PETROLEUM vs. PLUTONIUM*

By CLARK GOODMAN

INTRODUCTION

THE familiar saying "a little knowledge is a dangerous thing" is particularly apropos in the case of atomic energy. Following President Truman's announcement of the bombing of Hiroshima on August 6, 1945, the air was filled with radio reports. Virtually every newspaper and magazine in the country followed with feature articles on atomic power. These are continuing and, in addition, we are being exposed to a plague of books on the subject. In the sweep of publicity, the facts have often been ignored or hidden beneath a flood of over-enthusiastic extrapolation and speculation.

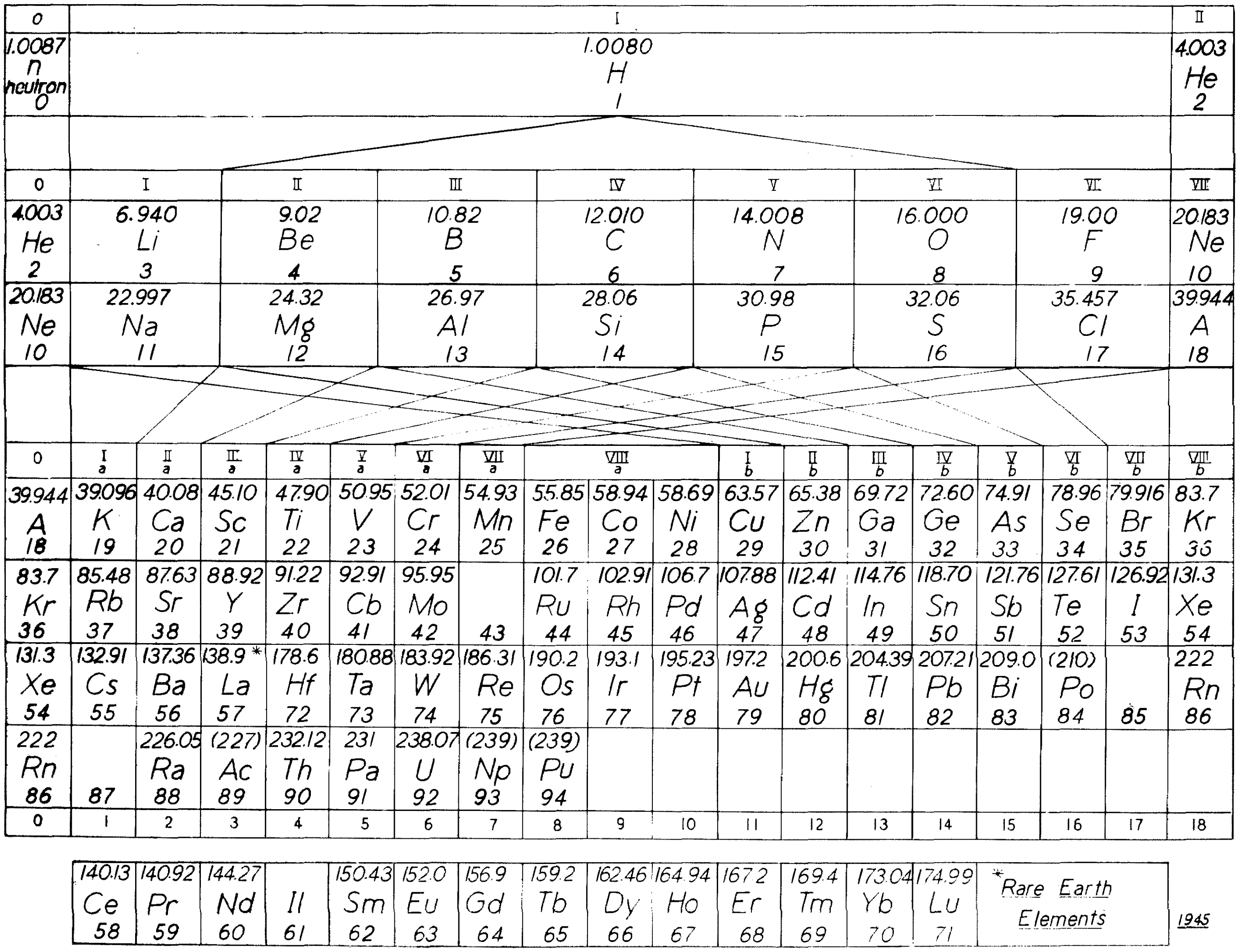
It seems particularly timely that an accurate evaluation be made of the present and future competition to petroleum of this new source of energy.

FUNDAMENTAL PRINCIPLES

The study of atomic energy constitutes part of the general field of nuclear physics. The first step in the understanding of atomic energy is a definition of the specialized words and symbols used.

Fig. 1 is only one of the various possible systematic arrangements of the elements that occur in nature, or have recently been produced. The elements are arranged in order of increasing atomic number, indicated by the figure immediately below the symbol of each element. Nuclear physicists think of the atomic number Z as the number of positively charged particles, called protons, contained in the core or nucleas of an atom of a given element.

A second important number in the periodic table is the atomic weight, listed just above the chemical symbol. The symbol A will be used for atomic weight. On this scale the lightest and simplest of elements, hydrogen, has an atomic weight of 1.0080. As $Z = 1$, hydrogen must contain only one proton in its nucleus. The single electron that swirls about this nucleus has a weight of only about 0.0005 units. Thus hydrogen nuclei are the charged particles, protons, that constitute building blocks in all nuclei, and the relative weight of each of these elementary particles before incorporation in such nuclei is 1.0075, *i.e.*, slightly greater than 1.



0	I	II
1.0087 n neutron 0	1.0080 H 1	4.003 He 2

0	I	II	III	IV	V	VI	VII	VIII
4.003 He 2	6.940 Li 3	9.02 Be 4	10.82 B 5	12.010 C 6	14.008 N 7	16.000 O 8	19.00 F 9	20.183 Ne 10
20.183 Ne 10	22.997 Na 11	24.32 Mg 12	26.97 Al 13	28.06 Si 14	30.98 P 15	32.06 S 16	35.457 Cl 17	39.944 A 18

0	I a	II a	III a	IV a	V a	VI a	VII a	VIII a			I b	II b	III b	IV b	V b	VI b	VII b	VIII b
39.944 A 18	39.096 K 19	40.08 Ca 20	45.10 Sc 21	47.90 Ti 22	50.95 V 23	52.01 Cr 24	54.93 Mn 25	55.85 Fe 26	58.94 Co 27	58.69 Ni 28	63.57 Cu 29	65.38 Zn 30	69.72 Ga 31	72.60 Ge 32	74.91 As 33	78.96 Se 34	79.916 Br 35	83.7 Kr 36
83.7 Kr 36	85.48 Rb 37	87.63 Sr 38	88.92 Y 39	91.22 Zr 40	92.91 Cb 41	95.95 Mo 42	43	101.7 Ru 44	102.91 Rh 45	106.7 Pd 46	107.88 Ag 47	112.41 Cd 48	114.76 In 49	118.70 Sn 50	121.76 Sb 51	127.61 Te 52	126.92 I 53	131.3 Xe 54
131.3 Xe 54	132.91 Cs 55	137.36 Ba 56	138.9 * La 57	178.6 Hf 72	180.88 Ta 73	183.92 W 74	186.31 Re 75	190.2 Os 76	193.1 Ir 77	195.23 Pt 78	197.2 Au 79	200.6 Hg 80	204.39 Tl 81	207.21 Pb 82	209.0 Bi 83	(210) Po 84	85	222 Rn 86
222 Rn 86	87	226.05 Ra 88	(227) Ac 89	232.12 Th 90	231 Pa 91	238.07 U 92	(239) Np 93	(239) Pu 94										
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

140.13 Ce 58	140.92 Pr 59	144.27 Nd 60	Il 61	150.43 Sm 62	152.0 Eu 63	156.9 Gd 64	159.2 Tb 65	162.46 Dy 66	164.94 Ho 67	167.2 Er 68	169.4 Tm 69	173.04 Yb 70	174.99 Lu 71	*Rare Earth Elements

1945

Fig. 1

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*Abstract of paper presented at General Session of the American Petroleum Institute, Chicago, Illinois, November 15, 1945.

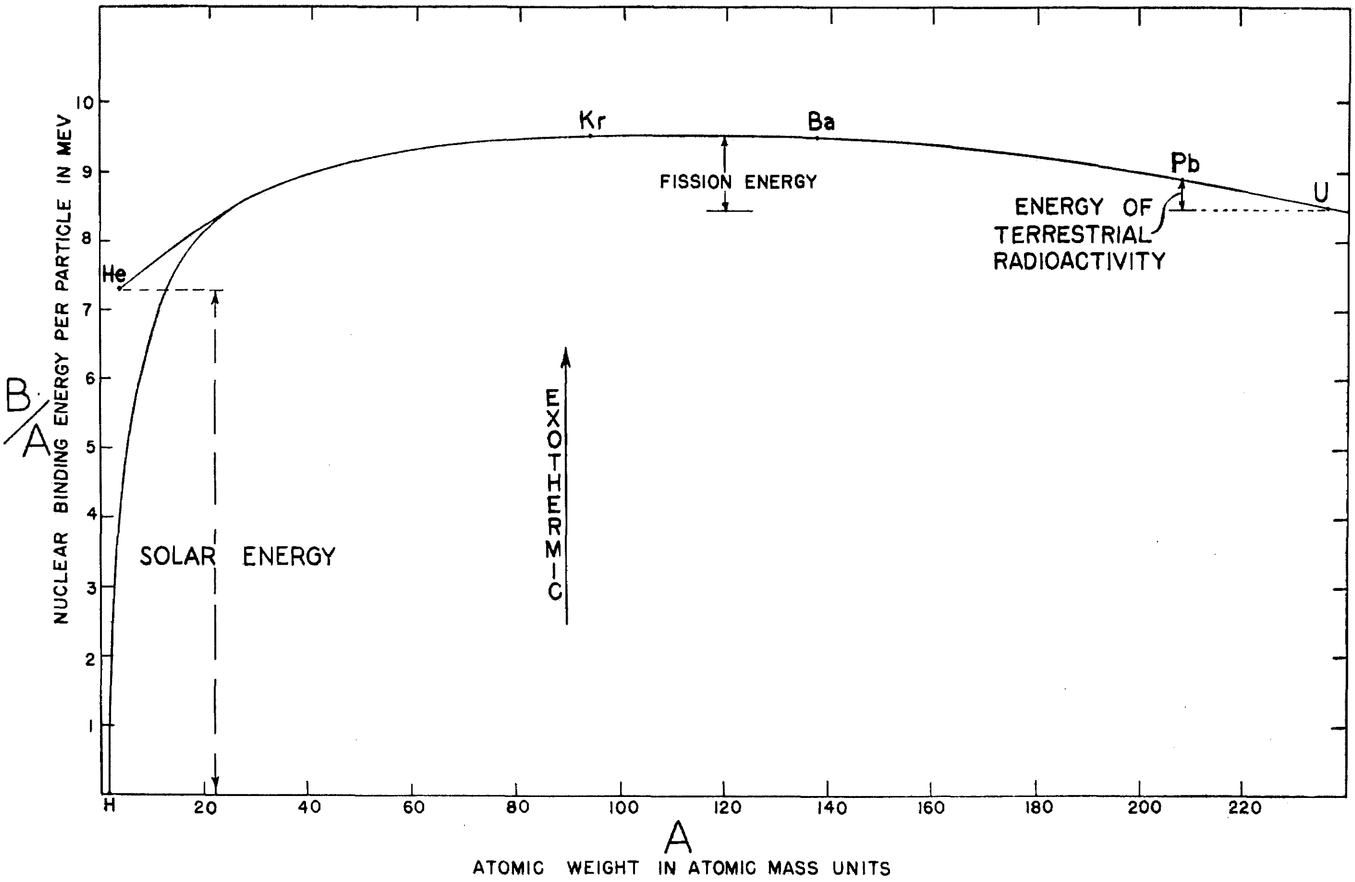


Fig. 2

The interlocking particles that bind the protons together, and prevent their flying apart by electrostatic repulsion, are electrically neutral, and for this reason are called neutrons. They have an atomic number zero and, relative to oxygen, a weight of 1.0087. All nuclei are considered to be made up of neutrons and protons only. However, for a given element, *i.e.*, a given *Z*, the number of neutrons present may vary somewhat. This variation, of course, results in different weights for the individual atoms of the element, even though they all have the same number of protons. The name "isotope" is given to such modifications of the same element. Even hydrogen is not simple. Common hydrogen, referred to above, has a single proton in its nucleus, but there is a rare form of hydrogen that has both a proton and a neutron in its nucleus. For obvious reasons, this is called heavy hydrogen (or deuterium), and water containing an unusually high proportion of this hydrogen is called heavy water. As we shall have occasion to note later, uranium consists of three isotopes, a common form with 92 protons and 146 neutrons known as

$$U^{238}$$

a rare variety with 92 protons and 143 neutrons known as

$$U^{235},$$

and a very rare form with 92 protons and 142 neutrons known alternately as

$$U^{234}$$

or UII. Naturally, with so many different isotopes present in various abundances, the average weight of a given element would not be expected to be a simple multiple of the weights of the constituent particles, the proton and the neutron. However, there is an additional explanation for the observed values of the atomic weights. *The weight of an aggregation of neutrons and protons is always less than the sum of the weights of the separate particles.* For example, the weight of two protons and two neutrons is $2 \times 1.0075 + 2 \times 1.0087 = 4.0324$, whereas the weight of helium (less two electrons) is seen from *Fig. 1* to be 4.0029. This decrease of about 0.03 weight units takes place when the four constitutent particles coalesce to form the helium nucleus. The nuclear reaction that expresses this fact can be written symbolically as:

$$2\,{}_1H^{1.0075} + 2\,{}_0n^{1.0087} \longrightarrow {}_2He^{4.0029} + 0.03 \text{ atomic-weight unit} \qquad (1)$$

Two fundamental axioms in physics require that the sum of the subscripts (charges) on the left must equal the sum on the right, and the sum of the weights on the left must equal the sum on the right. The coefficients in front of the symbols must, of course, be included in these considerations. In the foregoing equation, "0.03 atomic-weight unit" must appear on the right to balance the weight on the left.

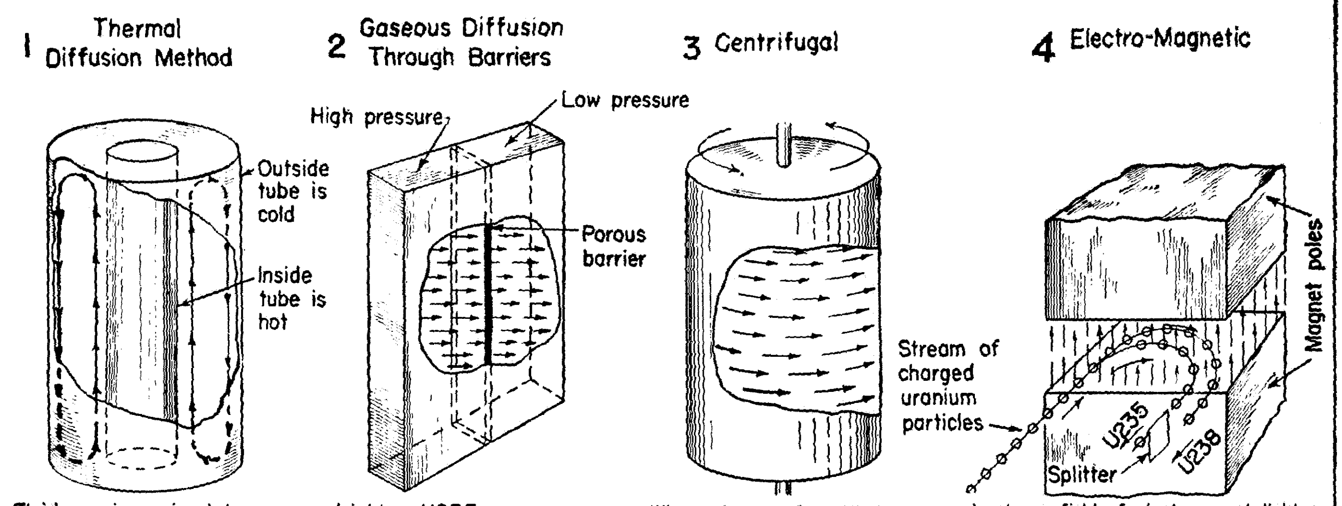
THE SOURCES OF ATOMIC ENERGY

Einstein postulated, and ample experimental evidence has since proved, that weight (or, more exactly, mass) and energy are equivalent and related by the simple expression:

$$\textit{Energy} = \textit{constant} \times \textit{mass} \qquad (2)$$

The proportionality constant in this relationship is so large that the production of a pound of helium from hydrogen + neutrons would liberate 29×10^{10} B.t.u. of heat energy. Alternately it would require the expenditure of this prodigious amount of energy to break one pound of helium into hydrogen and neutrons; *i.e.*, the helium nuclei are bound together with this amount of energy.

The formation of helium from elementary particles



Fluid uranium circulates, tends to concentrate lighter U235 at top.

Lighter U235 gas passes more readily through barrier.

When mixture of gasified U235 and U238 is spun rapidly, lighter U235 tends toward center

In strong field of giant magnet lighter U235 particles are deflected more than U238. Half way round, splitter separates two streams.

Fig. 3

symbolized above does *not* take place on the earth, because it requires very high temperatures. However, this reaction is believed to account for the tremendous thermal productivity of the sun, and takes place in six steps involving carbon and nitrogen as nuclear catalysts. A graphical representation of the relative binding energies of all known nuclei is given in *Fig. 2.* The binding energy per nuclear particle B/A is plotted against the atomic weight A for all known nuclei from hydrogen, $A = 1$, to heavy nuclei of $A = 240$. As we have already seen, the binding energy of helium nuclei is much greater than that of hydrogen nuclei and neutrons separately. Hence the B/A for helium lies well above that of hydrogen. The significance of the curve now becomes evident. Transformations which result in changes from a lower portion of the curve to an upper portion are exothermic, and vice versa. However, there is one important difference between the changes at low values of A as compared to those at high values. Certain heavy nuclei can be made to split into two or more fragments of medium atomic weight A at ordinary temperatures (0-200° C.). This process is known as nuclear fission, and the energy released by such a change has been designated as the fission energy in *Fig. 2.* Pound for pound, or on the basis of the number of nuclear particles involved, the fission of heavy nuclei generates about one-seventh as much energy as the formation of helium from hydrogen in the sun. It is small wonder that this process constitutes a potent source of energy.

Apparently, there is a minimal change in binding energy below which fission does not occur. Although nearly all of the heavy elements have been tested, fission apparently is appreciable only in those elements above about 210 in atomic weight. Of these elements, only uranium and thorium occur in appreciable quantities in terrestrial materials. Their presence indicates that uranium and thorium must be relatively stable, otherwise they would have long since disappeared during the two to four billion years since this planet was formed.

RADIOACTIVITY

Uranium and thorium are not completely stable, but undergo spontaneous transformations that result in elements of lower atomic weights. Radioactivity is the term used to describe these changes. In *Fig. 2* the small shift from $A = 238$ to $A = 206$ for the uranium series, and from $A = 232$ to $A = 208$ for the thorium series, releases sufficient energy to account for all the internal-heat flux of the earth.

The emission of an alpha ray ($2He^4$) by radioactive decay is similar to nuclear fission in that both processes result in the splitting of a nucleus into two parts, forming two new nuclei. However, these related phenomena differ in a number of important respects.

NUCLEAR FISSION

In the first place, radioactive decay is spontaneous, and not susceptible to any control. On the other hand, to produce fissions it is necessary to strike the nucleus with a particle or with radiation. There are a number of such *nuclear detonators*, but neutrons are by far the most effective. The absence of electric charge ($Z = 0$) enables these particles to penetrate easily; whereas protons, deuterons, and alphas—being positively charged—are strongly repelled by the large electrostatic fields of heavy nuclei.

The probability of a neutron-producing fission in a uranium or thorium nucleus is dependent upon a number of factors, not the least in importance being the velocity of the neutron. In fact, the less abundant isotope[1]

$$_{92}U^{235}$$

is very infrequently split by other than relatively slowly moving neutrons, the probability of fission being inversely proportional to the velocity of the neutrons. On the other hand, *thorium* nuclei

$$(_{90}Th^{232} \text{ only}) \text{ and } _{92}U^{238}$$

nuclei undergo fission under neutron bombardment only when the neutrons have high energies, called "fast neutrons." With slow and intermediate-velocity neutrons the following transformations occur:

$$_{90}Th^{232} + {}_0n^1 \text{ (slow)} \longrightarrow {}_{90}Th^{233} + \gamma \qquad (3)$$

$$_{92}U^{238} + {}_0n^1 \text{ (slow and intermediate)} \longrightarrow {}_{92}U^{239} + \gamma \qquad , (4)$$

The product nuclei do not undergo fission, but are less stable that the original nuclei, being beta-radioactive with half-lives of 26 minutes and 23 minutes, repectively.

The action of fast neutrons on

$$_{90}Th^{232} \text{ and } _{92}U^{238}$$

and of slow neutrons on

$$_{92}U^{235},$$

results in fission into two slightly unequal nuclei. The process is highly exothermic and considerably more complex than any of the foregoing reactions. One possible sequence for

$$_{92}U^{235}$$

will serve to illustrate the nature of the changes involved:

$$_{92}U^{235} + {_0}n^1 \text{ (slow)} \longrightarrow {_{92}U^{236}} \longrightarrow {_{56}Ba} + {_{36}Kr} + 2\,{_0}n^1 + \text{HEAT} \qquad (5)$$

This reaction occurs almost instantaneously and hence is explosive in character. The fission products,

$$_{56}Ba \text{ and } _{36}Kr,$$

fly apart with tremendous velocities. Because these nuclei contain too many neutrons to be stable,[2] several beta-disintegrations and possibly a neutron-decay are necessary before stable nuclei are formed. These secondary changes occur relatively slowly, and are accompanied by the evolution of about one-fourth as much heat as the fission reaction.

PROPERTIES OF PLUTONIUM

In the preceding section it was mentioned that slow- and intermediate-velocity neutrons on

$$_{92}U^{238}$$

produce a beta-radioactive isotope,

$$_{92}U^{239}.$$

The decay of this substance results in the formation of a new element of atomic number 93, called neptunium

$$(_{93}Np^{239}).$$

Neptunium, in turn, emits another beta particle, becoming plutonium[3]

$$(_{94}Pu^{239}),$$

which emits an alpha particle, thus decaying to

$$_{92}U^{235}$$

but so slowly that in effect it is a stable element.

Plutonium is fissionable with slow neutrons, and hence

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[1] Uranium is composed of 0.7 per cent

$$_{92}U^{235}$$

and 99.3 per cent

$$_{92}U^{238}$$

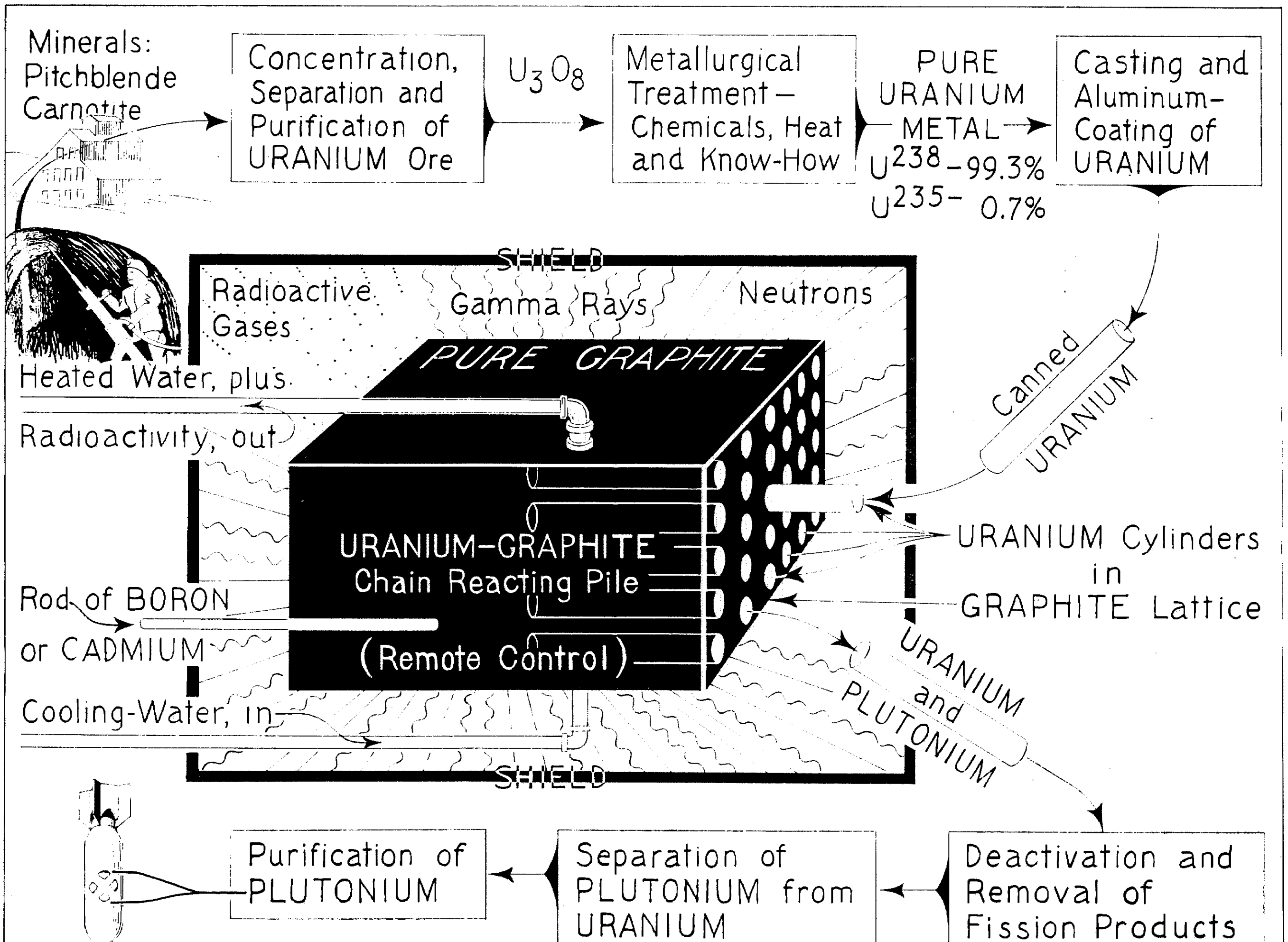

Fig. 4

is equivalent to

U^{235}

in this regard. However, plutonium is sufficiently different from its progenitor,

U^{238}

that it can be separated from uranium by chemical methods. The importance of this fact is made clear in a subsequent section.

SOURCES OF NEUTRONS

Thus far nothing has been said concerning the sources of neutrons. These uncharged nuclear particles are produced either by fissions or by the collision of nuclei at high velocities. There is a small neutron component in cosmic radiation, but much greater intensities are produced by bombarding certain light elements (for example, beryllium) with alpha particles, deuterons, or protons. Radon or radium mixed with beryllium provides a compact source of neutrons. It was by means of neutrons from such sources that fission was initially produced and studied. Deuterons or protons accelerated to a high velocity in a cyclotron can produce even more intense sources of neutrons.

However, enormously greater intensities are required to release significant amounts of atomic energy. As indicated in Equation (5), neutrons are released by the fission process itself. Under proper conditions, these secondary neutrons produce further fissions which release more neutrons to produce still more fissions, and so on. If the number of these self-induced fissions exceeds even by a minute amount the number produced by the initial neutrons, this avalanche-like reaction results. The propagation of the reaction is extraordinarily rapid. For this reason, unless carefully controlled, such reactions are violently explosive. The critical condition under which a self-sustained chain reaction occurs constitutes the crux of atomic energy as known today.

CRITICAL SIZE

In the official U. S. government publication, the now famous Smyth report,[4] this condition is summarized as follows: "The question of whether a chain reaction does or does not go depends on the result of a competition among four processes:

"(1) Escape of neutrons.
"(2) Non-fission capture of neutrons.
"(3) Non-fission capture by impurities.
"(4) Fission capture.

If the loss of neutrons by the first three processes is less than the surplus produced by the fourth, the chain reaction occurs; otherwise, it does not."

Two methods can be used to limit the escape of neutrons. The first is to enlarge the amount of active material to the point where the bulk of the neutrons produced is captured within the mass of the fissionable material itself. This procedure establishes a critical size above which the chain reaction takes place.[5] The second method of decreasing the loss of neutrons by escape is the use of a reflector surrounding the material. Heavy elements serve as reflectors of fast neutrons, for the relatively light neutron bounces off a heavy nucleus with very little change in speed. If reflection with a substantial decrease in velocity is desired, light-weight elements, called "moderators," are used.

The loss of neutrons by non-fission capture is equally important in determining the critical size. Certain elements, such as boron and cadmium, are very accessible to neutrons and behave like neutron sponges, because they so readily "soak up" neutrons. Most elements possess this characteristic to a considerably smaller degree. For example, nitrogen, iron, nickel, and vanadium have moderate capture cross-sections; whereas beryllium, magnesium, carbon, aluminum, zinc, tin, bismuth, and lead have very small capture cross-sections for neutrons. In establishing the critical size for the chain reaction, it is necessary that even minute traces of cadmium and boron be eliminated and that only traces of the medium cross-section elements be present. All essential structural materials must contain only elements with small capture cross-sections.

Because uranium and thorium ores are inevitably associated with elements of large or medium cross-section, a self-sustained reaction is impossible, regardless of the size of the ore deposit. In addition, because of the large proportion of

U^{238}

in ordinary uranium, the non-fission capture of neutrons by

U^{238}

predominates over the fission capture by

U^{238} and U^{235},

even in a very large mass of this material. Hence, not only are uranium ores stable to fission, but even pure uranium metal does not undergo spontaneous fission in bulk. An important exception to this conclusion is discussed in the following section.

PRODUCTION OF FISSIONABLE MATERIALS

In the foregoing, thorium has been included with uranium as a source material. Because of the susceptibility of

U^{235}

to slow neutrons and the possibility of producing plutonium from

U^{238}

the major effort of the Manhattan project centered on the direct or indirect use of uranium. No information has been released concerning chain reactions of thorium. Hence, this element will not be considered further, although thorium certainly constitutes a potential source of atomic energy.

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[2] The heaviest stable isotopes of these two elements are

$_{56}Ba^{138}$ and $_{36}Kr^{86}$.

[3] Neptunium (half-life 2.3 days) and plutonium (half-life about 20,000 years) do not occur in nature in any appreciable quantity. They lie beyond uranium in the periodic table (*Fig. 1*) and hence have been named for the planets Neptune and Pluto, which lie beyond the planet Uranus.

[4] H. D. Smyth, *A General Account of the Development of Methods of Using Atomic Energy for Military Purposes under the Auspices of the United States Government 1940-1945*, written at the request of Major General L. R. Groves, U. S. Army. Publication authorized as of August, 1945. Available from Princeton University Press, Princeton, N. J.

[5] The critical sizes for various materials are military secrets. Prior to the war it was estimated that a sphere of

U^{235}

six inches in diameter might be sufficient to sustain a chain reaction. This amount of

U^{235}

would weigh about 100 pounds. The Smyth report implies that somewhat less than 100 kilograms is necessary.

A large part of the efforts of the project was devoted to the difficult task of separating the isotopes of uranium. U^{238} and U^{235} are essentially identical in chemical properties; hence, they are separable only by processes depending on the small (1.3 per cent) difference in atomic weight.

Four large-scale physical methods have been used to produce U^{235} for atomic bombs (see *Fig. 3*). Several other methods offer promise, but have not progressed beyond the laboratory stage.

While these developments in the separation of uranium isotopes were taking place, another compartment of the Manhattan project was studying methods of producing plutonium. A most ingenious process was evolved which not only yields large amounts of this fissionable material, but appears as the most likely industrial source of atomic energy. It is in the production and utilization of plutonium that petroleum may find an atomic competitor.

The major steps involved in the production of plutonium are shown schematically in *Fig. 4*. The crude source material is pitchblende, carnotite, or some other uranium mineral. After mining and milling, the ore is concentrated and treated chemically to obtain the pure oxide, U_3O_8. The next step requires the preparation of essentially spectroscopically pure uranium metal. This very exacting metallurgical work requires considerable know-how, as do all of the other specialized techniques which have been so expeditiously developed under the Manhattan project. The metal, of course, contains the same proportion of isotopes as the original ore: viz., 99.3 per cent U^{238} and 0.7 per cent U^{235}. It is cast into bars, and is coated with a thin impervious layer of very pure aluminum to protect the uranium from direct contact with the cooling water. This "canned" uranium is then placed in a lattice structure made of highly purified graphite. The size of this so-called pile is very precisely determined. It contains just slightly more uranium than the critical amount required to maintain a chain reaction. A simplified explanation of the operation of the pile is as follows:

> When the pile has been assembled to the proper size, it is triggered by stray neutrons from cosmic radiation. These produce a few fissions of either U^{235} or U^{238}, depending on whether these initiating neutrons are slow or fast. The secondary neutrons resulting from the fissions are fast and, hence, cannot produce additional fissions in U^{235} although they may cause fissions in U^{238}. The most probable result, however, is that these secondary neutrons will be slowed down by collisions to intermediate velocities before producing such fissions. Because of the predominance of U^{238} most of these neutrons are captured to form U^{239}. However, by having pure carbon in the form of graphite alternating with the uranium, many of the secondary neutrons are slowed down to thermal velocities. Because the capture of neutrons by U^{235} increases inversely with the velocity of the neutrons, the probability of producing fissions in U^{235} is greatly increased by the use of the graphite moderator. In this way a self-sustained chain reaction is produced.

Of course, a large amount of cooling must be provided in order to limit the rise in temperature. Special pipes, made of elements with small capture cross-sections, provide channels for the cooling water. The magnitude of this cooling problem can be appreciated from the fact that an appreciable rise in temperature of the Columbia River takes place when one of the piles is operating at the Hanford plant in Washington. The production of a pound of plutonium per day releases energy in the form of heat at the rate of about 1,000,000 kilowatts.

The pile and its products are intensely radioactive and hence extremely dangerous to personnel. For this reason the operation of the pile and chemical treatment of the uranium, after removal from the pile, must be carried on by remote control within air-tight shields several feet in thickness. Following removal of the fission products, the relatively small amount of plutonium is separated from the bulk of the parent uranium, after which the plutonium is purified. This material is then ready for incorporation in an atomic bomb.

UTILIZATION OF ATOMIC ENERGY

The purpose of the present discussion is to consider the possible effects of atomic energy on the petroleum industry, not on military strategy. The fission reaction releases about 32 billion B.t.u. per pound of U^{235} or plutonium, and the radioactive decay of the fission products releases an additional eight billion B.t.u. This energy is more than a million times the heat of combustion of a good grade of coal (14,000 B.t.u. per pound) or of 100-octane gasoline (22,000 B.t.u. per pound). Yet the enormous amount of heat produced in the present piles is wasted. By means of heat exchangers, it probably would be relatively simple to use some of this energy for household or other low-temperature heating. In order to utilize such heat for industrial purposes, it would be necessary to operate the pile at temperatures comparable to those of modern steam power plants. Apparently, the problems involved in this transition are very large.

However, if developments in this field are allowed to flourish unhampered by military restrictions and government controls, it seems probable that these problems can be solved in a reasonably short time, and that atomic energy will be available for industrial purposes within the next decade. The question will then be: Can atomic power compete with petroleum, coal, and water power on an economic basis? Too many unknowns are involved to allow other than speculation, but in all likelihood the answer will not be clearcut.

Inasmuch as coal is generally used as fuel for large installations, it would appear that natural uranium piles may compete with coal, particularly in the generation of electric power. The piles could be located near the populated areas, but sufficiently remote to prevent radiation hazards. The heat released would be used to produce steam to drive turbo-electric generators. This electric power would actually be a by-product from the production of plutonium and radioactive fission materials and the treatment of substances by radiation. Some of the heat from these large piles also might be used to operate thermal or diffusion plants for separating U^{235} from uranium.

The natural uranium and graphite piles, which may compete with coal, are far too bulky to be used in units for mobile power. By using uranium that has been enriched in U^{235} or to which plutonium has been added, the size of the pile can be considerably reduced. The use of heavy water (deuterium oxide) as a moderator in place of graphite also allows substantial reduction in size.

With the decrease in size of power units, the competition with petroleum would probably begin in replacing fuel oil in large transports and naval vessels. Full speed ahead would be achieved by pulling out the cadmium "throttle." A distinct advantage for naval vessels would be that "refueling" would be infrequent. An additional consideration would be that the atomic fuel is noninflammable. Shielding would be a major problem, and would add considerably to the weight and size of the units. Such applications of atomic energy might be entirely ruled out on this basis alone.

Pure U^{235} and plutonium in excess of the critical sizes can be assembled—provided cadmium, boron, or some other neutron absorber is preesnt in sufficient amount to prevent the chain reaction. If the absorber were gradually removed until the critical point is reached, a controlled release of energy from a very compact source might be possible. However, with pure U^{235} or plutonium, this procedure would be extremely sensitive—a slight movement of the absorber might result in a violent explosion. For this reason, compact units will probably use a mixture of U^{235} and U^{238} containing not more than about 20 per cent of the lighter isotope and some moderator in order to obtain a safe degree of controllability. Even more problems than arise with the larger units must be solved before diminutive atomic engines will be possible. For military purposes such engines might supply the power for guided missiles or robot planes. In order to compete seriously with diesel oil and gasoline, atomic engines must be adaptable to trains, trucks, planes, and automobiles. For these purposes the shielding problem would be most acute. The compactness gained in using atomic fuel might be more than offset by the large amount of shielding required. Of course, all of these considerations have been limited to the source of atomic energy now known; *i.e.*, to nuclear fission of heavy elements. It will be recalled that the consolidation of light elements into medium-weight elements releases considerable amounts of energy. Although such nuclear syntheses have never been accomplished on a large scale, they have been achieved in minute amounts in the laboratory. If future research extends the range of available atomic energy to include the light elements, many of the foregoing limitations may be removed. In addition, these light elements would probably be far more plentiful than the relatively scarce fissionable elements, uranium and thorium.

Within the bounds of available information, it would appear that petroleum and coal will probably continue for at least another generation as the primary sources of energy for transportation and heating. Water power and coal will probably generate most of the electricity during the next fifty years. Although atomic energy may gradually enter as a competitor, its most extensive applications will probably be in new fields of human endeavor. Industrial processes at extremely high temperatures, ultra-high-speed transportation, the production of radioactive materials for industrial and medical purposes, as well as for some scientific investigations, the manufacture of rare elements by transmutation, and the treatment of materials by radiation, are among the more likely specialized uses of fission energy in addition to the continued production of atomic explosives.

For some time the more conservative members of the petroleum industry have been concerned about what the world would use for fuel when the petroleum and coal reserves were exhausted. Prior to 1935 new discoveries more than offset the increased consumption of petroleum. During the past 10 years the discovery rate has rapidly declined while production has soared. Although there will be a postwar respite, this trend is likely to continue for some time. However, the petroleum industry now has somewhat less occasion to regret the expenditure of a large part of the earth's supply of chemical energy. By the time this source is exhausted there should be plenty of atomic energy available.

Although this change seems inevitable, it will certainly not be rapid. Few of us will live to drive atomic automobiles or fly jet planes powered by nuclear energy. When this time arrives, there will still be a petroleum industry, but it may have changed rather remarkably in character. Instead of petroleum being primarily used for fuel, it will be the raw material for all kinds of organic substances. The refinery of the future will be more of a chemical factory than a producer of fuel.

To Establish Firm in Brazil

FOLLOWING his resignation as vice-president and director of Northrop Aircraft, Inc., Theodore C. Coleman of the class of 1926, left with his family in November for Brazil, where he will establish his own company to be devoted to distribution and maintenance of aircraft and other U. S.-manufactured products in South America.

A resident of Pasadena since 1922, when he entered Caltech, Mr. Coleman has been prominent in business and civic affairs in southern California for 20 years. Prior to his joining the Northrop Company shortly after its formation, he was vice-president and partner of the old southern California banking firm of Banks, Huntley & Co.

Mr. Coleman spent two months last summer in South America on a business trip, and heard news of V-J Day by shortwave while in the interior of Brazil. He will live in Sao Paulo with Mrs. Coleman and their two children.