Ge 71 11d
Ge 72 27.4
Ge73
28
30
32
34
36
38
40

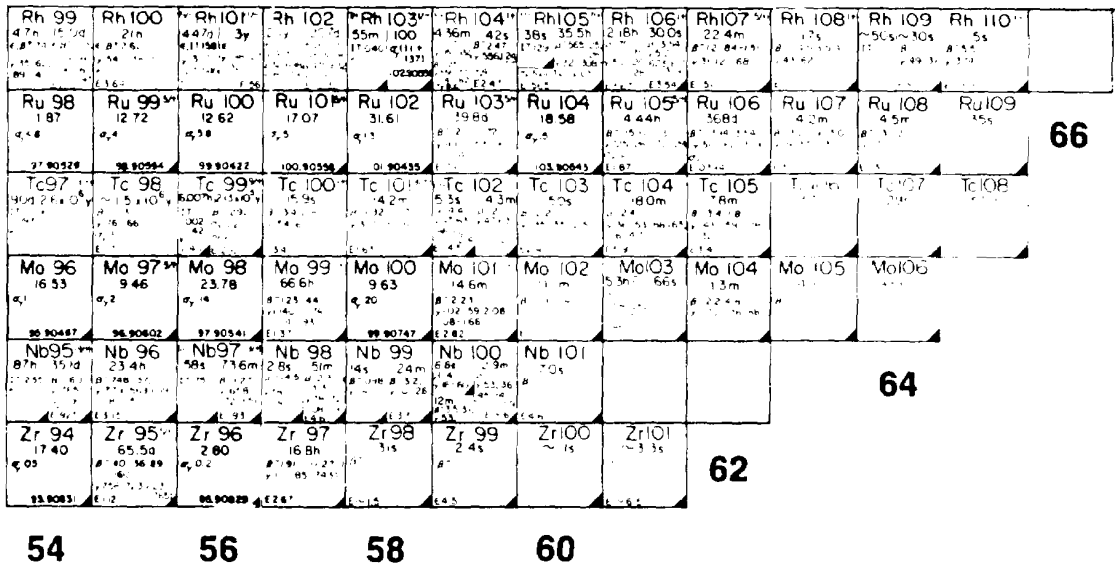

Zr 87 1.6h
Zr 88 85d
Zr 89 4.20m 78.4h
Zr 90 0.80s 51.45
Zr 91 11.23
Zr 92 17.11
Zr 93 9.5 x 10³y
Zr 94 17.40
Zr 95 65.5d
Zr 96 2.80
Zr 97 16.8h
Zr98 31s
Zr 99 2.4s
Zr100 ~1s
Zr101 ~3.3s
Y 86 14.6h
Y 87 13h 80h
Y 88 0.30ms 106.6d
Y 89 15.7s 100
Y 90 3.19h 64.0h
Y 91 60.5m 58.8d
Y 92 3.53h
Y 93 10.2h
Y 94 20.3m
Y 95 10.5m
Y 96 2.3m
Y97 1.11s
Y99 ~0.8s
Sr85 70m 64.7d
Sr 86 9.87
Sr 87 2.83h 7.04
Sr 88 82.53
Sr 89 50.8d
Sr 90 28.9y
Sr 91 9.67h
Sr 92 2.69h
Sr 93 7.5m
Sr 94 1.29m
Sr 95 26s
Sr96 4.0s
Sr97 ~0.4s
Rb 84 33.0d 20m
Rb 85 72.15
Rb 86 18.66d 1.00m
Rb 87 27.85 5.02 x 10¹⁰y
Rb 88 17.7m
Rb 89 15.2m
Rb 90 4.28m 2.7m
Rb 91 57.9s
Rb 92 4.48s
Rb 93 5.87s
Rb 94 2.67s
Rb 95 0.36s
Rb96 0.23s
Rb97 14s
Kr 83 11.55
Kr 84 56.90
Kr 85 4.4h 10.74y
Kr 86 17.37
Kr 87 76m
Kr 88 2.79h
Kr 89 3.18m
Kr 90 32.3s
Kr 91 8.6s
Kr 92 1.84s
Kr 93 1.29s
Kr 94 1s
Kr 95 Short
Br 82 6.1m 35.4h
Br 83 2.40h
Br 84 6.0m 31.8m
Br85 3.0m
Br 86 54s
Br 87 55.6s
Br 88 16s
Br 89 4.5s
Br 90 1.6s
Se81 57m 18m
Se 82 9.19
Se83 69s 23m
Se 84 3.2m
Se 85 39s
Se86 ≥16s
Se 87 5.8s
48
50
52
54
56
58
60

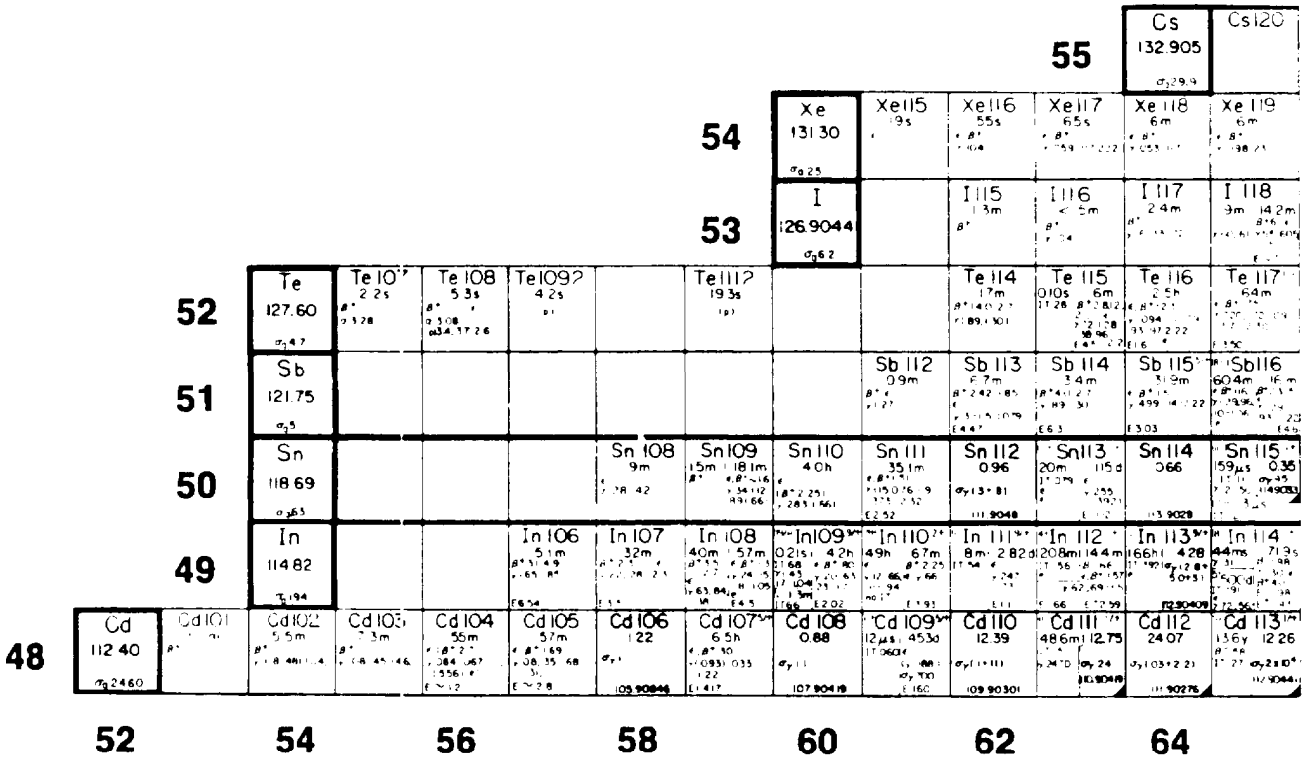

Se 76 9.02
Se 77 7.58
Se 78 23.52
Se 79 3.9m ≥6.5x10⁴y
Se 80 49.82
Se81 57m 18m
Se 82 9.19
Se83 69s 1.23m
Se 84 3.2m
Se 85 39s
Se86 ≥16s
Se 87 5.8s
As 75 100
As 76 26.4h
As77 38.8h
As 78 1.52h
As79 9.0m
As 80 15s
As 81 32s
As82 15s
As83 14s
As84 5.8s
As 85 2.1s
As86
As87 <1.5s
Ge 74 36.5
Ge75 82.8m
Ge 76 7.8
Ge 77
Ge 78
Ge 79
42
44
46
48
50
52
54

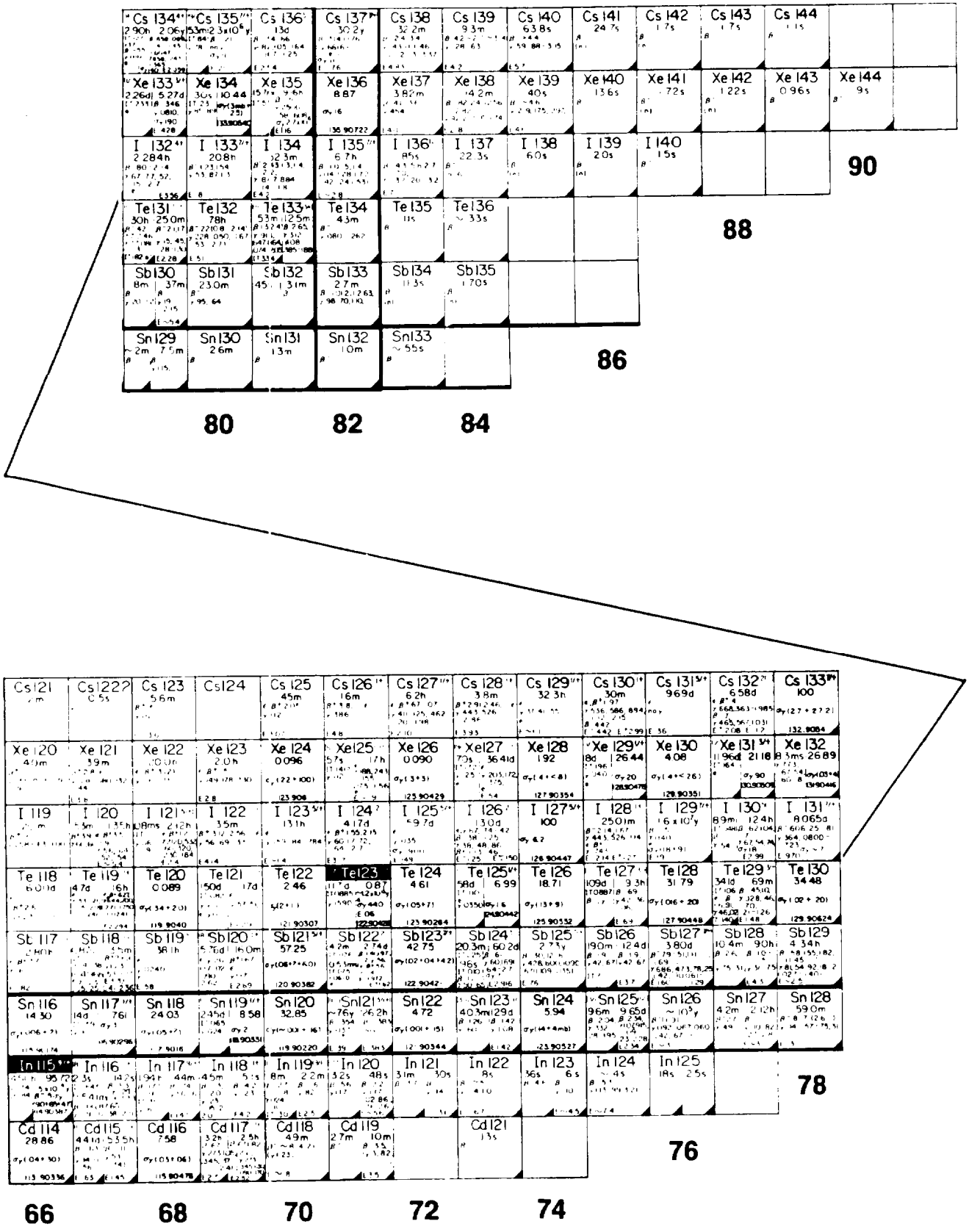

48
47
46
45
Cd 112.40
Ag 107.868
Pd 106.4
Rh 102.905
Cd101
Cd102
Cd103
Cd104
Cd105
Cd106 1.22
Cd107
Cd 108 0.88
Ag99 1.8m
Ag 100 8m
Ag101 10.8m
Ag 102 8m 14m
Ag103
Ag 104
Ag 105 41 Cd
Ag 106 8.4d 24.1m
Ag 107 44s 51.82
Pd 98 17.5m
Pd 99 23m
Pd 100 3.7d
Pd 101 8.3h
Pd 102 0.96
Pd103 17d
Pd 104 10.97
Pd 105 22.23
Pd 106 27.33
Rh95 4.8m
Rh96
Rh 97 33m
Rh 98 ~3m 8.7m
Rh 99 4.7h 15.0d
Rh 100 21h
Rh101 447d 3y
Rh 102 2.1y 207d
Rh 103 55m 100
Rh 104 4.36m 42s
Rh105 38s 35.5h
48
50
52
54
56
58
60

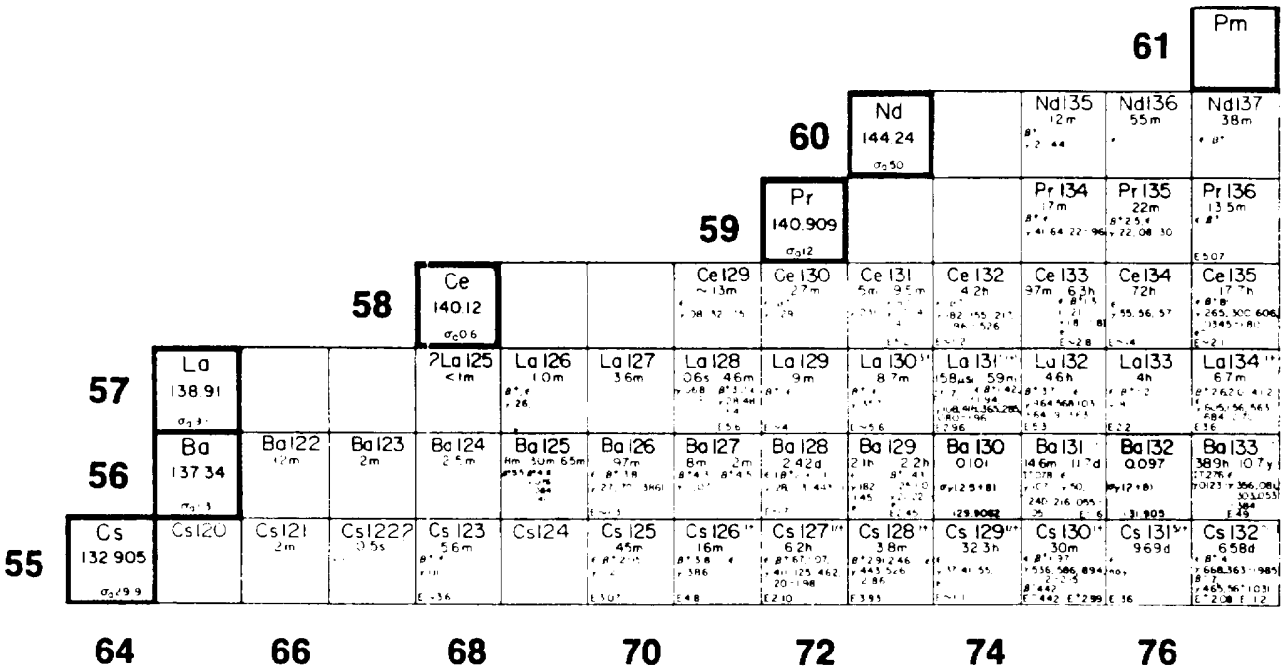

45
44
43
42
41
40
Rh 102.905
Ru 101.07
Tc
Mo 95.94
Nb 92.906
Zr 91.22
Rh95 4.8m
Rh96
Rh 97 33m
Rh 98 ~3m 8.7m
Ru 93
Ru 94 52m
Ru 95 1.65h
Ru 96 5.51
Ru 97 1.8ms 2.89d
Tc 92 4.4m
Tc93
Tc 94 52m 4.8h
Tc 95 61d 20.0h
Tc 96 52m 4.3d
Mo 88? 27m
Mo 89? 7m
Mo 90 5.7h
Mo91 65s 15.49m
Mo 92 15.84
Mo93 6.9h
Mo 94 9.04
Mo 95 15.72
Nb 88 14m
Nb89
Nb90
Nb 91 62d long
Nb 92 1013d >350y
Nb93 13.6y 100
Nb 94 6.26m 20.3x10^4y
Zr 81
Zr 82
Zr 83
Zr 84
Zr 85 1.4h
Zr 86 16.5h
Zr 87 1.6h
Zr 88 85d
Zr 89 4.20m 78.4h
Zr 90 0.80s 51.46
Zr 91 11.23
Zr 92 17.11
Zr 93 9.5 x 10^5y
40
42
44
46
48
50
52

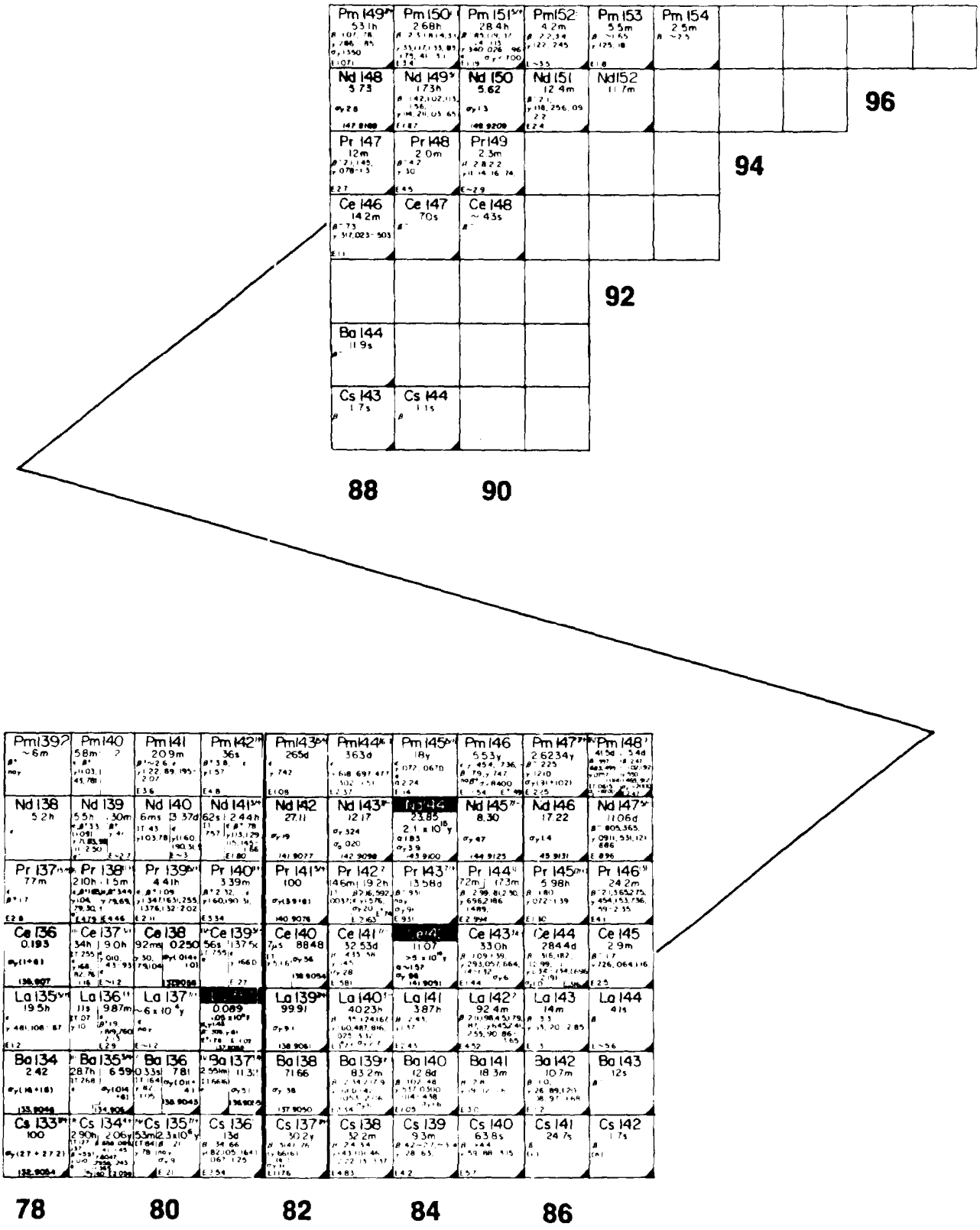

Cd 109
Cd 110
12.39
Cd 111
12.75
Cd 112
24.07
Cd 113
12.26
Cd 114
28.86
Cd 115
Cd 116
7.58
Cd 117
Cd 118
49m
Cd 119
27m
10m
Cd 121
Ag 108
Ag 109
48.18
Ag 110
Ag 111
Ag 112
Ag 113
Ag 114
Ag 115
Ag 116
Ag 117
Ag 118
Ag 119
Pd 107
Pd 108
26.71
Pd 109
Pd 110
Pd 111
Pd 112
Pd 113
Pd 114
Pd 115
Pd 117
Pd 118
Rh 106
Rh 107
Rh 108
Rh 109
Rh 110
74
68
70
72
62
64
66

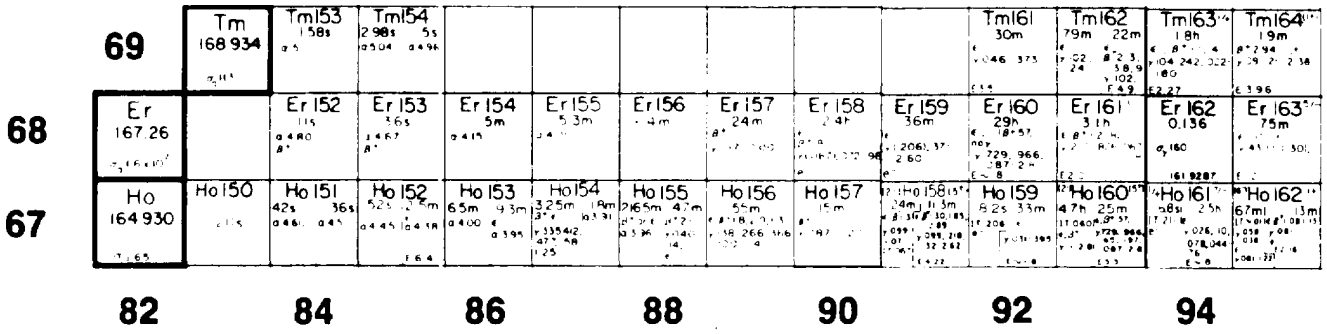

Rh 99
Rh 100
Rh 101
Rh 102
Rh 103
Rh 104
Rh 105
Rh 106
Rh 107
Rh 108
Rh 109
Rh 110
Ru 98
Ru 99
12.72
Ru 100
12.62
Ru 101
17.07
Ru 102
31.61
Ru 103
39.80
Ru 104
18.58
Ru 105
4.44h
Ru 106
368.2
Ru 107
4.2m
Ru 108
4.5m
Ru 109
Tc 97
Tc 98
Tc 99
Tc 100
Tc 101
Tc 102
Tc 103
Tc 104
18.0m
Tc 105
Tc 107
Tc 108
Mo 96
16.53
Mo 97
9.46
Mo 98
23.78
Mo 99
66.6h
Mo 100
9.63
Mo 101
14.6m
Mo 102
Mo 103
Mo 104
1.3m
Mo 105
Mo 106
Nb 95
Nb 96
23.4h
Nb 97
Nb 98
Nb 99
Nb 100
Nb 101
Zr 94
17.40
Zr 95
65.5d
Zr 96
2.80
Zr 97
16.8h
Zr 98
Zr 99
Zr 100
Zr 101
66
64
62
54
56
58
60

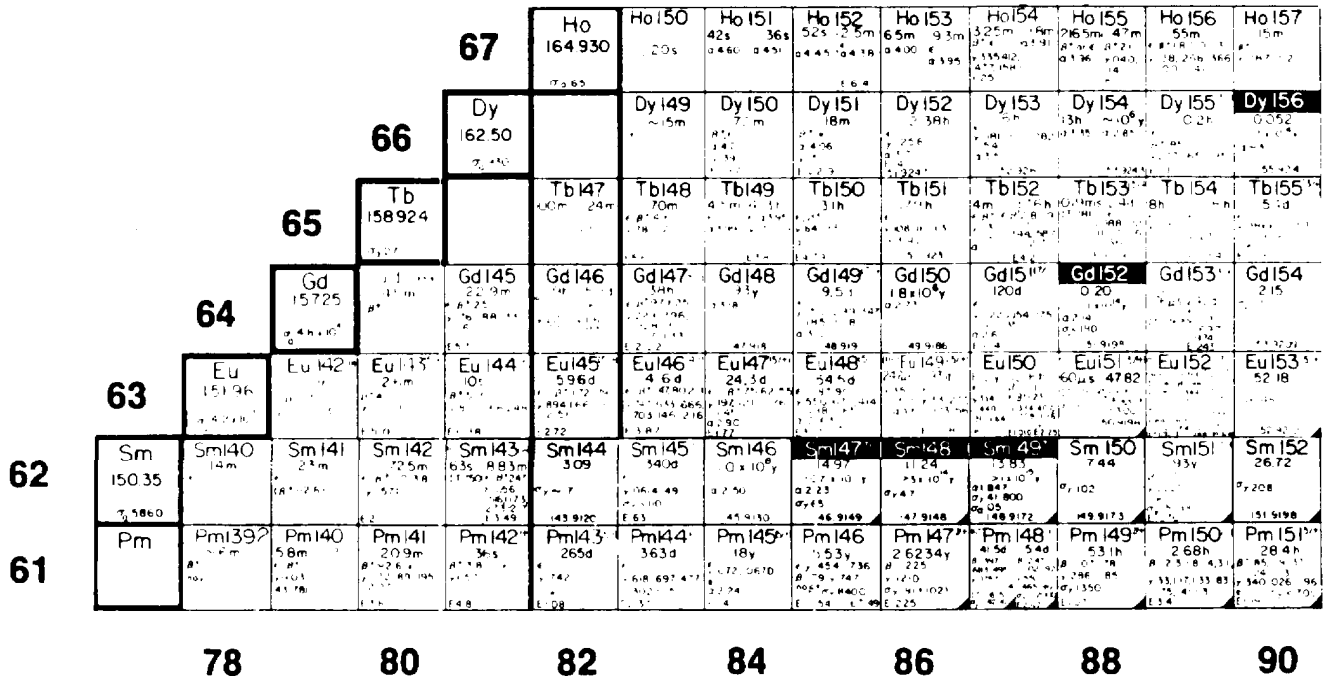

55
Cs 132.905
Cs120
54
Xe 131.30
Xe115 19s
Xe116 55s
Xe117 65s
Xe118 6m
Xe119 6m
53
I 126.9044
I115 1.3m
I116 <5m
I117 2.4m
I118 9m 14.2m
52
Te 127.60
Te107 2.2s
Te108 5.3s
Te109? 4.2s
Te111? 19.3s
Te114 17m
Te115 0.10s 6m
Te116 2.5h
Te117 64m
51
Sb 121.75
Sb112 0.9m
Sb113 6.7m
Sb114 3.4m
Sb115 31.9m
Sb116 60.4m 16m
50
Sn 118.69
Sn108 9m
Sn109 15m 18.1m
Sn110 4.0h
Sn111 35.1m
Sn112 0.96
Sn113 20m 115d
Sn114 0.66
Sn115 159μs 0.35
49
In 114.82
In106 5.1m
In107 32m
In108 40m 57m
In109 0.21s 4.2h
In110 49h 67m
In111 8m 2.82d
In112 208m 14.4m
In113 166h 4.28
In114 44ms 71.9s
48
Cd 112.40
Cd101
Cd102 5.5m
Cd103 7.3m
Cd104 55m
Cd105 57m
Cd106 1.22
Cd107 6.5h
Cd108 0.88
Cd109 12μs 453d
Cd110 12.39
Cd111 48.6m 12.75
Cd112 24.07
Cd113 13.6y 12.26
52
54
56
58
60
62
64

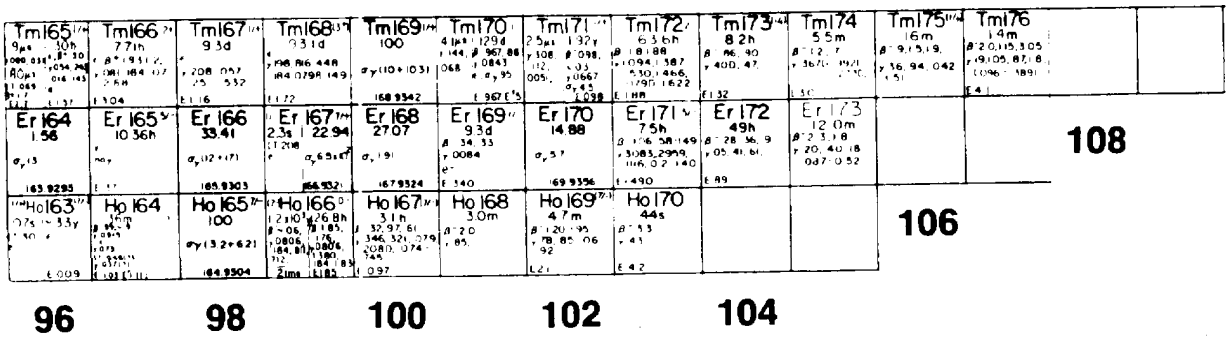

Cs 134
Cs 135
Cs 136
Cs 137
Cs 138
Cs 139
Cs 140
Cs 141
Cs 142
Cs 143
Cs 144
Xe 133
Xe 134
Xe 135
Xe 136
Xe 137
Xe 138
Xe 139
Xe 140
Xe 141
Xe 142
Xe 143
Xe 144
I 132
I 133
I 134
I 135
I 136
I 137
I 138
I 139
I 140
Te 131
Te 132
Te 133
Te 134
Te 135
Te 136
Sb 130
Sb 131
Sb 132
Sb 133
Sb 134
Sb 135
Sn 129
Sn 130
Sn 131
Sn 132
Sn 133
80
82
84
86
88
90
Cs 121
Cs 122
Cs 123
Cs 124
Cs 125
Cs 126
Cs 127
Cs 128
Cs 129
Cs 130
Cs 131
Cs 132
Cs 133
Xe 120
Xe 121
Xe 122
Xe 123
Xe 124
Xe 125
Xe 126
Xe 127
Xe 128
Xe 129
Xe 130
Xe 131
Xe 132
I 119
I 120
I 121
I 122
I 123
I 124
I 125
I 126
I 127
I 128
I 129
I 130
I 131
Te 118
Te 119
Te 120
Te 121
Te 122
Te 123
Te 124
Te 125
Te 126
Te 127
Te 128
Te 129
Te 130
Sb 117
Sb 118
Sb 119
Sb 120
Sb 121
Sb 122
Sb 123
Sb 124
Sb 125
Sb 126
Sb 127
Sb 128
Sb 129
Sn 116
Sn 117
Sn 118
Sn 119
Sn 120
Sn 121
Sn 122
Sn 123
Sn 124
Sn 125
Sn 126
Sn 127
Sn 128
In 115
In 116
In 117
In 118
In 119
In 120
In 121
In 122
In 123
In 124
In 125
Cd 114
Cd 115
Cd 116
Cd 117
Cd 118
Cd 119
Cd 121
66
68
70
72
74
76
78

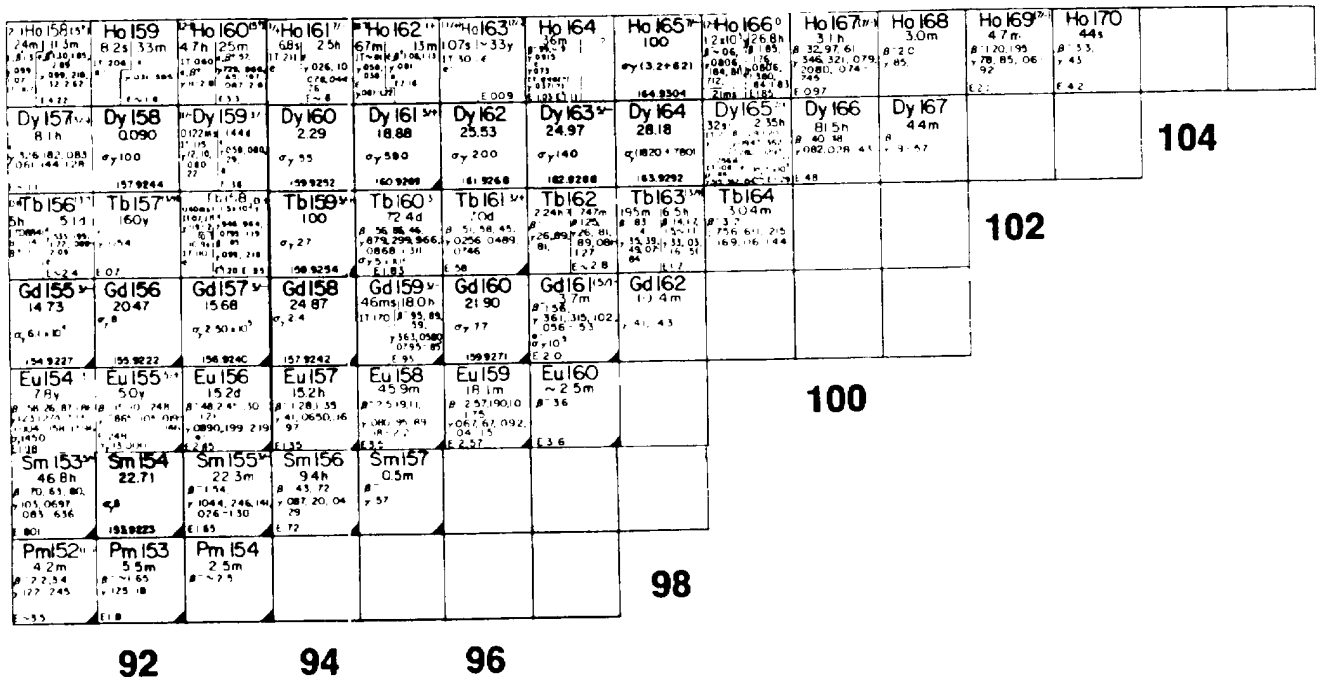

61
Pm
60
Nd
144.24
59
Pr
140.909
58
Ce
140.12
57
La
138.91
56
Ba
137.34
55
Cs
132.905
64
66
68
70
72
74
76

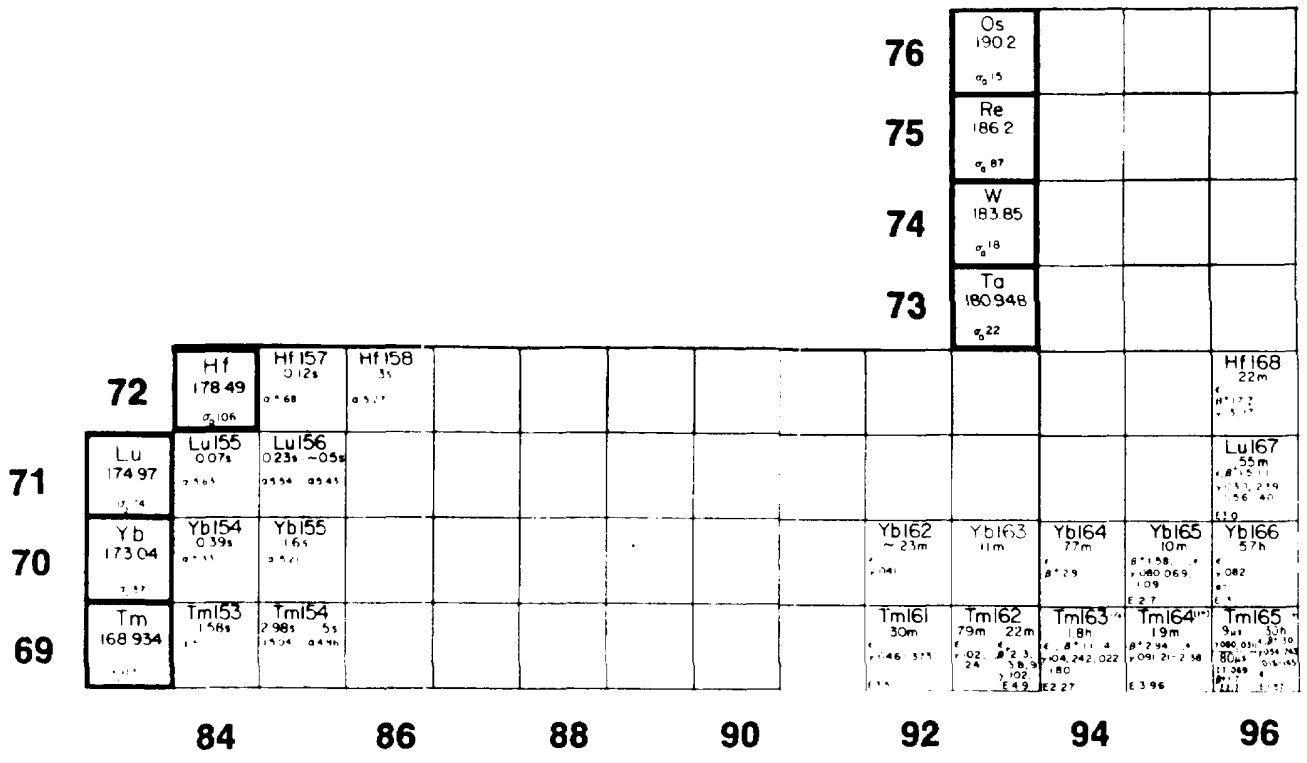

Pm 149
53 1h
Pm 150
2 68h
Pm 151
28 4h
Pm152
4 2m
Pm 153
5 5m
Pm 154
2 5m
Nd 148
5 73
Nd 149
1 73h
Nd 150
5 62
Nd 151
12 4m
Nd152
11 7m
96
Pr 147
12m
Pr 148
2 0m
Pr149
2 3m
94
Ce 146
14 2m
Ce 147
70s
Ce 148
~ 43s
92
Ba 144
11 9s
Cs 143
1 7s
Cs 144
1 1s
88
90
Pm139
~6m
Pm140
5 8m
Pm 141
20 9m
Pm 142
36s
Pm143
265d
Pm144
363d
Pm 145
18y
Pm 146
5 53y
Pm 147
2 6234y
Pm 148
41 3d
Nd 138
5 2h
Nd 139
5 5h
30m
Nd 140
6 ms
3 37d
Nd 141
62s
2 44h
Nd 142
27 11
Nd 143
12 17
Nd 144
23 85
2 1 x 10^15 y
Nd 145
8 30
Nd 146
17 22
Nd 147
11 06d
Pr 137
77m
Pr 138
210h
1 5m
Pr 139
4 41h
Pr 140
3 39m
Pr 141
100
Pr 142
19 2h
Pr 143
13 58d
Pr 144
17 3m
Pr 145
5 98h
Pr 146
24 2m
Ce 136
0 193
Ce 137
34h
9 0h
Ce 138
0 250
Ce 139
137 5x
Ce 140
8848
Ce 141
32 53d
Ce 142
11 07
>5 x 10^16 y
Ce 143
33 0h
Ce 144
284 4d
Ce 145
2 9m
La 135
19 5h
La 136
9 87m
La 137
~6 x 10^4 y
0 089
La 139
99 91
La 140
40 23h
La 141
3 87h
La 142
92 4m
La 143
14m
La 144
4 1s
Ba 134
2 42
Ba 135
28 7h
6 59h
Ba 136
0 33s
7 81
Ba 137
2 55m
11 3
Ba 138
71 66
Ba 139
83 2m
Ba 140
12 8d
Ba 141
18 3m
Ba 142
10 7m
Ba 143
12s
Cs 133
100
Cs 134
2 90h
2 06y
Cs 135
53m
2 3 x 10^6 y
Cs 136
13d
Cs 137
30 2y
Cs 138
32 2m
Cs 139
9 3m
Cs 140
63 8s
Cs 141
24 7s
Cs 142
1 7s
78
80
82
84
86

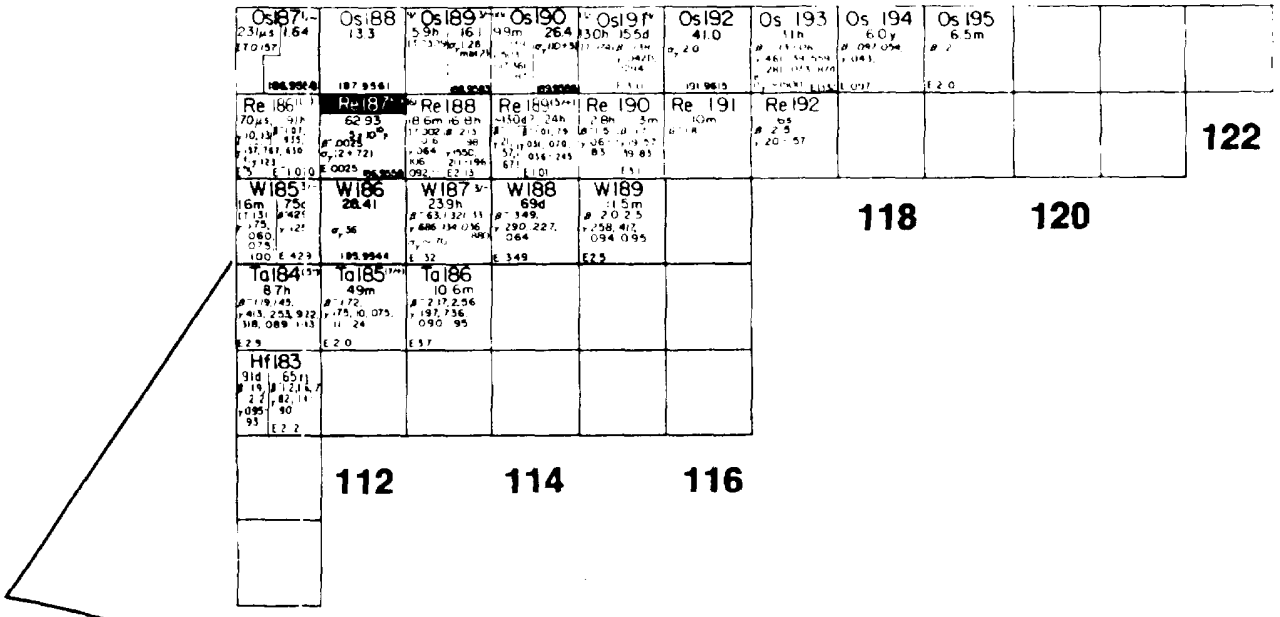

69
68
67
Tm 168.934
Er 167.26
Ho 164.930
Tm153 1.58s
Tm154 2.98s 5s
Er 152 11s
Er 153 3.6s
Er 154 5m
Er 155 5.3m
Er 156 ~4m
Er 157 24m
Er 158 2.4h
Er 159 36m
Er 160 29h
Er 161 3.1h
Er 162 0.136
Er 163 75m
Tm161 30m
Tm162 79m 22m
Tm163 1.8h
Tm164 1.9m
Ho150
Ho 151 42s 36s
Ho 152 5.2s 2.5m
Ho 153 6.5m 9.3m
Ho 154 3.25m 1.8m
Ho 155 2.65m 47m
Ho 156 55m
Ho 157 15m
Ho 158 24m 11.3m
Ho 159 6.25 33m
Ho 160 47h 25m
Ho 161 ≈8h 2.5h
Ho 162 67m 15m
82
84
86
88
90
92
94

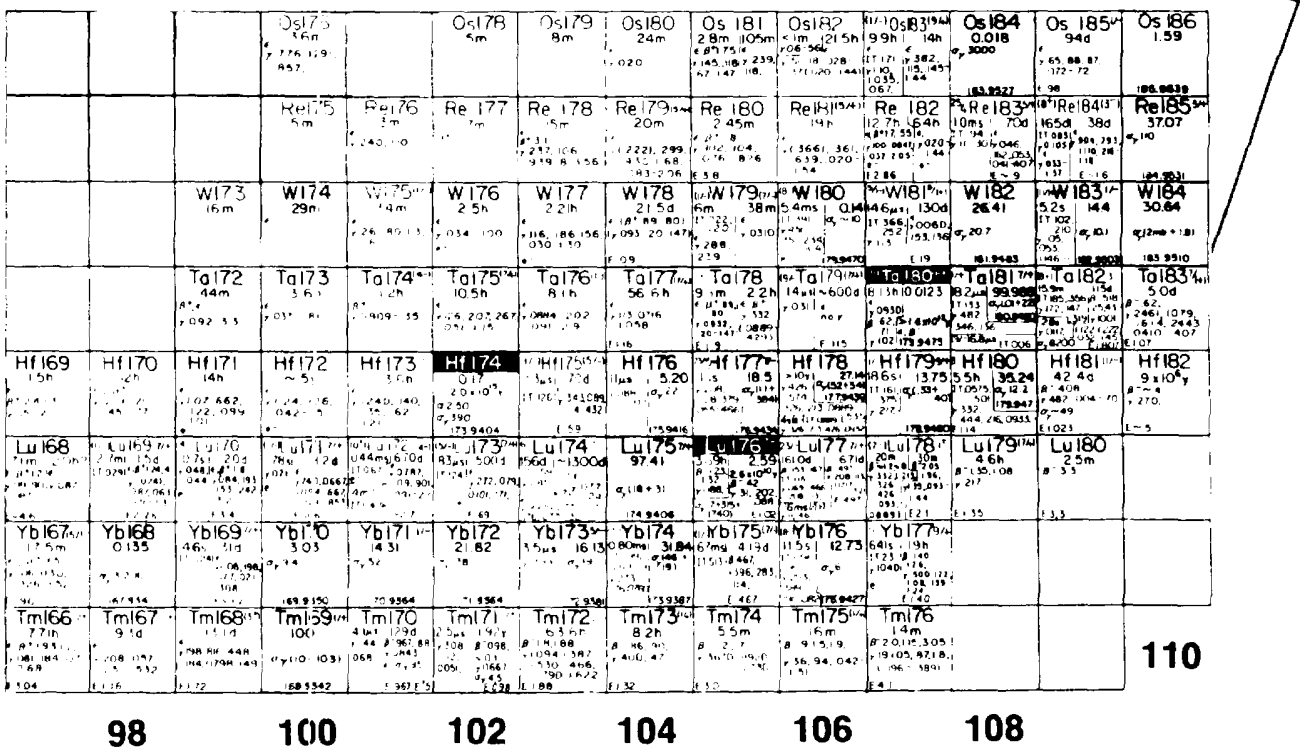

67
66
65
64
63
62
61
Ho 164.930
Dy 162.50
Tb 158.924
Gd 157.25
Eu 151.96
Sm 150.35
Pm
Ho150 29s
Ho151 42s 36s
Ho152 5.2s 2.5m
Ho153 6.5m 9.3m
Ho154 3.25m 1.8m
Ho155 2.65m 47m
Ho156 55m
Ho157 15m
Dy149 ~15m
Dy150 7m
Dy151 18m
Dy152 2.38h
Dy153 6h
Dy154 3h ~10^6 y
Dy155 0.2h
Dy156 0.052
Tb147 24m
Tb148 70m
Tb149 4.1h
Tb150 3.1h
Tb151 17.6h
Tb152 4m
Tb153 2.1d
Tb154 21.8h
Tb155 5.3d
Gd145 22.9m
Gd146 48.6d
Gd147 38h
Gd148 93y
Gd149 9.5d
Gd150 1.8x10^6 y
Gd151 120d
Gd152 0.20
Gd153 240d
Gd154 2.15
Eu142 2.4s
Eu143 2.6m
Eu144 10s
Eu145 5.96d
Eu146 4.6d
Eu147 24.5d
Eu148 54.5d
Eu149 93.1d
Eu150
Eu151 60μs 47.82
Eu152
Eu153 52.18
Sm140 14m
Sm141 23m
Sm142 72.5m
Sm143 6.6s 8.83m
Sm144 3.09
Sm145 340d
Sm146 0.9x10^8 y
Sm147 1.49
Sm148 1.24x10^15 y
Sm149 1.9x10^8 y
Sm150 7.44
Sm151 93y
Sm152 26.72
Pm139? 4m
Pm140 5.8m
Pm141 20.9m
Pm142 39.5s
Pm143 265d
Pm144 363d
Pm145 18y
Pm146 5.53y
Pm147 2.6234y
Pm148 5.4d
Pm149 53.1h
Pm150 2.68h
Pm151 28.4h
78
80
82
84
86
88
90

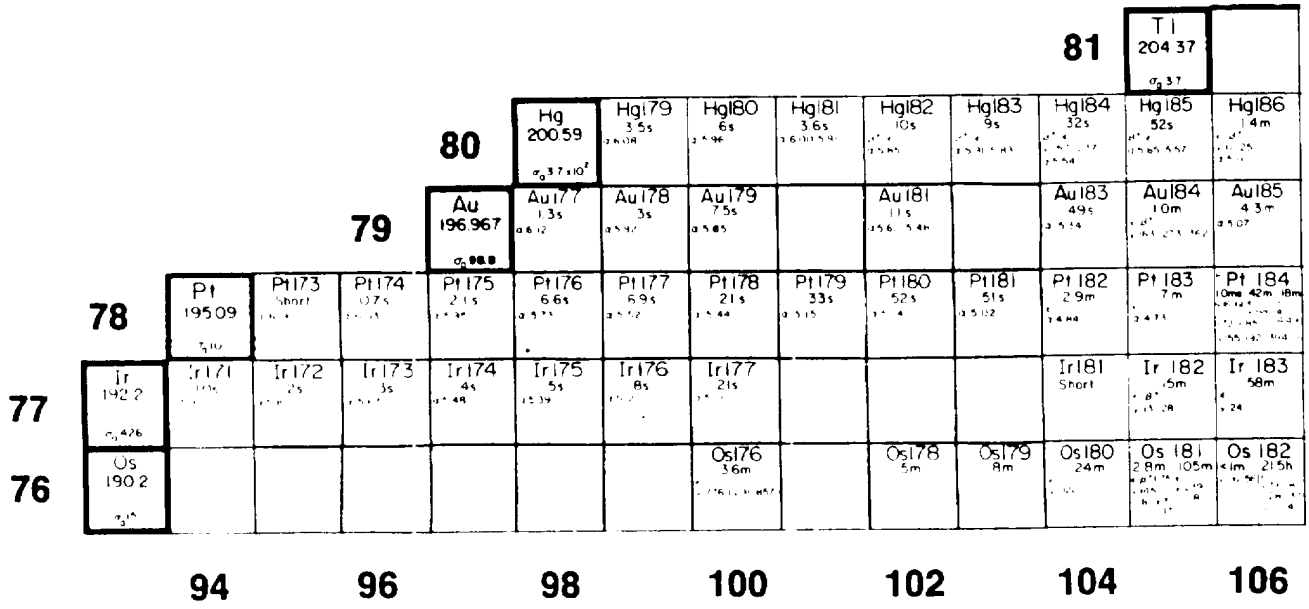

Tm165
Tm166
Tm167
Tm168
Tm169
Tm170
Tm171
Tm172
Tm173
Tm174
Tm175
Tm176
Er164
Er165
Er166
Er167
Er168
Er169
Er170
Er171
Er172
Er173
Ho163
Ho164
Ho165
Ho166
Ho167
Ho168
Ho169
Ho170
108
106
96
98
100
102
104

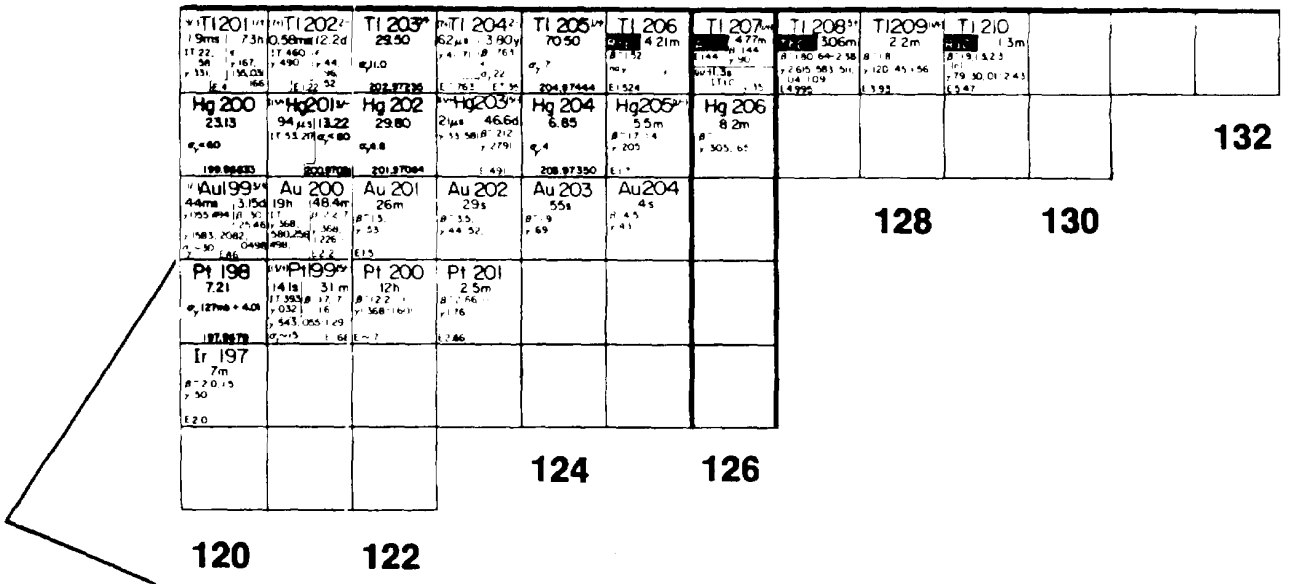

Ho158
Ho159
Ho160
Ho161
Ho162
Ho163
Ho164
Ho165
Ho166
Ho167
Ho168
Ho169
Ho170
Dy157
Dy158
Dy159
Dy160
Dy161
Dy162
Dy163
Dy164
Dy165
Dy166
Dy167
Tb156
Tb157
Tb159
Tb160
Tb161
Tb162
Tb163
Tb164
Gd155
Gd156
Gd157
Gd158
Gd159
Gd160
Gd161
Gd162
Eu154
Eu155
Eu156
Eu157
Eu158
Eu159
Eu160
Sm153
Sm154
Sm155
Sm156
Sm157
Pm152
Pm153
Pm154
104
102
100
98
92
94
96

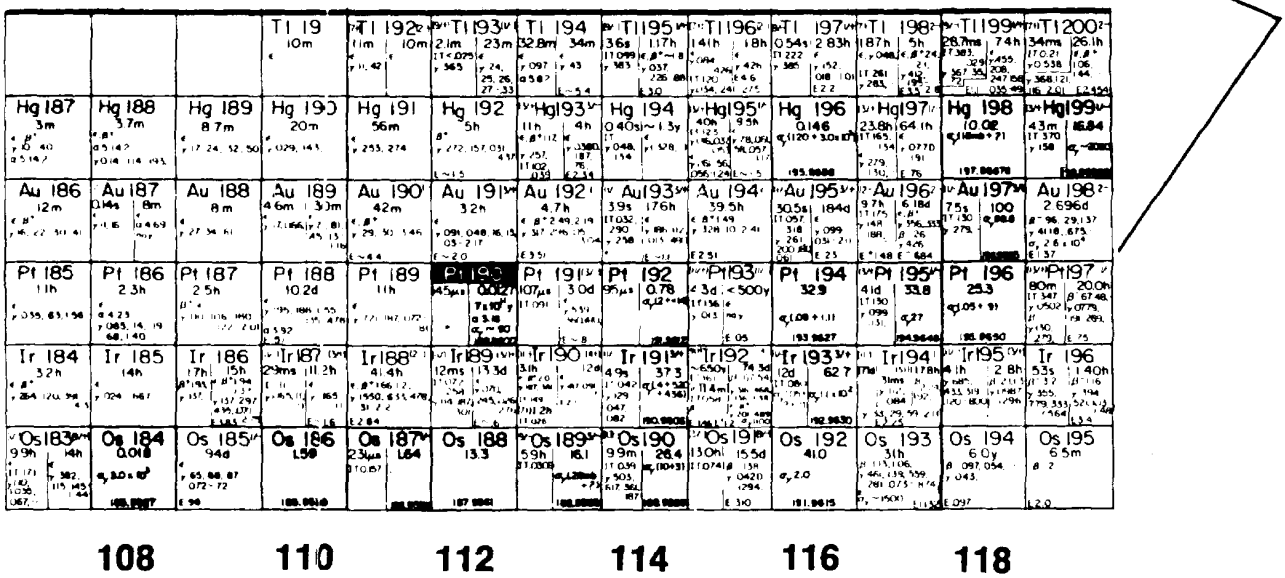

76
75
74
73
72
71
70
69
Os 190.2
Re 186.2
W 183.85
Ta 180.948
Hf 178.49
Lu 174.97
Yb 173.04
Tm 168.934
Hf157
Hf158
Hf168 22m
Lu155 0.07s
Lu156
Lu167 55m
Yb154 0.39s
Yb155
Yb162 ~23m
Yb163 11m
Yb164 77m
Yb165 10m
Yb166 57h
Tm153 1.58s
Tm154 2.98s
Tm161 30m
Tm162 79m 22m
Tm163 1.8h
Tm164 1.9m
Tm165 30h
84
86
88
90
92
94
96

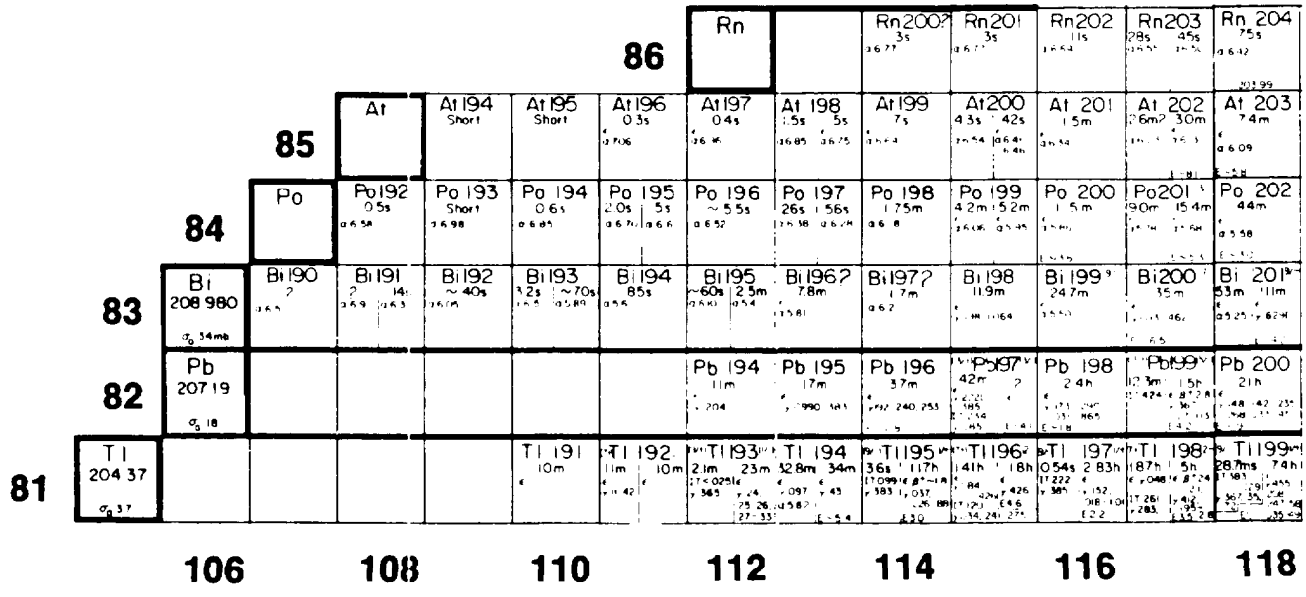

Os187
Os188
Os189
Os190
Os191
Os192
41.0
Os 193
Os 194
Os 195
6.5m
Re 186
Re 187
62.93
Re 188
Re 189
Re 190
Re 191
Re 192
W185
W186
28.41
W187
239h
W188
69d
W189
Ta184
8.7h
Ta185
49m
Ta186
10.6m
Hf183
91d
112
114
116
118
120
122

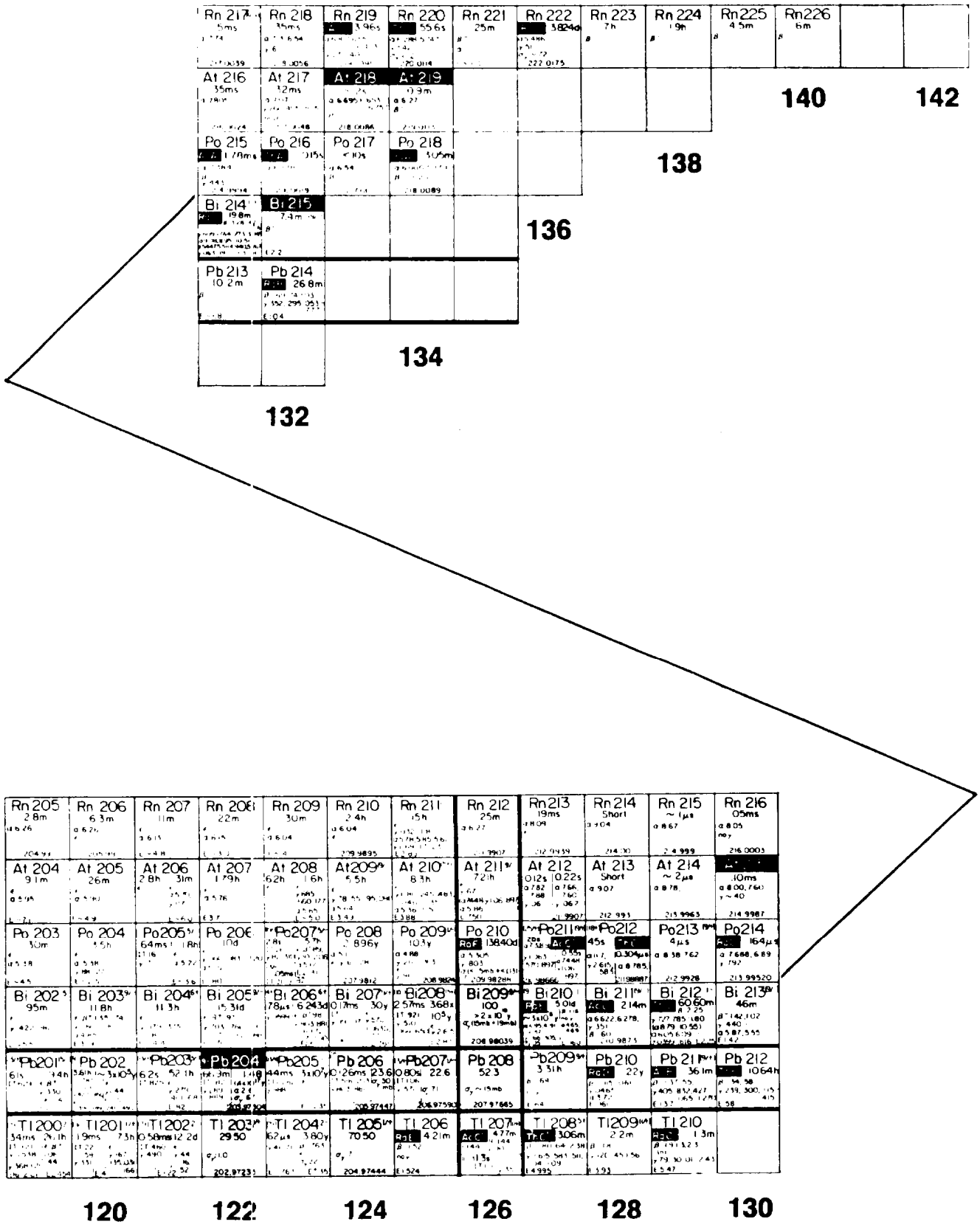

Os175
Os178
Os179
Os180
Os 181
Os182
Os183
Os184
0.018
Os 185
Os 186
1.59
Re175
Re176
Re 177
Re 178
Re179
Re 180
Re181
Re 182
Re183
Re184
Re185
37.07
W173
W174
29m
W175
W176
2.5h
W177
W178
21.5d
W179
W180
W181
W182
26.41
W183
W184
30.64
Ta172
44m
Ta173
Ta174
Ta175
10.5h
Ta176
8.1h
Ta177
56.6h
Ta178
Ta179
Ta180
Ta181
Ta182
Ta183
5.0d
Hf169
Hf170
Hf171
Hf172
Hf173
Hf174
Hf175
Hf176
Hf177
Hf178
Hf179
Hf180
Hf181
42.4d
Hf182
Lu168
Lu169
Lu170
Lu171
Lu172
Lu173
Lu174
Lu175
97.41
Lu176
Lu177
Lu178
Lu179
4.6h
Lu180
2.5m
Yb167
Yb168
0.135
Yb169
Yb170
3.03
Yb171
Yb172
Yb173
Yb174
Yb175
Yb176
Yb177
Tm166
Tm167
Tm168
Tm169
Tm170
Tm171
Tm172
Tm173
Tm174
Tm175
Tm176
98
100
102
104
106
108
110

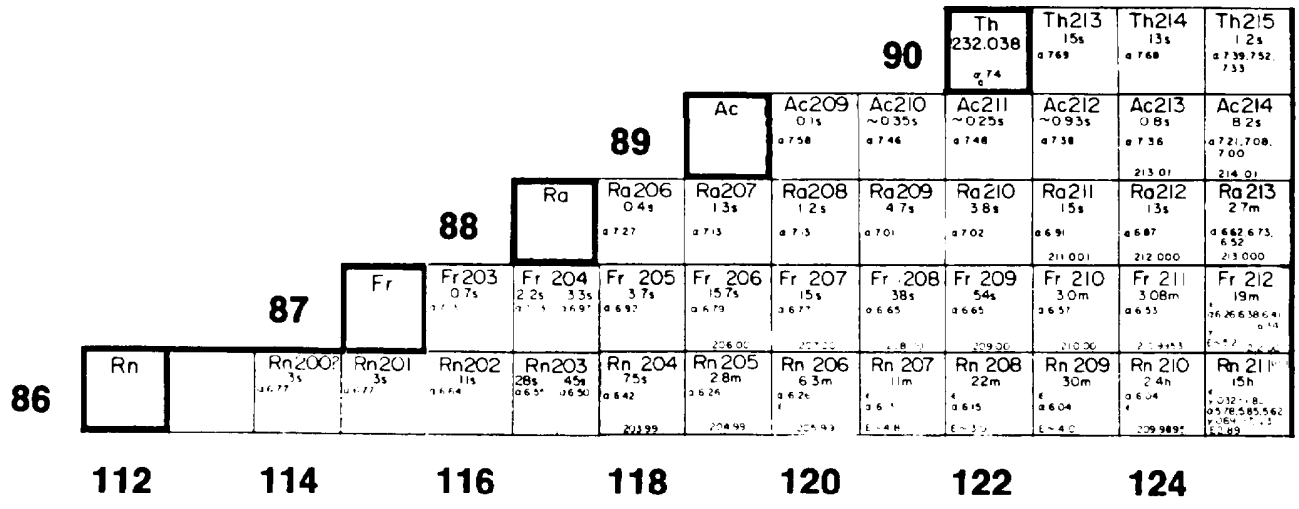

81
Tl 204.37
80
Hg 200.59
Hg179 3.5s
Hg180 6s
Hg181 3.6s
Hg182 10s
Hg183 9s
Hg184 32s
Hg185 52s
Hg186 1.4m
79
Au 196.967
Au177 1.3s
Au178 3s
Au179 7.5s
Au181 11s
Au183 49s
Au184 1.0m
Au185 4.3m
78
Pt 195.09
Pt173 Short
Pt174 0.7s
Pt175 2.1s
Pt176 6.6s
Pt177 6.9s
Pt178 21s
Pt179 33s
Pt180 52s
Pt181 51s
Pt182 2.9m
Pt183 7m
Pt 184
77
Ir 192.2
Ir171
Ir172 2s
Ir173 3s
Ir174 4s
Ir175 5s
Ir176 8s
Ir177 21s
Ir181 Short
Ir 182 15m
Ir 183 58m
76
Os 190.2
Os176 3.6m
Os178 5m
Os179 8m
Os180 24m
Os 181 2.8m 105m
Os 182 <1m 21.5h
94
96
98
100
102
104
106

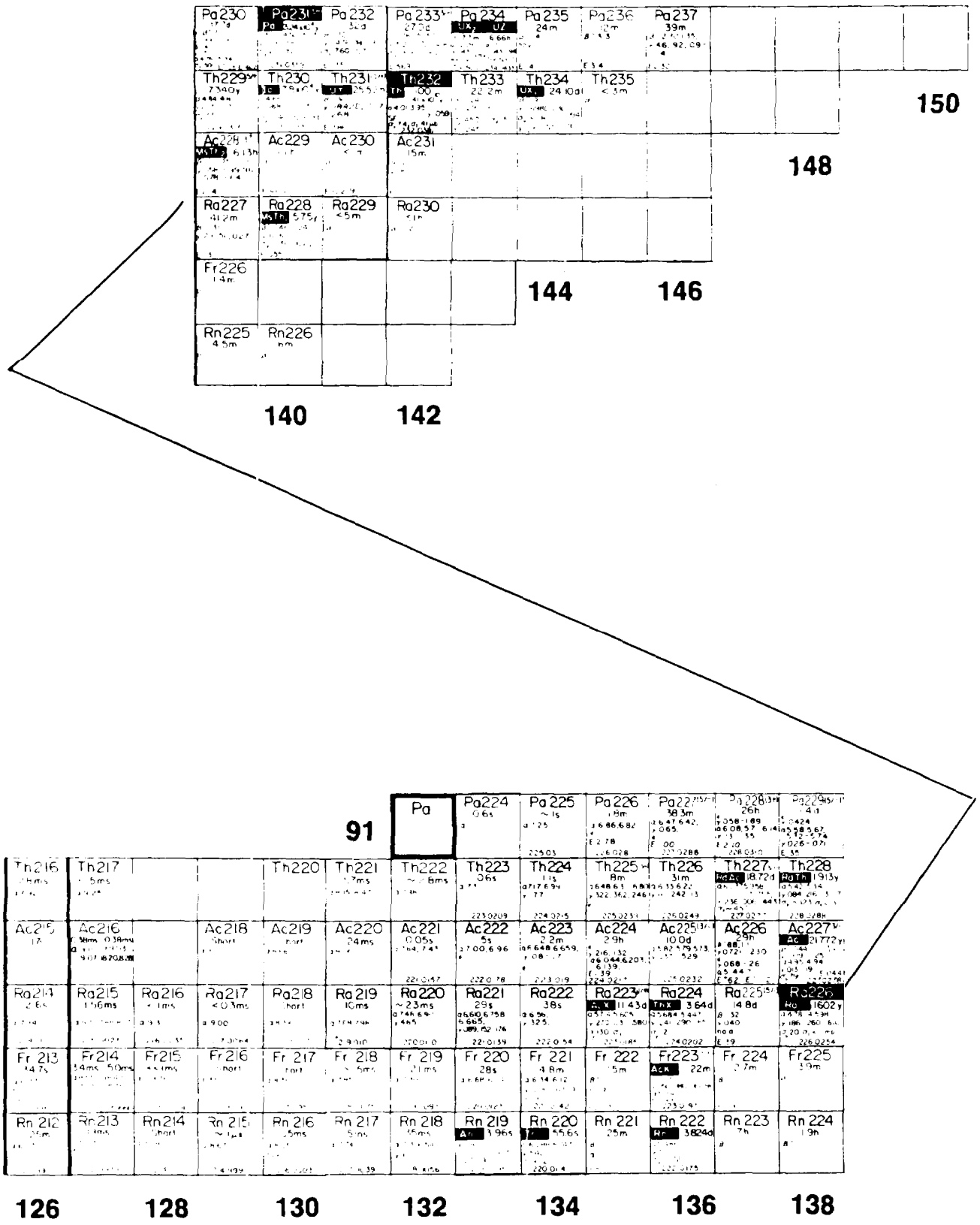

Tl 201
Tl 202
Tl 203
Tl 204
Tl 205
Tl 206
Tl 207
Tl 208
Tl 209
Tl 210
Hg 200
Hg 201
Hg 202
Hg 203
Hg 204
Hg 205
Hg 206
Au 199
Au 200
Au 201
Au 202
Au 203
Au 204
Pt 198
Pt 199
Pt 200
Pt 201
Ir 197
120
122
124
126
128
130
132

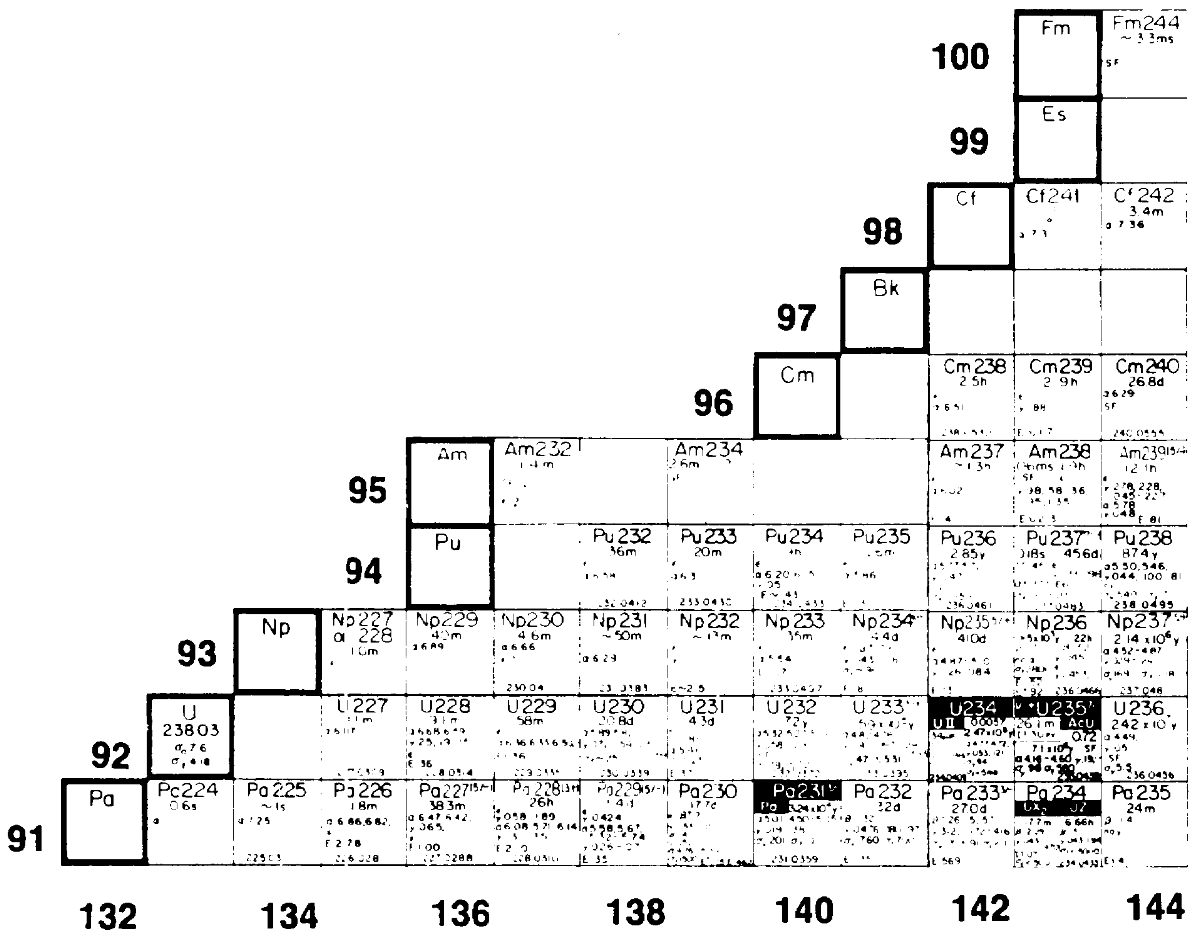

Tl 19
Tl 192
Tl 193
Tl 194
Tl 195
Tl 196
Tl 197
Tl 198
Tl 199
Tl 200
Hg 187
Hg 188
Hg 189
Hg 190
Hg 191
Hg 192
Hg 193
Hg 194
Hg 195
Hg 196
Hg 197
Hg 198
Hg 199
Au 186
Au 187
Au 188
Au 189
Au 190
Au 191
Au 192
Au 193
Au 194
Au 195
Au 196
Au 197
Au 198
Pt 185
Pt 186
Pt 187
Pt 188
Pt 189
Pt 190
Pt 191
Pt 192
Pt 193
Pt 194
Pt 195
Pt 196
Pt 197
Ir 184
Ir 185
Ir 186
Ir 187
Ir 188
Ir 189
Ir 190
Ir 191
Ir 192
Ir 193
Ir 194
Ir 195
Ir 196
Os 183
Os 184
Os 185
Os 186
Os 187
Os 188
Os 189
Os 190
Os 191
Os 192
Os 193
Os 194
Os 195
108
110
112
114
116
118

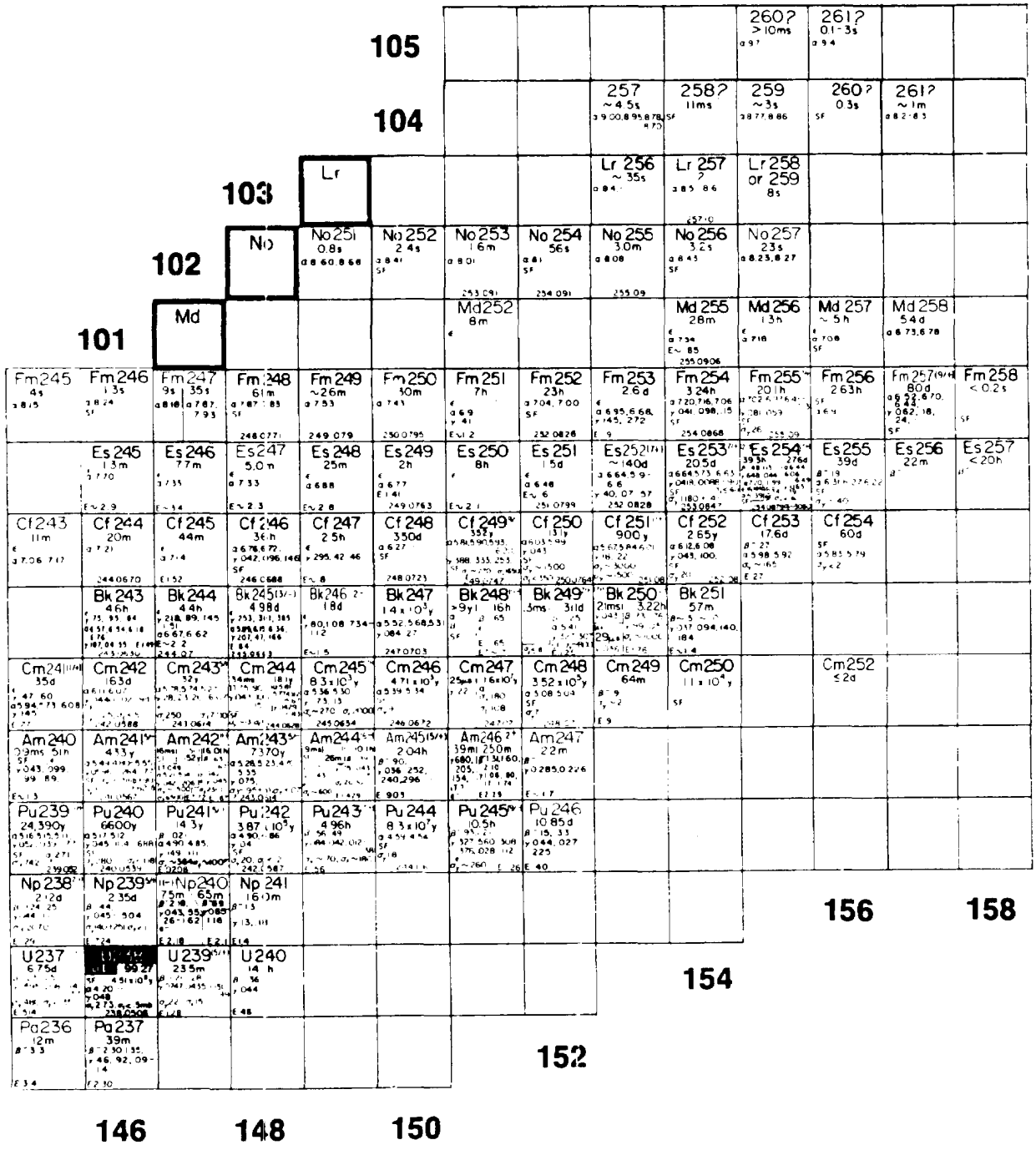

86
Rn
Rn200? 3s
Rn201 3s
Rn202 11s
Rn203 28s 45s
Rn 204 75s
85
At
At194 Short
At195 Short
At196 0.3s
At197 0.4s
At 198 1.5s 5s
At199 7s
At200 4.3s 42s
At 201 1.5m
At 202 6m? 30m
At 203 7.4m
84
Po
Po192 0.5s
Po 193 Short
Po 194 0.6s
Po 195 2.0s 5s
Po 196 ~5.5s
Po 197 26s 1.56s
Po 198 1.75m
Po 199 4.2m 5.2m
Po 200 1.5m
Po201 90m 15.4m
Po 202 44m
83
Bi 208 980
Bi190 ?
Bi191 ? 14s
Bi192 ~40s
Bi193 3.2s ~70s
Bi194 85s
Bi195 ~60s 2.5m
Bi196? 7.8m
Bi197? 1.7m
Bi198 11.9m
Bi199 ? 24.7m
Bi200 35m
Bi 201 53m 11m
82
Pb 207 19
Pb 194 11m
Pb 195 17m
Pb 196 37m
Pb197 42m ?
Pb 198 2.4h
Pb199 2.3m 1.5h
Pb 200 21h
81
Tl 204 37
Tl 191 10m
Tl 192 11m 10m
Tl193 2.1m 23m
Tl 194 32.8m 34m
Tl195 36s 1.17h
Tl196 1.41h 1.8h
Tl 197 0.54s 2.83h
Tl 198 1.87h 5h
Tl199 28.7ms 7.4h
106
108
110
112
114
116
118


Rn 217
5ms
Rn 218
35ms
Rn 219
3.96s
Rn 220
55.6s
Rn 221
25m
Rn 222
3.824d
Rn 223
7h
Rn 224
1.9h
Rn225
4.5m
Rn226
6m
At 216
35ms
At 217
32ms
At 218
At 219
0.9m
Po 215
Po 216
Po 217
<10s
Po 218
Bi 214
19.8m
Bi 215
7.4m
Pb 213
10.2m
Pb 214
26.8m
132
134
136
138
140
142
Rn 205
2.8m
Rn 206
6.3m
Rn 207
11m
Rn 208
22m
Rn 209
30m
Rn 210
2.4h
Rn 211
15h
Rn 212
25m
Rn 213
19ms
Rn 214
Short
Rn 215
~1μs
Rn 216
0.5ms
At 204
9.1m
At 205
26m
At 206
2.8h
31m
At 207
1.79h
At 208
1.62h
1.6h
At209
5.5h
At 210
8.3h
At 211
7.21h
At 212
0.12s
0.22s
At 213
Short
At 214
~2μs
10ms
Po 203
50m
Po 204
4.5h
Po205
64ms
1.8h
Po 206
10d
Po207
Po 208
0.896y
Po 209
103y
Po 210
RaF
138.40d
Po211
0.5s
Po212
45s
0.304μs
Po213
4μs
Po214
164μs
Bi 202
95m
Bi 203
11.8h
Bi 204
11.3h
Bi 205
15.31d
Bi 206
78μs
6.243d
Bi 207
0.17ms
30y
Bi208
2.57ms
368x
10^5y
Bi 209
100
Bi 210
5.01d
Bi 211
2.14m
Bi 212
60.60m
Bi 213
46m
Pb201
6.1s
3.4h
Pb 202
3.61h
~3x10^5y
Pb203
6.2s
52.1h
Pb 204
1.4m
Pb205
44ms
5x10^7y
Pb 206
0.26ms
23.6
Pb207
0.80s
22.6
Pb 208
52.3
Pb209
3.51h
Pb 210
RaG
22y
Pb 211
36.1m
Pb 212
10.64h
Tl200
54ms
Tl201
1.9ms
7.3h
Tl202
0.58ms
12.2d
Tl 203
29.50
Tl 204
62μs
3.80y
Tl 205
70.50
Tl 206
RaE
4.21m
Tl 207
ActC
4.77m
Tl 208
ThC
3.06m
Tl209
2.2m
Tl 210
RaC
1.3m
120
122
124
126
128
130


90
Th 232.038
Th213 15s
Th214 13s
Th215 1.2s
89
Ac
Ac209 0.1s
Ac210 ~0.35s
Ac211 ~0.25s
Ac212 ~0.93s
Ac213 0.8s
Ac214 8.2s
88
Ra
Ra206 0.4s
Ra207 1.3s
Ra208 1.2s
Ra209 4.7s
Ra210 3.8s
Ra211 15s
Ra212 13s
Ra213 2.7m
87
Fr
Fr203 0.7s
Fr 204 2.2s 3.3s
Fr 205 3.7s
Fr 206 15.7s
Fr 207 15s
Fr 208 38s
Fr 209 54s
Fr 210 3.0m
Fr 211 3.08m
Fr 212 19m
86
Rn
Rn200? 3s
Rn201 3s
Rn202 11s
Rn203 28s 45s
Rn 204 7.5s
Rn 205 2.8m
Rn 206 6.3m
Rn 207 11m
Rn 208 22m
Rn 209 30m
Rn 210 2.4h
Rn 211 15h
112
114
116
118
120
122
124


Pa230
Pa231
Pa232
Pa233
Pa234
Pa235
Pa236
Pa237
Th229
Th230
Th231
Th232
Th233
Th234
Th235
Ac228
Ac229
Ac230
Ac231
Ra227
Ra228
Ra229
Ra230
Fr226
Rn225
Rn226
150
148
144
146
140
142
91
Pa
Pa224
Pa225
Pa226
Pa227
Pa228
Pa229
Th216
Th217
Th220
Th221
Th222
Th223
Th224
Th225
Th226
Th227
Th228
Ac215
Ac216
Ac218
Ac219
Ac220
Ac221
Ac222
Ac223
Ac224
Ac225
Ac226
Ac227
Ra214
Ra215
Ra216
Ra217
Ra218
Ra219
Ra220
Ra221
Ra222
Ra223
Ra224
Ra225
Ra226
Fr 213
Fr214
Fr215
Fr216
Fr 217
Fr 218
Fr 219
Fr 220
Fr 221
Fr 222
Fr223
Fr 224
Fr225
Rn 212
Rn 213
Rn 214
Rn 215
Rn 216
Rn 217
Rn 218
Rn 219
Rn 220
Rn 221
Rn 222
Rn 223
Rn 224
126
128
130
132
134
136
138


100
99
98
97
96
95
94
93
92
91
Fm
Es
Cf
Bk
Cm
Am
Pu
Np
U
Pa
132
134
136
138
140
142
144


105
104
103
102
101
Lr
No
Md
260?
>10ms
261?
0.1-3s
257
~4.5s
258?
11ms
259
~3s
260?
0.3s
261?
~1m
Lr 256
~35s
Lr 257
?
Lr 258
or 259
8s
No 251
0.8s
No 252
2.4s
No 253
1.6m
No 254
56s
No 255
3.0m
No 256
3.2s
No 257
23s
Md252
8m
Md 255
28m
Md 256
1.3h
Md 257
~5h
Md 258
54d
Fm245
4s
Fm246
1.3s
Fm247
9s
35s
Fm248
61m
Fm249
~26m
Fm250
30m
Fm251
7h
Fm252
23h
Fm253
2.6d
Fm254
3.24h
Fm255
20.1h
Fm256
2.63h
Fm257
80d
Fm258
<0.2s
Es245
1.3m
Es246
7.7m
Es247
5.0m
Es248
25m
Es249
2h
Es250
8h
Es251
1.5d
Es252
~140d
Es253
20.5d
Es254
Es255
39d
Es256
22m
Es257
<20h
Cf243
11m
Cf244
20m
Cf245
44m
Cf246
36h
Cf247
2.5h
Cf248
350d
Cf249
Cf250
13y
Cf251
900y
Cf252
2.65y
Cf253
17.6d
Cf254
60d
Bk243
4.6h
Bk244
4.4h
Bk245
4.98d
Bk246
1.8d
Bk247
1.4x10³y
Bk248
>9y
16h
Bk249
330d
Bk250
3.22h
Bk251
57m
Cm241
35d
Cm242
163d
Cm243
Cm244
Cm245
8.3x10³y
Cm246
4.71x10³y
Cm247
1.6x10⁷y
Cm248
3.52x10⁵y
Cm249
64m
Cm250
1.1x10⁴y
Cm252
≤2d
Am240
29ms
Am241
433y
Am242
Am243
7370y
Am244
Am245
2.04h
Am246
39ml
Am247
22m
Pu239
24,390y
Pu240
6600y
Pu241
14.3y
Pu242
3.87x10⁵y
Pu243
4.96h
Pu244
8.3x10⁷y
Pu245
10.5h
Pu246
10.85d
Np238
2.12d
Np239
2.35d
Np240
7.5m
65m
Np241
16.0m
U237
6.75d
U239
23.5m
U240
14 h
Pa236
12m
Pa237
39m
146
148
150
152
154
156
158

LIST OF ATOMIC ELEMENTS

Actinium	Ac	89
Aluminum	Al	13
Americium	Am	95
Antimony	Sb	51
Argon	Ar	18
Arsenic	As	33
Astatine	At	85
Barium	Ba	56
Berkelium	Bk	97
Beryllium	Be	4
Bismuth	Bi	83
Boron	B	5
Bromine	Br	35
Cadmium	Cd	48
Calcium	Ca	20
Californium	Cf	98
Carbon	C	6
Cerium	Ce	58
Cesium	Cs	55
Chlorine	Cl	17
Chromium	Cr	24
Cobalt	Co	27
Copper	Cu	29
Curium	Cm	96
Dysprosium	Dy	66
Einsteinium	Es	99
Erbium	Er	68
Europium	Eu	63
Fermium	Fm	100
Fluorine	F	9
Francium	Fr	87
Gadolinium	Gd	64
Gallium	Ga	31
Germanium	Ge	32
Gold	Au	79
Hafnium	Hf	72
Helium	He	2
Holmium	Ho	67
Hydrogen	H	1
Indium	In	49
Iodine	I	53
Iridium	Ir	77
Iron	Fe	26
Krypton	Kr	36
Lanthanum	La	57
Lawrencium	Lw	103
Lead	Pb	82
Lithium	Li	3
Lutetium	Lu	71
Magnesium	Mg	12
Manganese	Mn	25
Mendelevium	Md	101
Mercury	Hg	80
Molybdenum	Mo	42
Neodymium	Nd	60
Neon	Ne	10
Neptunium	Np	93
Nickel	Ni	28
Niobium	Nb	41
Nitrogen	N	7
Nobelium	No	102
Osmium	Os	76
Oxygen	O	8
Palladium	Pd	46
Phosphorus	P	15
Platinum	Pt	78
Plutonium	Pu	94
Polonium	Po	84
Potassium	K	19
Praseodymium	Pr	59
Promethium	Pm	61
Protactinium	Pa	91
Radium	Ra	88
Radon	Rn	86
Rhenium	Re	75
Rhodium	Rh	45
Rubidium	Rb	37
Ruthenium	Ru	44
Samarium	Sm	62
Scandium	Sc	21
Selenium	Se	34
Silicon	Si	14
Silver	Ag	47
Sodium	Na	11
Strontium	Sr	38
Sulfur	S	16
Tantalum	Ta	73
Technetium	Tc	43
Tellurium	Te	52
Terbium	Tb	65
Thallium	Tl	81
Thorium	Th	90
Thulium	Tm	69
Tin	Sn	50
Titanium	Ti	22
Tungsten	W	74
Uranium	U	92
Vanadium	V	23
Xenon	Xe	54
Ytterbium	Yb	70
Yttrium	Y	39
Zinc	Zn	30
Zirconium	Zr	40