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DISCOVERY OF LAWRENCIUM, ELEMENT 103

Author
Latimer, Robert M.

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UNIVERSITY OF CALIFORNIA

Ernest O. Lawrence Radiation Laboratory

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By Robert M. Latimer

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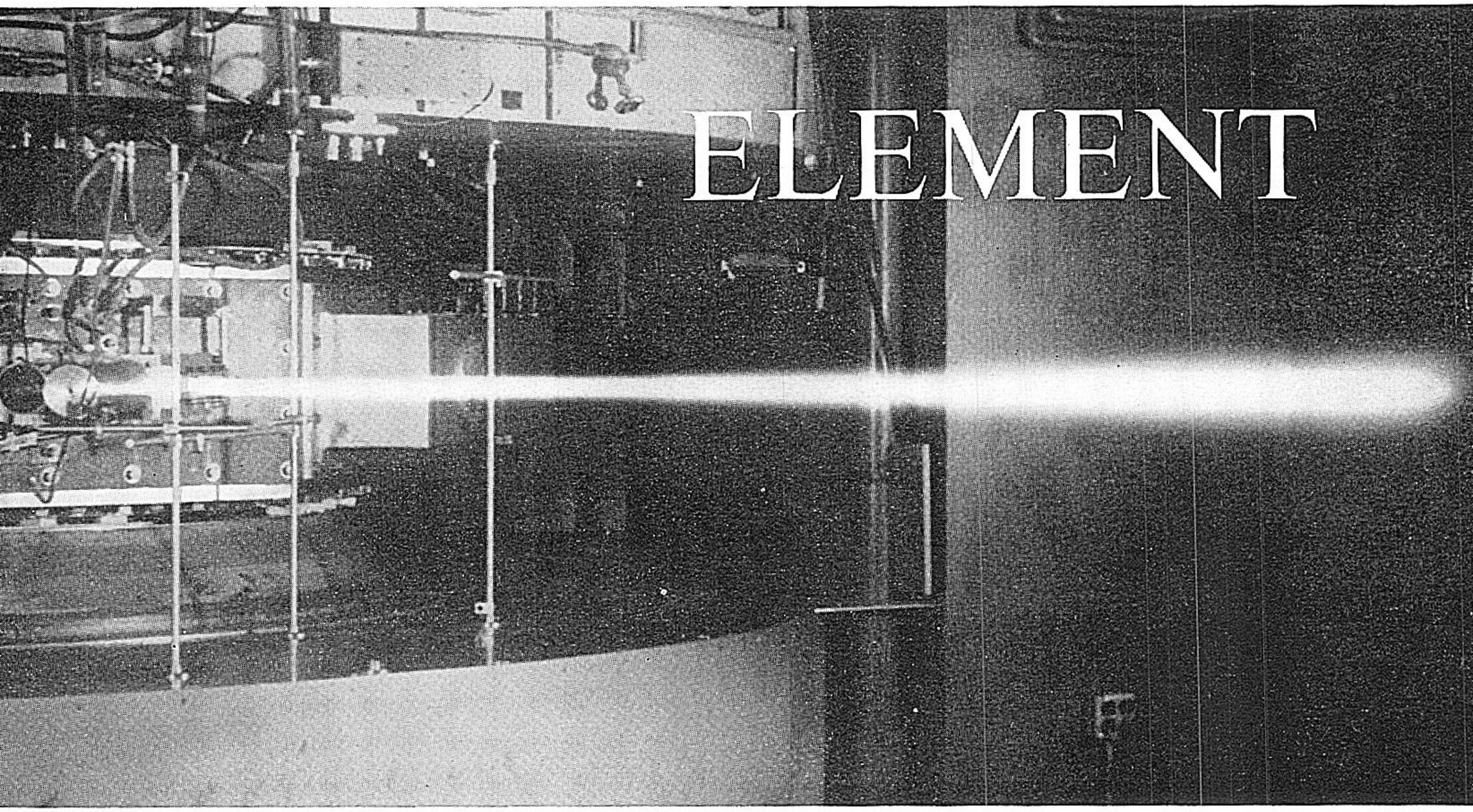
DISCOVERY OF Lawrencium ELEMENT



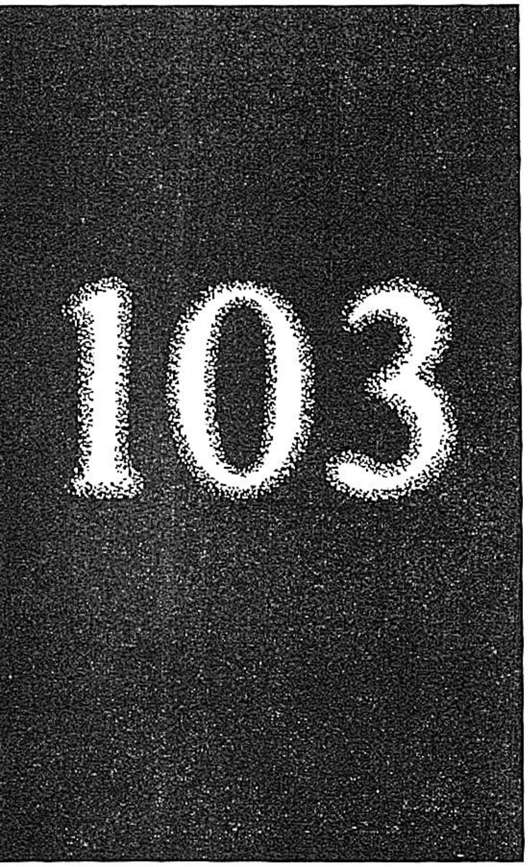
Comprehensive studies of the nucleus are possible with high energy accelerators. Shown is a beam of deuterons with an energy of 60 million electron volts emerging from the target chamber of the University of California 60-inch cyclotron. The deuteron beam is visible (in a dark room) because of the ultraviolet light given off when the deuterons strike air molecules.

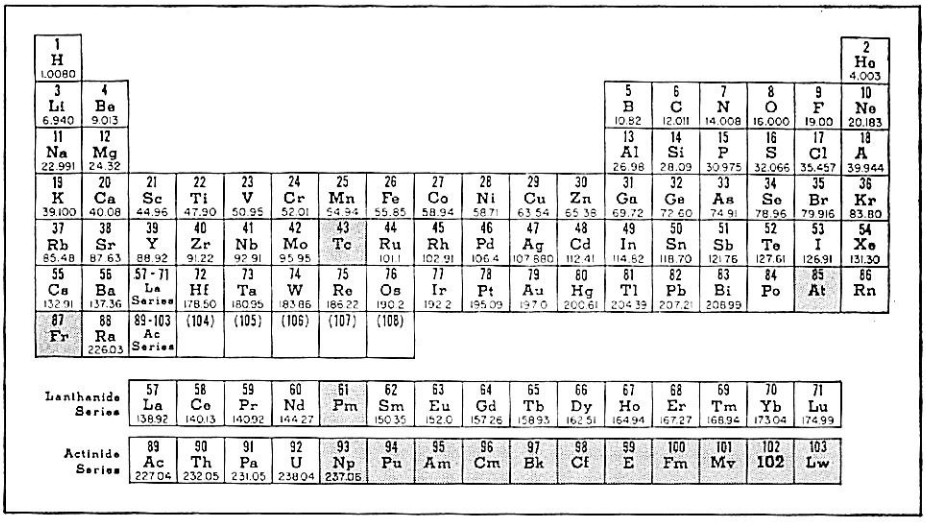
By ROBERT M. LATIMER

Chemist, Lawrence Radiation Laboratory, University of California, Berkeley, California

EARLIER this year a new element, *lawrencium* (Lw), was discovered at the Lawrence Radiation Laboratory in Berkeley, California. This now becomes the fifteenth "man-made" element. The discovery was made by nuclear chemists Albert Ghiorso (codiscoverer of eight other new elements), Torbjorn Sikkeland, Almon E. Larsh, and Robert M. Latimer.

The modern Periodic Table of Elements (Figure 1) is somewhat changed from the fanciful chart used by the early alchemists and scientists for the elementary substances of nature (fire, water, air, etc.). Only nine elements were included in the references used by experimenters in the sixteenth century, but their work did make a contribu-



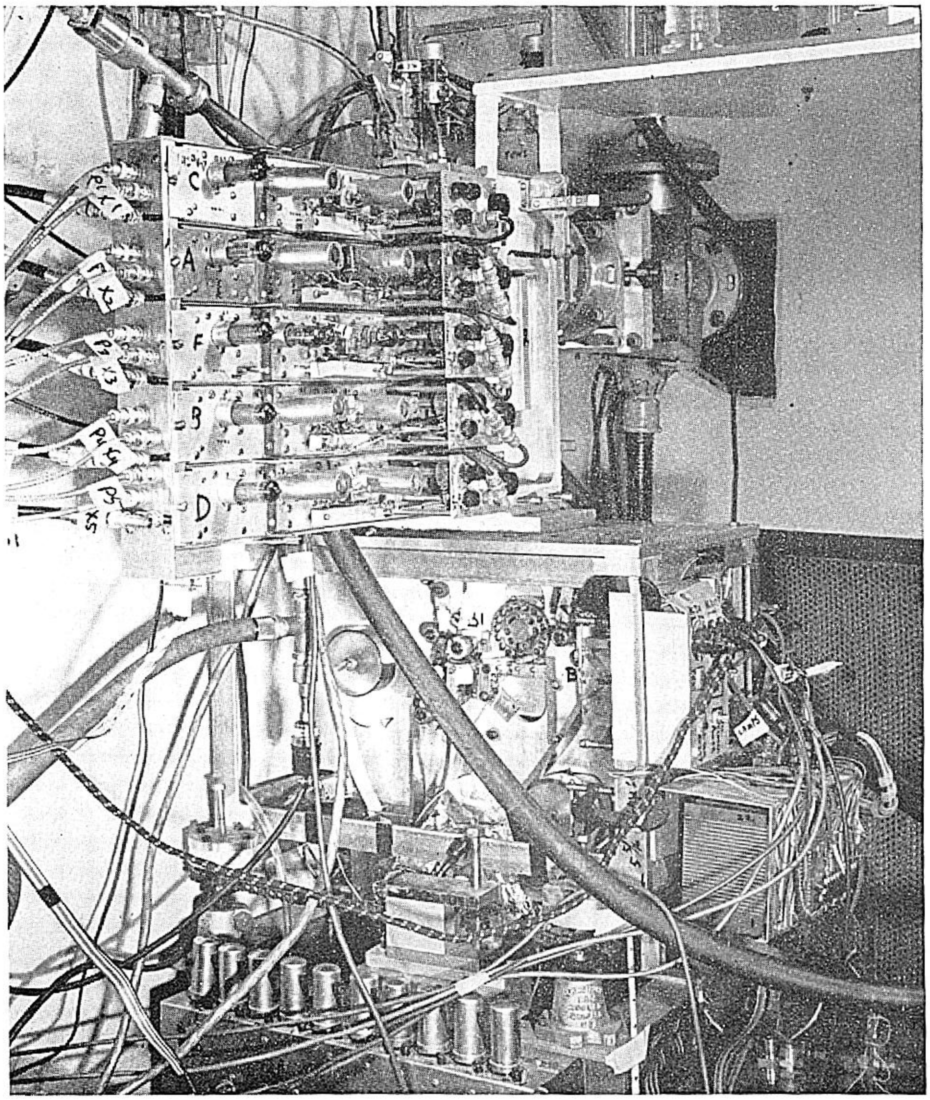


1 H 1.0080																	2 He 4.003
3 Li 6.940	4 Be 9.013											5 B 10.82	6 C 12.011	7 N 14.008	8 O 16.000	9 F 19.00	10 Ne 20.183
11 Na 22.991	12 Mg 24.32											13 Al 26.98	14 Si 28.09	15 P 30.975	16 S 32.066	17 Cl 35.457	18 A 39.944
19 K 39.100	20 Ca 40.08	21 Sc 44.96	22 Ti 47.90	23 V 50.95	24 Cr 52.01	25 Mn 54.94	26 Fe 55.85	27 Co 58.94	28 Ni 58.71	29 Cu 63.54	30 Zn 65.38	31 Ga 69.72	32 Ge 72.60	33 As 74.91	34 Se 78.96	35 Br 79.916	36 Kr 83.80
37 Rb 85.48	38 Sr 87.63	39 Y 88.92	40 Zr 91.22	41 Nb 92.91	42 Mo 95.95	43 Tc	44 Ru 101.1	45 Rh 102.91	46 Pd 106.4	47 Ag 107.880	48 Cd 112.41	49 In 114.82	50 Sn 118.70	51 Sb 121.76	52 Te 127.61	53 I 126.91	54 Xe 131.30
55 Cs 132.91	56 Ba 137.36	57 - 71 La Series	72 Hf 178.50	73 Ta 180.95	74 W 183.86	75 Re 186.22	76 Os 190.2	77 Ir 192.2	78 Pt 195.09	79 Au 197.0	80 Hg 200.61	81 Tl 204.39	82 Pb 207.21	83 Bi 208.99	84 Po	85 At	86 Rn
87 Fr	88 Ra 226.03	89 - 103 Ac Series	(104)	(105)	(106)	(107)	(108)										

Lanthanide Series	57 La 138.92	58 Ce 140.13	59 Pr 140.92	60 Nd 144.27	61 Pm	62 Sm 150.35	63 Eu 152.0	64 Gd 157.26	65 Tb 158.93	66 Dy 162.51	67 Ho 164.94	68 Er 167.27	69 Tm 168.94	70 Yb 173.04	71 Lu 174.99
Actinide Series	89 Ac 227.04	90 Th 232.05	91 Pa 231.05	92 U 238.04	93 Np 237.06	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 E	100 Fm	101 Mv	102 102	103 Lw

FIGURE 1. Periodic Table of the Elements. The synthetic elements are shaded.

View of the equipment used in the 103 experiment.



tion. These were carbon (C), sulfur (S), iron (Fe), copper (Cu), silver (Ag), tin (Sn), gold (Au), mercury (Hg), and lead (Pb). The beginning work of these men was with crude equipment, such as the retort and mortar and pestle. But however limited, through their interest in theory and experimentation, they were able to pin

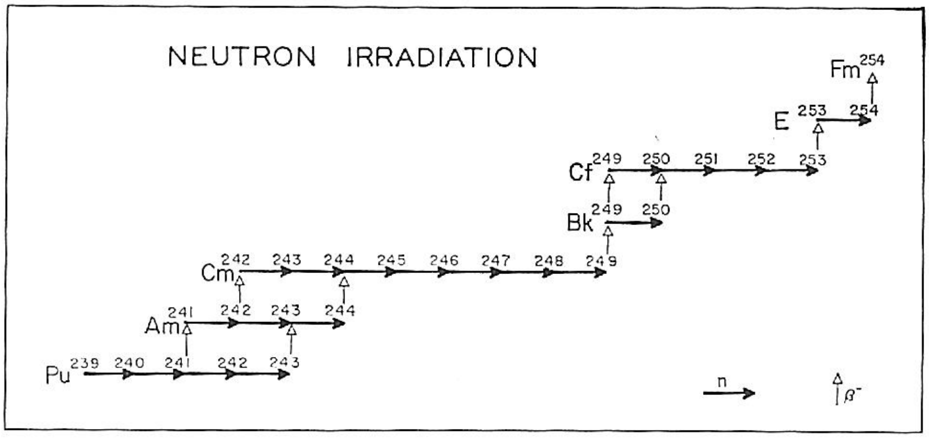


FIGURE 2. Production of heavy elements via slow neutron irradiation.

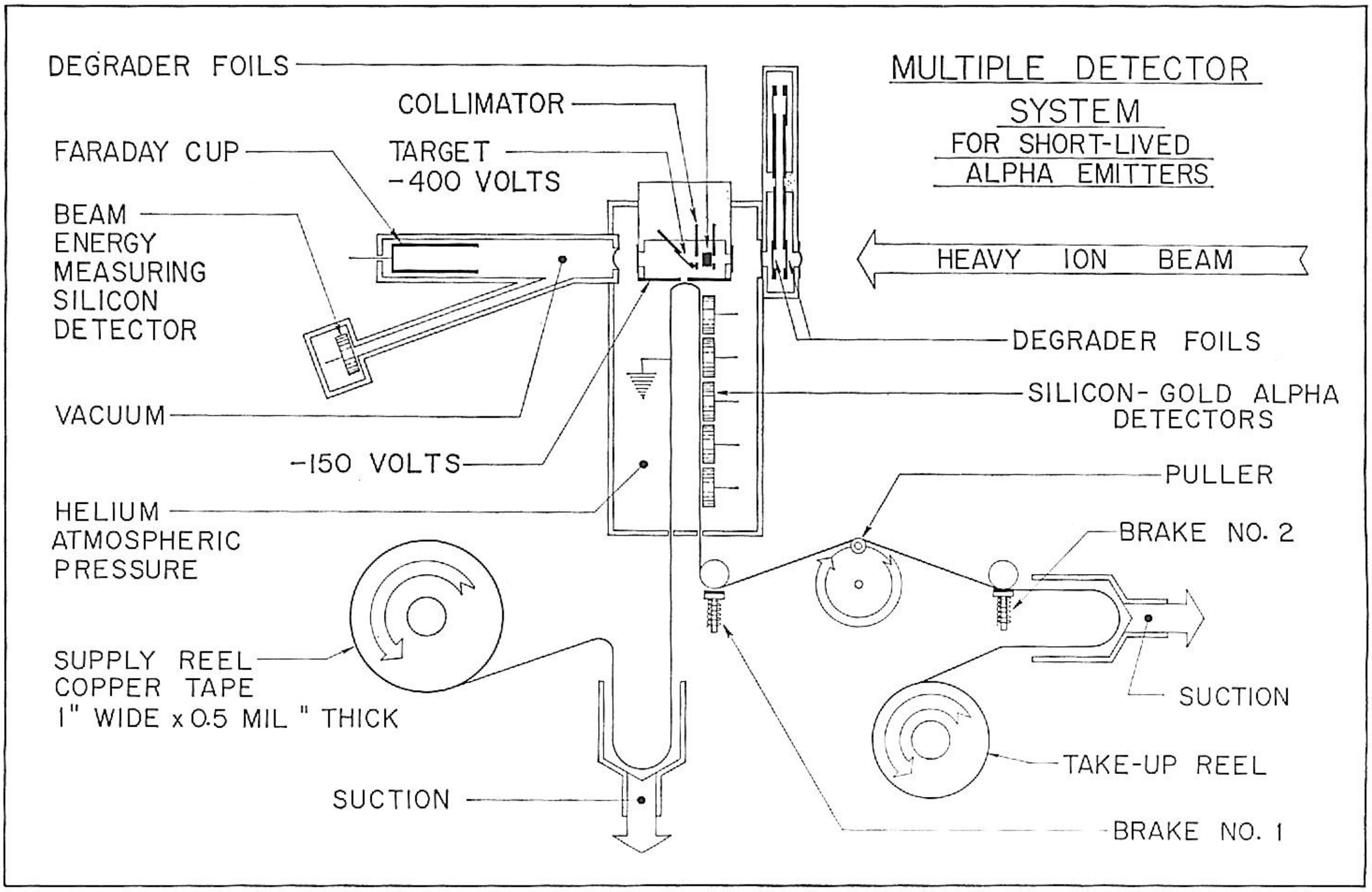
down some important elements known today. By the middle of the seventeenth century, thirteen elements were known, but none of the discoveries have been recorded in history.

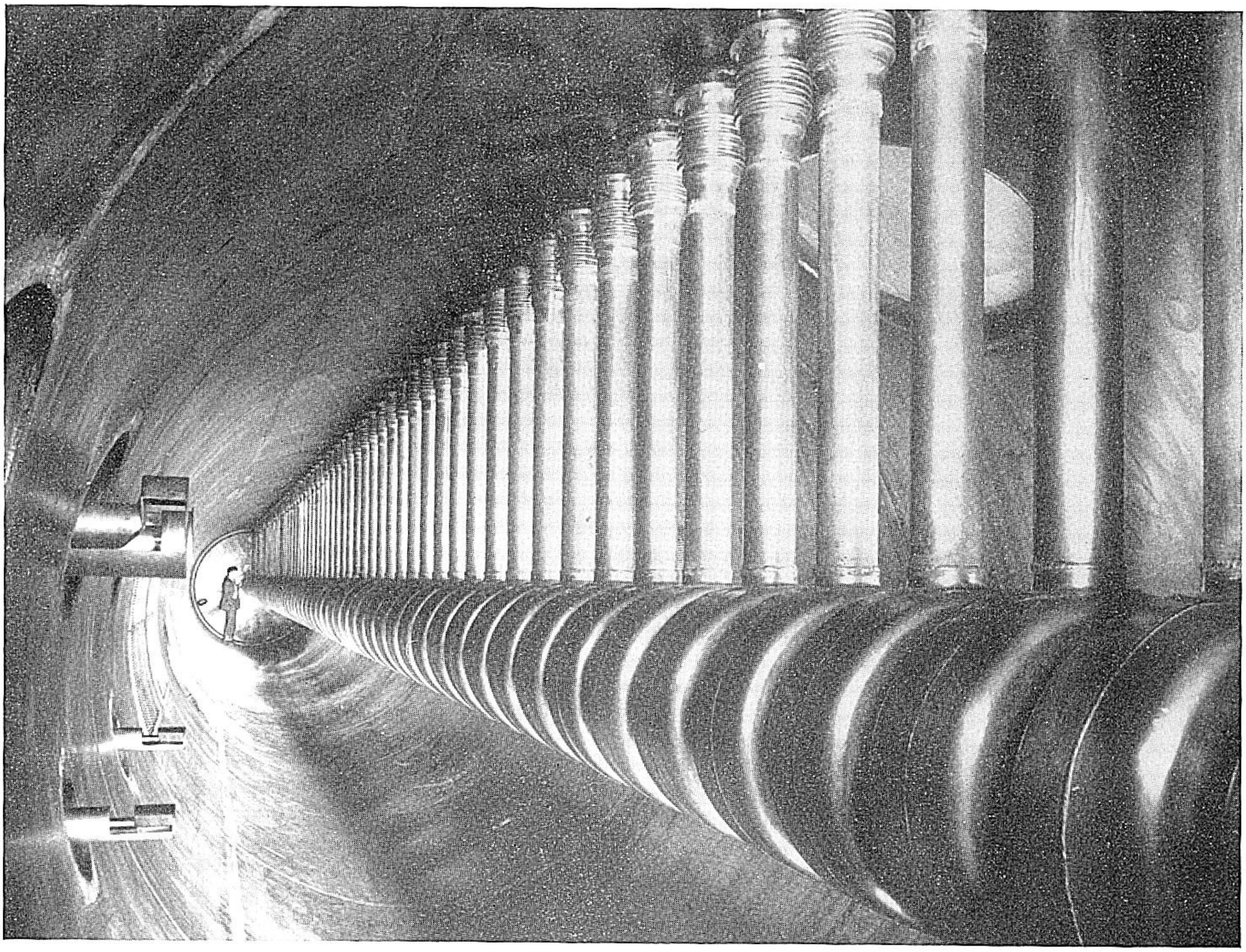
Today, man has considerable equipment and methods with which to learn of the environment of the universe. Unlike early man who used simple tools to reshape natural materials, the present-day scientist relies on complicated machinery and equipment to perform the necessary chemistry of our day. In isolating tiny quantities of materials, it is necessary to use "hot" cave laboratories, cyclotrons, reactors, accelerators, and other complicated equipment. Accelerators are designed specifically for the purpose of producing heavy ions and are used by scientists to broaden their knowledge of the nature of atoms and atomic nuclei. The Berkeley accelerator (HILAC), used in the element-103 experiment, can bombard targets with particles as heavy as neon ions or even heavier ones.

The transuranium elements up to fermium (Fm) can be most easily prepared by neutron irradiation of plutonium (Pu) for several years in a high flux reactor (see Figure 2). Einsteinium (E) has been produced by neutron irradiation in barely weighable amounts. Above fermium the heavy isotopes decay just about as fast as they are made. Therefore, this method holds little promise currently for the production of elements as heavy as 103. Lawrencium decays with a half life of *8 + 2* seconds and emits an alpha particle with an energy of 8.6 mev.

About ten years after the discovery of rhenium (Re) in 1925, it was theorized that any subsequent "new elements" should be radioactive and would

FIGURE 3. Schematic diagram of the equipment used in the 103 experiment.





The interior of a new type of atom-smasher or accelerator (the HILAC) constructed for an Atomic Energy Commission research program at the University of California Radiation Laboratory, Berkeley. Heavy fragments of matter are hurled through the doughnut-shaped "drift tubes" that extend the length of the atom "gun's" barrel. Man standing at the end of the big barrel (the post-stripper), gives idea of the size of the tank—90 feet long and 10 feet in diameter.

probably therefore have to be synthesized. Actually, some of the lighter synthetic elements do exist in nature in uranium ores—elements 43 and 61 as radioactive fission fragments, elements 85 and 87 as members of a rare decay chain, and at least two of the "transuranium elements" from neutron capture. All the transuranium elements, and perhaps some yet undiscovered elements, may have existed some four billion years ago when the earth was formed. But in the long time interval that has elapsed since the formation, it is expected that all have decayed away.

Charged-particle bombardment is the only path left open for the production of the very heaviest elements. To produce a new heavy nucleus out of two lighter nuclei, one must overcome the coulombic repulsion of the two atoms. For this purpose, the heavy-ion linear accelerator—HILAC—was built several years ago at the Lawrence Radiation Laboratory. The HILAC accelerates particles up to 10 mev per nucleon, that is, for instance 110-mev B^{11}. With this energy, it is possible to push two atoms together and create a new one.

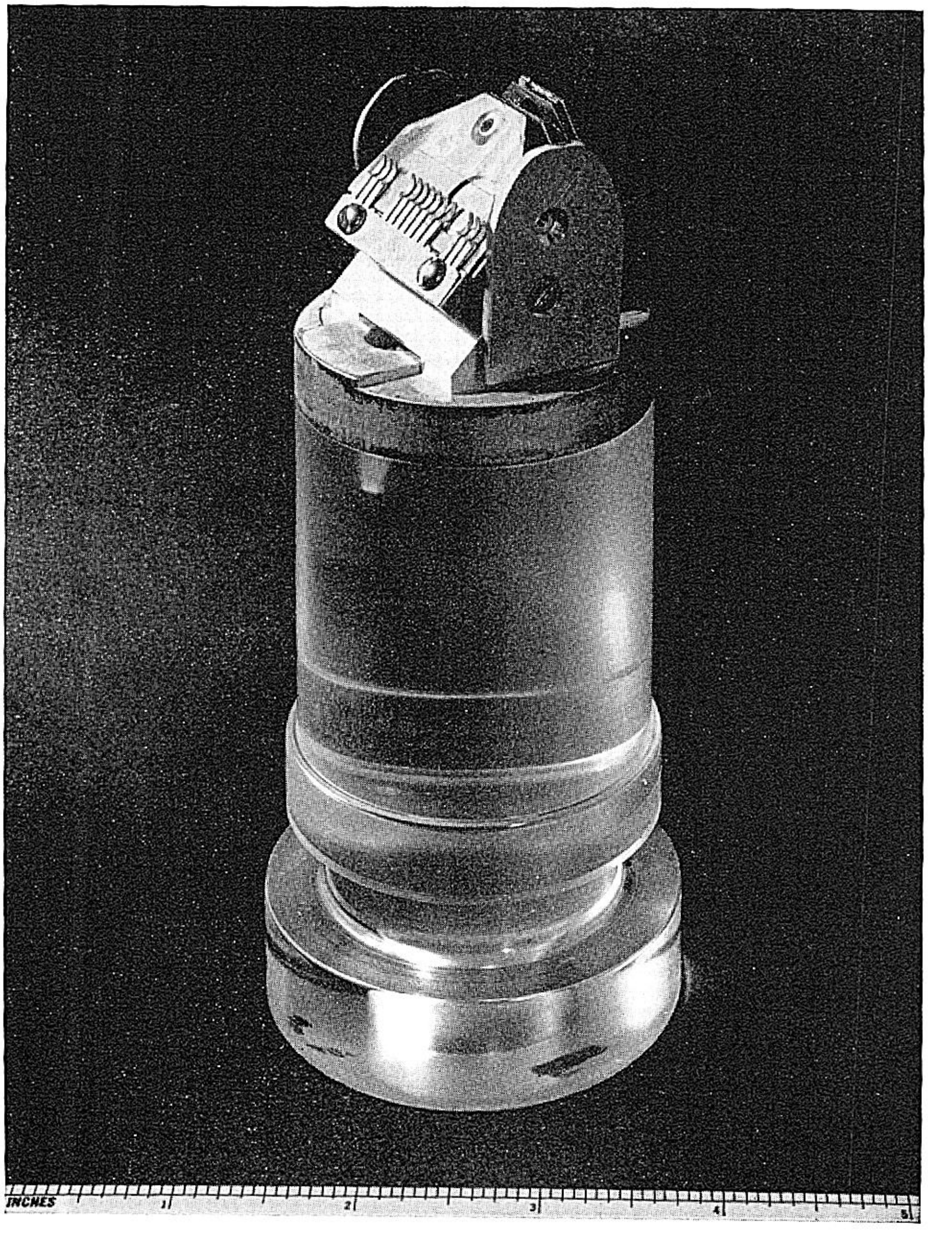
In the 103 experiment, californium (Cf) was bombarded by boron ions. The californium had previously been produced by neutron irradiation. Three micrograms of californium, one-half the world's supply, was electroplated in an area 0.10 inch in diameter on a very thin nickel foil. The heavy-ion beam was collimated so as to pass only through the target material.

When a boron atom hits a californium atom, a new compound nucleus is formed which has a very excited state. This new nucleus then does one of two things to lose some of its extra energy. Most likely it breaks up or fissions, but a few of the new nuclei lose their extra energy by emitting neutrons, or neutrons and protons in some combination. This de-excitement or loss of energy takes place immediately (less than 10^{-12} sec) after the compound nucleus is formed.

The few atoms during a bombardment that de-excited themselves by losing particles recoiled from the target and stopped in a helium atmosphere. The new atoms were then carried with the helium gas out through a 0.050-inch orifice and electrically collected on a copper conveyor tape (see Figure 3). This tape was periodically pulled along a short distance in order to place the successive groups of collected atoms in front of Au-Si (gold-silicon) solid-state detectors. Each time the tape was pulled, a new group of collected atoms was brought in front of the first of the five detectors, while the group that had been there moved to the second collector, and so on. The tape was pulled automatically every ten seconds, and about once in every hundred pulls or experiments the detectors would record the decay of an atom of 103. When the tape was pulled once every ten seconds, an activity with a 10-second half life produced twice as many counts in the first detector as in the second, the second twice as many as in the third, etc.

Au-Si solid-state detectors are a very recent development. Each one, with its volume of about a cubic inch, can replace a Frisch grid chamber with a volume of about one cubic foot. The detectors are solid-state ionization chambers. They are in many respects just half a transistor—a diode. When a charged particle—an alpha particle, for instance—passes into the detector, ion pairs are produced. These ion pairs are collected in the depletion region of the detector and an electrical pulse develops which is proportional to the energy of the charged particle. The pulse is then amplified and analyzed in a 100-channel pulse-height analyzer.

After californium (Cf) is bombarded by neutron irratiation, it is placed in the target holder illustrated.



Before the experiments started, it was predicted that 103 would have a half life somewhere between 0.3 and 30 seconds and have an alpha-decay energy in the range of 8.0 mev to 8.8 mev. With everything working correctly, up to five counts an hour might be detected during the operation.

In the experiments, counts from decaying 103 atoms were not, unfortunately, the only counts expected. Tracer amounts of lead and bismuth also produce, when bombarded with boron atoms, alpha activity of 8.1 and 8.8 mev. Early experiments showed that this activity could completely mask any activity produced from the californium, unless the amounts of lead and bismuth were reduced to a very low level. The target material was finally purified by heating californium in a vacuum and boiling out the lead and bismuth. It was impossible to separate out the impurities chemically, as even the best reagents available contain too much lead and bismuth. After the "pure" target had been bombarded for many hours, the 8.6-mev activity began to stand out. Many more hours of bombardment were needed to determine that its half life was about 8 seconds. When these two feats had been accomplished, many different targets such as curium (Cm), americium (Am), lead (Pb), and bismuth (Bi) were bombarded under exactly the same conditions to show that they would not produce the activity. During a two-month period, about 100 countable atoms of lawrencium were produced.

Although *lawrencium* has not been chemically isolated, the experiments conclusively showed that it is a new element. Chemically, it will exhibit the properties of an actinide element. The last *5f* electron is filled in lawrencium, thus making it the last of the actinide series. In the future, when increased amounts of lawrencium are produced, its chemical and physical properties can be further studied.

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