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Synthesis, and Analysis, by Glen W. Watson

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\*\*\* START OF THIS PROJECT GUTENBERG EBOOK ELEMENT DISCOVERY \*\*\*

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[Transcriber's Notes: The following errors are noted, but have not been

corrected:

Page 17, footnote: "plutomium" should be "plutonium"

Page 8: "knowns" should be "knows"

In element names, {} represents subscripted numbers and <> represents

superscripted numbers. Readers may also refer to the HTML version of the

text, in which super and subscripted numbers are represented visually.

Italic emphasis is indicated by surrounding the word with \_underscores\_.

Greek letters in the original text are marked in brackets, e. g. [alpha]

or [gamma].

Table I (THE TRANSURANIUM ELEMENTS) has been moved from pages 12-13, in

the middle of the book, to the end of the text.]

A Brief History

of

ELEMENT DISCOVERY,

SYNTHESIS, and ANALYSIS

Glen W. Watson

September 1963

[Illustration]

LAWRENCE RADIATION LABORATORY

University of California

Berkeley and Livermore

Operating under contract with the

United States Atomic Energy Commission

[Illustration: Radioactive elements: alpha particles from a speck of

radium leave tracks on a photographic emulsion. (Occhialini and Powell,

1947)]

A BRIEF HISTORY OF ELEMENT DISCOVERY, SYNTHESIS, AND ANALYSIS

It is well known that the number of elements has grown from four in the

days of the Greeks to 103 at present, but the change in methods needed

for their discovery is not so well known. Up until 1939, only 88

naturally occurring elements had been discovered. It took a dramatic

modern technique (based on Ernest O. Lawrence's Nobel-prize-winning atom

smasher, the cyclotron) to synthesize the most recently discovered

elements. Most of these recent discoveries are directly attributed to

scientists working under the Atomic Energy Commission at the University

of California's Radiation Laboratory at Berkeley.

But it is apparent that our present knowledge of the elements stretches

back into history: back to England's Ernest Rutherford, who in 1919

proved that, occasionally, when an alpha particle from radium strikes a

nitrogen atom, either a proton or a hydrogen nucleus is ejected; to the

Dane Niels Bohr and his 1913 idea of electron orbits; to a once unknown

Swiss patent clerk, Albert Einstein, and his now famous theories; to

Poland's Marie Curie who, in 1898, with her French husband Pierre

laboriously isolated polonium and radium; back to the French scientist

H. A. Becquerel, who first discovered something he called a "spontaneous

emission of penetrating rays from certain salts of uranium"; to the

German physicist W. K. Roentgen and his discovery of x rays in 1895; and

back still further.

During this passage of scientific history, the very idea of "element"

has undergone several great changes.

The early Greeks suggested earth, air, fire, and water as being the

essential material from which all others were made. Aristotle considered

these as being combinations of four properties: hot, cold, dry, and

moist (see Fig. 1).

[Illustration: Fig. 1. The elements as proposed by the early Greeks.]

Later, a fifth "essence," ether, the building material of the heavenly

bodies was added.

Paracelsus (1493-1541) introduced the three alchemical symbols salt,

sulfur, and mercury. Sulfur was the principle of combustability, salt

the fixed part left after burning (calcination), and mercury the

essential part of all metals. For example, gold and silver were

supposedly different combinations of sulfur and mercury.

Robert Boyle in his "Sceptical Chymist" (1661) first defined the word

element in the sense which it retained until the discovery of

radioactivity (1896), namely, a form of matter that could not be split

into simpler forms.

The first discovery of a true element in historical time was that of

phosphorus by Dr. Brand of Hamburg, in 1669. Brand kept his process

secret, but, as in modern times, knowledge of the element's existence

was sufficient to let others, like Kunkel and Boyle in England, succeed

independently in isolating it shortly afterward.

As in our atomic age, a delicate balance was made between the

"light-giving" (desirable) and "heat-giving" (feared) powers of a

discovery. An early experimenter was at first "delighted with the white,

waxy substance that glowed so charmingly in the dark of his laboratory,"

but later wrote, "I am not making it any more for much harm may come of

it."

Robert Boyle wrote in 1680 of phosphorus, "It shone so briskly and lookt

so oddly that the sight was extreamly pleasing, having in it a mixture

of strangeness, beauty and frightfulness."

These words describe almost exactly the impressions of eye witnesses of

the first atom bomb test at Alamagordo, New Mexico, July 16, 1945.

For the next two and three-quarters centuries the chemists had much fun

and some fame discovering new elements. Frequently there was a long

interval between discovery and recognition. Thus Scheele made chlorine

in 1774 by the action of "black manganese" (manganese dioxide) on

concentrated muriatic acid (hydrochloric acid), but it was not

recognized as an element till the work of Davy in 1810.

Occasionally the development of a new technique would lead to the "easy"

discovery of a whole group of new elements. Thus Davy, starting in 1807,

applied the method of electrolysis, using a development of Volta's pile

as a source of current; in a short time he discovered aluminum, barium,

boron, calcium, magnesium, potassium, sodium, and strontium.

The invention of the spectroscope by Bunsen and Kirchhoff in 1859

provided a new tool which could establish the purity of substances

already known and lead to the discovery of others. Thus, helium was

discovered in the sun's spectrum by Jansen and isolated from uranite by

Ramsay in 1895.

The discovery of radioactivity by Becquerel in 1896 (touched off by

Roentgen's discovery of x rays the year before) gave an even more

sensitive method of detecting the presence or absence of certain kinds

of matter. It is well known that Pierre and Marie Curie used this

new-found radioactivity to identify the new elements polonium and

radium. Compounds of these new elements were obtained by patient

fractional recrystallization of their salts.

The "explanation" of radioactivity led to the discovery of isotopes by

Rutherford and Soddy in 1914, and with this discovery a revision of our

idea of elements became necessary. Since Boyle, it had been assumed that

all atoms of the individual elements were identical and unlike any

others, and could not be changed into anything simpler. Now it became

evident that the atoms of radioactive elements were constantly changing

into other elements, thereby releasing very large amounts of energy, and

that many different forms of the same element (lead was the first

studied) were possible. We now think of an element as a form of matter

in which all atoms have the same nuclear charge.

The human mind has always sought order and simplification of the

external world; in chemistry the fruitful classifications were

Dobereiner's Triads (1829), Newland's law of octaves (1865), and

Mendeleev's periodic law (1869). The chart expressing this periodic law

seemed to indicate the maximum extent of the elements and gave good

hints "where to look for" and "the probable properties of" the remaining

ones (see Fig. 2).

By 1925, all but four of the slots in the 92-place file had been filled.

The vacancies were at 43, 61, 85, and 87.

[Illustration: Fig. 2. Periodic chart of the elements (1963)]

Workers using traditional analytical techniques continued to search for

these elements, but their efforts were foredoomed to failure. None of

the nuclei of the isotopes of elements 43, 61, 85, and 87 are stable;

hence weighable quantities of them do not exist in nature, and new

techniques had to be developed before we could really say we had

"discovered" them.

In 1919, Rutherford accomplished scientifically what medieval alchemists

had failed to do with "magic" experiments and other less sophisticated

techniques. It wasn't gold (the goal of the alchemists) he found but

something more valuable with even greater potential for good and evil: a

method of transmuting one element into another. By bombarding nitrogen

nuclei with alpha particles from radium, he found that nitrogen was

changed into oxygen.

The process for radioactive transmutation is somewhat like a common

chemical reaction. An alpha particle, which has the same charge (+2) and

atomic mass (4) as a helium nucleus, penetrates the repulsive forces of

the nitrogen nucleus and deposits one proton and one neutron; this

changes the nitrogen atom into an oxygen atom. The reaction is written

{7}N<14> + {2}He<4> --> {1}H<1> + {8}O<17>.

The number at the lower left of each element symbol in the above

reaction is the proton number. This number determines the basic chemical

identity of an atom, and it is this number scientists must change before

one element can be transformed into another. The common way to

accomplish this artificially is by bombarding nuclei with nuclear

projectiles.

Rutherford used naturally occurring alpha particles from radium as his

projectiles because they were the most effective he could then find. But

these natural alpha particles have several drawbacks: they are

positively charged, like the nucleus itself, and are therefore more or

less repulsed depending on the proton number of the element being

bombarded; they do not move fast enough to penetrate the nuclei of

heavier elements (those with many protons); and, for various other

reasons (some of them unexplained), are inefficient in breaking up the

nucleus. It is estimated that only 1 out of 300,000 of these alpha

particles will react with nitrogen.

Physicists immediately began the search for artificial means to

accelerate a wider variety of nuclear particles to high energies.

Protons, because they have a +1 charge rather than the +2 charge of the

alpha particles, are repulsed less strongly by the positive charge on

the nucleus, and are therefore more useful as bombarding projectiles. In

1929, E. T. S. Walton and J. D. Cockcroft passed an electric discharge

through hydrogen gas, thereby removing electrons from the hydrogen atom;

this left a beam of protons (i. e., hydrogen ions), which was then

accelerated by high voltages. This Cockcroft-Walton voltage multiplier

accelerated the protons to fairly high energies (about 800,000 electron

volts), but the protons still had a plus charge and their energies were

still not high enough to overcome the repulsive forces (Coulombic

repulsion) of the heavier nuclei.

A later development, the Van de Graaff electrostatic generator, produced

a beam of hydrogen ions and other positively charged ions, and electrons

at even higher energies. An early model of the linear accelerator also

gave a beam of heavy positive ions at high energies. These were the next

two instruments devised in the search for efficient bombarding

projectiles. However, the impasse continued: neither instrument allowed

scientists to crack the nuclei of the heavier elements.

Ernest O. Lawrence's cyclotron, built in 1931, was the first device

capable of accelerating positive ions to the very high energies needed.

Its basic principle of operation is not difficult to understand. A

charged particle accelerated in a cyclotron is analogous to a ball being

whirled on a string fastened to the top of a pole. A negative electric

field attracts the positively charged particle (ball) towards it and

then switches off until the particle swings halfway around; the field

then becomes negative in front of the particle again, and again attracts

it. As the particle moves faster and faster it spirals outward in an

ever increasing circle, something like a tether ball unwinding from a

pole. The energies achieved would have seemed fantastic to earlier

scientists. The Bevatron, a modern offspring of the first cyclotron,

accelerates protons to 99.13% the speed of light, thereby giving them

6.2 billion electron volts (BeV).

Another instrument, the heavy-ion linear accelerator (Hilac),

accelerates ions as heavy as neon to about 15% the speed of light. It is

called a linear accelerator because it accelerates particles in a

straight line. Stanford University is currently (1963) in the process of

building a linear accelerator approximately two miles long which will

accelerate charged particles to 99.9% the speed of light.

But highly accelerated charged particles did not solve all of science's

questions about the inner workings of the nucleus.

In 1932, during the early search for more efficient ways to bombard

nuclei, James Chadwick discovered the neutron. This particle, which is

neutral in charge and is approximately the same mass as a proton, has

the remarkable quality of efficiently producing nuclear reactions even

at very low energies. No one exactly knowns why. At low energies,

protons, alpha particles, or other charged particles do not interact

with nuclei because they cannot penetrate the electrostatic energy

barriers. For example, slow positive particles pick up electrons, become

neutral, and lose their ability to cause nuclear transformations. Slow

neutrons, on the other hand, can enter nearly all atomic nuclei and

induce fission of certain of the heavier ones. It is, in fact, these

properties of the neutron which have made possible the utilization of

atomic energy.

With these tools, researchers were not long in accurately identifying

the missing elements 43, 61, 85, and 87 and more--indeed, the list of

new elements, isotopes, and particles now seems endless.

Element 43 was "made" for the first time as a result of bombarding

molybdenum with deuterons in the Berkeley cyclotron. The chemical work

of identifying the element was done by Emilio Segrè and others then

working at Palermo, Sicily, and they chose to call it technetium,

because it was the element first made by artificial technical methods.

Element 61 was made for the first time from the fission disintegration

products of uranium in the Clinton (Oak Ridge) reactor. Marinsky and

Glendenin, who did the chemical work of identification, chose to call it

promethium because they wished to point out that just as Prometheus

stole fire (a great force for good or evil) from the hidden storehouse

of the gods and presented it to man, so their newly assembled reactor

delivered to mankind an even greater force, nuclear energy.

Element 85 is called astatine, from the Greek astatos, meaning

"unstable," because astatine \_is\_ unstable (of course all other elements

having a nuclear charge number greater than 84 are unstable, too).

Astatine was first made at Berkeley by bombarding bismuth with alpha

particles, which produced astatine and released two neutrons. The

element has since been found in nature as a small constituent of the

natural decay of actinium.

The last of the original 92 elements to be discovered was element 87,

francium. It was identified in 1939 by French scientist Marguerite

Perey.

Children have a game in which they pile blocks up to see how high they

can go before they topple over. In medieval times, petty rulers in their

Italian states vied with one another to see who could build the tallest

tower. Some beautiful results of this game still remain in Florence,

Siena, and other Italian hill cities. Currently, Americans vie in a

similar way with the wheelbase and overall length of their cars. After

1934, the game among scientists took the form of seeing who could extend

the length of the periodic system of the elements; as with medieval

towers, it was Italy that again began with the most enthusiasm and

activity under the leadership of Enrico Fermi.

Merely adding neutrons would not be enough; that would make only a

heavier isotope of the already known heaviest elements, uranium.

However, if the incoming neutron caused some rearrangement within the

nucleus and if it were accompanied by expulsion of electrons, that

\_would\_ make a new element. Trials by Fermi and his co-workers with

various elements led to unmistakeable evidence of the expulsion of

electrons (beta activity) with at least four different rates of decay

(half-lives). Claims were advanced for the creation of elements 93 and

94 and possibly further (the transuranium elements, Table I). Much

difficulty was experienced, however, in proving that the activity really

was due to the formation of elements 93 and 94. As more people became

interested and extended the scope of the experiments, the picture became

more confused rather than clarified. Careful studies soon showed that

the activities did \_not\_ decay logarithmically--which means that they

were caused by mixtures, not individual pure substances--and the

original four activities reported by Fermi grew to at least nine.

As a matter of fact, the way out of the difficulty had been indicated

soon after Fermi's original announcement. Dr. Ida Noddack pointed out

that no one had searched among the products of Fermi's experiment for

elements \_lighter\_ than lead, but no one paid any attention to her

suggestion at the time. The matter was finally cleared up by Dr. Otto

Hahn and F. Strassmann. They were able to show that instead of uranium

having small pieces like helium nuclei, fast electrons, and super-hard

x-rays, knocked off as expected, the atom had split into two roughly

equal pieces, together with some excess neutrons. This process is called

nuclear fission. The two large pieces were unstable and decayed further

with the loss of electrons, hence the [beta] activity. This process is

so complicated that there are not, as originally reported, only four

half-lives, but at least 200 different varieties of at least 35

different elements. The discovery of fission attended by the release of

enormous amounts of energy led to feverish activity on the part of

physicists and chemists everywhere in the world. In June 1940, McMillan

and Abelson presented definite proof that element 93 had been found in

uranium penetrated by neutrons during deuteron bombardment in the

cyclotron at the University of California Radiation Laboratory.

The California scientists called the newly discovered element neptunium,

because it lies beyond the element uranium just as the planet Neptune

lies beyond Uranus. The particular isotope formed in those first

experiments was {93}Np<239>; this is read neptunium having a nuclear charge

of 93 and an atomic mass number of 239. It has a half-life of 2.3 days,

during which it gives up another electron ([beta] particle) and becomes

element 94, or plutonium (so called after Pluto, the next planet beyond

Neptune). This particular form of plutonium ({94}Pu<239>) has such a long

half-life (24,000 years) that it could not be detected. The first

isotope of element 94 to be discovered was Pu<238>, made by direct deuteron

bombardment in the Berkeley 60-inch cyclotron by Radiation Laboratory

scientists Seaborg, McMillan, Kennedy, and Wahl; it had an [alpha]-decay

half-life of 86.4 years, which gave it sufficient radioactivity so that

its chemistry could be studied.

Having found these chemical properties in Pu<238>, experimenters knew

{94}Pu<239> would behave similarly. It was soon shown that the nucleus of

{94}Pu<239> would undergo fission in the same way as {92}U<235> when

bombarded with slow neutrons and that it could be produced in the newly

assembled atomic pile. Researchers wished to learn as much as possible

about its chemistry; therefore, during the summer of 1942 two large

cyclotrons at St. Louis and Berkeley bombarded hundreds of pounds of

uranium almost continuously. This resulted in the formation of 200

micrograms of plutonium. From this small amount, enough of the chemical

properties of the element were learned to permit correct design of the

huge plutonium-recovery plant at Hanford, Washington. In the course of

these investigations, balances that would weigh up to 10.5 mg with a

sensitivity of 0.02 microgram were developed. The "test tubes" and

"beakers" used had internal diameters of 0.1 to 1 mm and could measure

volumes of 1/10 to 1/10,000 ml with an accuracy of 1%. The fact that

there was no intermediate stage of experimentation, but a direct

scale-up at Hanford of ten billion times, required truly heroic skill

and courage.

By 1944 sufficient plutonium was available from uranium piles (reactors)

so that it was available as target material for cyclotrons. At Berkeley

it was bombarded with 32-MeV doubly charged helium ions, and the

following reactions took place:

{94}Pu<239> ([alpha], n) {96}Cm<242> [alpha] / 150 days --> {94}Pu<238>.

This is to be read: plutonium having an atomic number of 94 (94

positively charged protons in the nucleus) and a mass number of 239 (the

whole atom weighs approximately 239 times as much as a proton), when

bombarded with alpha particles (positively charged helium nuclei) reacts

to give off a neutron and a new element, curium, that has atomic number

96 and mass number 242. This gives off alpha particles at such a rate

that half of it has decomposed in 150 days, leaving plutonium with

atomic number 94 and mass number 238. The radiochemical work leading to

the isolation and identification of the atoms of element 96 was done at

the metallurgical laboratory of the University of Chicago.

The intense neutron flux available in modern reactors led to a new

element, americium (Am), as follows:

{94}Pu<239> (n, [gamma]) {94}Pu<240> (n, [gamma]) {94}Pu<241> [beta]

--> {95}Am<241>.

The notation (n, [gamma]) means that the plutonium absorbs a neutron and

gives off some energy in the form of gamma rays (very hard x rays); it

first forms {94}Pu<240> and then {94}Pu<241>, which is unstable and gives

off fast electrons ([beta]), leaving {95}Am<241>.

Berkelium and californium, elements 97 and 98, were produced at the

University of California by methods analogous to that used for curium,

as shown in the following equations:

{95}Am<240> + [alpha] --> {97}Bk<243> + {0}n<1>,

and {96}Cm<241> + [alpha] --> {98}Cf<244> + {0}n<1>.

The next two elements, einsteinium ({99}Es) and fermium ({100}Fm), were

originally found in the debris from the thermonuclear device "Mike,"

which was detonated on Eniwetok atoll November 1952. (This method of

creating new substances is somewhat more extravagant than the mythical

Chinese method of burning down a building to get a roast pig.)

These elements have since been made in nuclear reactors and by

bombardment. This time the "bullet" was N<14> stripped of electrons till it

had a charge of +6, and the target was plutonium.

Researchers at the University of California used new techniques in

forming and identifying element 101, mendelevium. A very thin layer of

{99}Es<253> was electroplated onto a thin gold foil and was then bombarded,

from behind the layer, with 41-MeV [alpha] particles. Unchanged {99}Es<253>

stayed on the gold, but those atoms hit by [alpha] particles were

knocked off and deposited on a "catcher" gold foil, which was then

dissolved and analyzed (Fig. 3). This freed the new element from most of

the very reactive parent substances, so that analysis was easier. Even

so, the radioactivity was so weak that the new element was identified

"one atom at a time"; this is possible because its daughter element,

fermium, spontaneously fissions and releases energy in greater bursts

than any possible contaminant.

[Illustration: Fig. 3. The production of mendelevium.]

In 1957, in Stockholm, element 102 was reported found by an

international team of scientists (who called it nobelium), but diligent

and extensive research failed to duplicate the Stockholm findings.

However, a still newer technique developed at Berkeley showed the

footprints--if not the living presence--of 102 (see Fig. 4). The rare

isotope curium-246 is coated on a small piece of nickel foil, enclosed

in a helium-filled container, and placed in the heavy-ion linear

accelerator (Hilac) beam. Positively charged atoms of element 102 are

knocked off the foil by the beam, which is of carbon-12 or carbon-13

nuclei, and are deposited on a negatively charged conveyor apron. But

element 102 doesn't live long enough to be actually measured. As it

decays, its daughter product, {100}Fm<250>, is attracted onto a charged

aluminum foil where it can be analyzed. The researchers have decided

that the hen really did come first: they have the egg; therefore the hen

must have existed. By measuring the time distance between target and

daughter product, they figure that the hen-mother (element 102) must

have a half-life of three seconds.

[Illustration: Fig. 4. The experimental arrangement used in the

discovery of element 102.]

In an experiment completed in 1961, researchers at the University of

California at Berkeley unearthed similar "footprints" belonging to

element 103 (named lawrencium in honor of Nobel prizewinner Ernest O.

Lawrence). They found that the bombardment of californium with boron

ions released [alpha] particles which had an energy of 8.6 MeV and

decayed with a half-life of 8 ± 2 seconds. These particles can only be

produced by element 103, which, according to one scientific theory, is a

type of "dinosaur" of matter that died out a few weeks after creation of

the universe.

The half-life of lawrencium (Lw) is about 8 seconds, and its mass number

is thought to be 257, although further research is required to establish

this conclusively.

Research on lawrencium is complicated. Its total [alpha] activity

amounts to barely a few counts per hour. And, since scientists had the

[alpha]-particle "footprints" only and not the beast itself, the

complications increased. Therefore no direct chemical techniques could

be used, and element 103 was the first to be discovered solely by

nuclear methods.[A]

For many years the periodic system was considered closed at 92. It has

now been extended by at least eleven places (Table I), and one of the

extensions (plutonium) has been made in truckload lots. Its production

and use affect the life of everyone in the United States and most of the

world.

Surely the end is again in sight, at least for ordinary matter, although

persistent scientists may shift their search to the other-world "anti"

particles. These, too, will call for very special techniques for

detection of their fleeting presence.

Early enthusiastic researchers complained that a man's life was not long

enough to let him do all the work he would like on an element. The

situation has now reached a state of equilibrium; neither man nor

element lives long enough to permit all the desired work.

[A] In August 1964 Russian scientists claimed that they created element

104 with a half-life of about 0.3 seconds by bombarding plutomium with

accelerated neon-22 ions.

Table I. THE TRANSURANIUM ELEMENTS

========================================================================

Element Name (Symbol) Mass Year Discovered; by whom;

Number where; how

------------------------------------------------------------------------

93 Neptunium (Np) 238 1940; E. M. McMillan, P. H.

Abelson; University of California

at Berkeley; slow-neutron

bombardment of U<238> in the

60-inch cyclotron.

------------------------------------------------------------------------

94 Plutonium (Pu) 238 1941; J. W. Kennedy, E. M.

McMillan, G. T. Seaborg, and A. C.

Wahl; University of California at

Berkeley; 16-MeV deuteron

bombardment of U<238> in the

60-inch cyclotron.

(Pu) 239 Pu<239>; the fissionable isotope

of plutonium, was also discovered

in 1941 by J. W. Kennedy, G. T.

Seaborg, E. Segrè and A. C. Wahl;

University of California at

Berkeley; slow-neutron bombardment

of U<238> in the 60-inch

cyclotron.

------------------------------------------------------------------------

95 Americium (Am) 241 1944-45; Berkeley scientists A.

Ghiorso, R. A. James, L. O.

Morgan, and G. T. Seaborg at the

University of Chicago; intense

neutron bombardment of plutonium

in nuclear reactors.

------------------------------------------------------------------------

96 Curium (Cm) 242 1945; Berkeley scientists A.

Ghiorso, R. A. James, and G. T.

Seaborg at the University of

Chicago; bombardment of Pu<239>

by 32-MeV helium ions from the

60-inch cyclotron.

------------------------------------------------------------------------

97 Berkelium (Bk) 243 1949; S. G. Thompson, A. Ghiorso,

and G. T. Seaborg; University of

California at Berkeley; 35-MeV

helium-ion bombardment of

Am<241>.

------------------------------------------------------------------------

98 Californium (Cf) 245 1950; S. G. Thompson, K. Street,

A. Ghiorso, G. T. Seaborg;

University of California at

Berkeley; 35-MeV helium-ion

bombardment of Cm<242>.

------------------------------------------------------------------------

99 Einsteinium (Es) 253 1952-53; A. Ghiorso, S. G.

100 Fermium (Fm) 255 Thompson, G. H. Higgins, G. T.

Seaborg, M. H. Studier, P. R.

Fields, S. M. Fried, H. Diamond,

J. F. Mech, G. L. Pyle, J. R.

Huizenga, A. Hirsch, W. M.

Manning, C. I. Browne, H. L.

Smith, R. W. Spence; "Mike"

explosion in South Pacific; work

done at University of California

at Berkeley, Los Alamos Scientific

Laboratory, and Argonne National

Laboratory; both elements created

by multiple capture of neutrons in

uranium of first detonation of a

thermonuclear device. The elements

were chemically isolated from the

debris of the explosion.

------------------------------------------------------------------------

101 Mendelevium (Md) 256 1955; A. Ghiorso, B. G. Harvey, G.

R. Choppin, S. G. Thompson, G. T.

Seaborg; University of California

at Berkeley; 41-MeV helium-ion

bombardment of Es<253> in 60-inch

cyclotron.

------------------------------------------------------------------------

102 Unnamed[B] 254 1958; A. Ghiorso, T. Sikkeland, A.

E. Larsh, R. M. Latimer;

University of California, Lawrence

Radiation Laboratory, Berkeley;

68-MeV carbon-ion bombardment of

Cm<246> in heavy-ion linear

accelerator (Hilac).

------------------------------------------------------------------------

103 Lawrencium 257 1961; A. Ghiorso, T. Sikkeland, A.

E. Larsh, R. M. Latimer;

University of California, Lawrence

Radiation Laboratory, Berkeley;

70-MeV boron-ion bombardment of

Cf<250>, Cf<251>, and Cf<252>

in Hilac.

========================================================================

[B] A 1957 claim for the synthesis and identification of element 102 was

accepted at that time by the International Union of Pure and Applied

Chemistry, and the name nobelium (symbol No) was adopted. The University

of California scientists, A. Ghiorso et al., cited here believe they

have disproved the earlier claim and have the right to suggest a

different name for the element.

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