$$y_2 = x(T_0)(1 - e^{-\lambda_f(t-T_0)})e^{-\lambda_r(t-T_0)}$$
$$= \frac{R_0}{(\lambda_f+\lambda_r)}[1 - e^{-(\lambda_f+\lambda_r)T_0}] \times (1 - e^{-\lambda_f(t-T_0)})e^{-\lambda_r(t-T_0)}$$
$$= \frac{R_0}{(\lambda_f+\lambda_r)}\left\{[e^{\lambda_r T_0} - e^{-\lambda_f T_0}]e^{-\lambda_r t} + [1 - e^{(\lambda_f+\lambda_r)T_0}]\, e^{-(\lambda_f+\lambda_r)t}\right\}$$

Hence the total amount of radioactivity on the ground at time $t > T_0$ is

$$y(t) = y_1 + y_2$$
$$= \frac{R_0}{(\lambda_f+\lambda_r)}\left\{\left[\frac{\lambda_f}{\lambda_r}e^{\lambda_r T_0} + e^{-\lambda_f T_0} - \left(\frac{\lambda_f}{\lambda_r}+1\right)\right]e^{-\lambda_r t} + [e^{\lambda_r T_0} - e^{-\lambda_f T_0}] \times e^{-\lambda_r t} + [1 - e^{(\lambda_f+\lambda_r)T_0}]\, e^{-(\lambda_f+\lambda_r)t}\right\}$$

$$y(t) = \frac{R_0}{(\lambda_f+\lambda_r)}\left\{\left(\frac{\lambda_f}{\lambda_r}+1\right)[e^{\lambda_r T_0} - 1]e^{-\lambda_r t} - [e^{(\lambda_f+\lambda_r)T_0} - 1]\, e^{-(\lambda_f+\lambda_r)t}\right\} \quad (12)$$

This equation is plotted as curve 1 of Fig. 1.

4) *Future dosage if rate of testing should continue to rise at a constant rate.* The idealized case which is selected as a plausible upper limit to the likely future world-wide testing is taken to be that in which $R(t)$, the rate of production of radioactive materials, increases in direct proportion to the time t. Then if R_0 is the average rate of production during the interval from $t=0$ to $t=T_0$, the rate at any time t is

$$R(t) = (2R_0/T_0)\,t \quad (13)$$

and the material produced in the interval between t_i and $(t_i + dt_i)$ is

$$(2R_0/T_0)\,t_i \cdot dt_i.$$

When this replaces A in Eqs. 3 and 4 and the sums are replaced by integrals over the time t_i, the result is

$$x(t) = \int_0^t (2R_0/T_0)\,t_i e^{-(\lambda_f+\lambda_r)(t-t_i)}dt_i \quad (14)$$

$$y(t) = \int_0^t (2R_0/T_0)\,t_i \times [1 - e^{-\lambda_f(t-t_i)}]e^{-\lambda_r(t-t_i)}dt_i \quad (15)$$

Hence

$$x(t) = \frac{2R_0}{T_0(\lambda_f+\lambda_r)^2} \times [(\lambda_f+\lambda_r)t - 1 + e^{-(\lambda_f+\lambda_r)t}] \quad (16)$$

$$y(t) = \frac{2R_0}{T_0}\left[\frac{\lambda_r t - 1 + e^{-\lambda_r t}}{\lambda_r^2} - \frac{(\lambda_f+\lambda_r)t - 1 + e^{-(\lambda_f+\lambda_r)t}}{(\lambda_f+\lambda_r)^2}\right]$$
$$= \frac{2R_0\lambda_f}{T_0\lambda_r(\lambda_f+\lambda_r)} \times \left[t - \left(\frac{1}{\lambda_r} + \frac{1}{(\lambda_f+\lambda_r)}\right) + \left(\frac{1}{\lambda_f}+\frac{1}{\lambda_r}\right)e^{-\lambda_r t} + \left(\frac{1}{(\lambda_f+\lambda_r)} - \frac{1}{\lambda_f}\right)e^{-(\lambda_f+\lambda_r)t}\right] \quad (17)$$

The latter result, which is shown as curve 3 of Fig. 3, is expressed somewhat more neatly if the decay constants λ_f, λ_r and $(\lambda_f + \lambda_r)$ are replaced by the corresponding mean lives τ_f, τ_r, and τ_t.

For late times, for which $t \gg 1/\lambda_r$, the exponentials in Eqs. 16 and 17 approach zero, so $x(t)$ and $y(t)$ approach the asymptotic values

$$x = \frac{2R_0}{T_0(\lambda_f+\lambda_r)}\left[t - \frac{1}{(\lambda_f+\lambda_r)}\right] \quad (18)$$

$$y = \frac{2R_0\lambda_f}{T_0\lambda_r(\lambda_f+\lambda_r)}\left\{t - \left[\frac{1}{\lambda_r} + \frac{1}{(\lambda_f+\lambda_r)}\right]\right\} \quad (19)$$

With the assumed numerical values for the constants, Eq. 19 becomes

$$y = (38.4\ \text{mc/mi}^2)(t/\text{yr} - 48). \quad (20)$$

This asymptote is shown as the dashed straight line at the right in Fig. 3.

This assumption of a steadily increasing rate of testing is not, of course, the best possible approximation to the course of events over the past few years. However, refinements in the assumptions for this period have little significance because the effects of these early tests are overshadowed at much later times by the large amounts of activity resulting from the assumed accelerated rate of testing.

References and Notes

1. AEC release, 12 Oct. 1956; W. F. Libby, *Proc. Natl. Acad. Sci. U.S.* 42, 365 (1956).
2. W. F. Libby, *Proc. Natl. Acad. Sci. U.S.* 42, 945 (1956).
3. AEC release, Apr. 1957.

4. This work was performed, under the auspices of the U.S. Atomic Energy Commission, mainly in late 1956, which is the closing date for the data used in the examples. I am grateful to Dr. W. F. Libby, Dr. J. E. Rose, Dr. F. E. Throw, and Dr. L. A. Turner for discussion and suggestions. The order of presentation in the text and the "primed" curves on the graphs were kindly arranged by Dr. Throw.
5. Note that these calculations take no account of the radioactivity introduced directly into the troposphere, especially by fission explosions. Actually, in the Northern Hemisphere, tropospheric fallout constitutes a large fraction of the total, so the stratospheric burdens estimated in this paper are probably too high. Moreover, the biological effectiveness of fallout depends significantly on such factors as its precipitation as an insoluble salt and its redistribution in depth because of soil movements. [See W. F. Libby, *Proc. Natl. Acad. Sci., U.S.* 43, 758 (1957).] Such effects would change the numerical values for the stratospheric component of fallout without altering the general course of events. If certain scientists are correct in believing that horizontal mixing in the stratosphere is not very rapid (for example, L. Machta, "Hearings before the Joint Committee on Atomic Energy on the Nature of Radioactive Fallout and Its Effects on Man," May 27–June 3, 1957), the fallout over the earth's surface will be more or less nonuniform.

6. A. F. Stehney and H. F. Lucas, Jr., *Acta Radiol.* 43, 43 (1955); Geneva Conference, vol. 8, p. 852 (1955). Reference is also made to a forthcoming article by J. E. Rose. I am indebted to Dr. Rose for this and related information which suggested these calculations.

Irving Langmuir, Man of Many Interests

In these days of near hysteria on the world-wide scene, as claims and counterclaims are made of the superiority of this or that method of teaching science, of conducting scientific research, and of supporting basic research studies, it would do everyone involved in this turmoil a lot of good if he would pause a moment to consider Irving Langmuir's life, background and attitude toward science [V. J. Schaefer, "Irving Langmuir, Versatile Scientist," *Bull. Am. Meteorol. Soc.* **38**, 483 (1957); "In Memoriam: Irving Langmuir—Scientist," *J. Colloid Sci.* **13**, 3 (1958)]. With his death, on 16 August 1957, the world lost another of the scientific giants who strode across the scientific scene during the first half of the 20th century, leaving a trail of pioneering achievements which those with pessimistic attitudes attempt to explain away as "due to that period being the golden age of science when scientific breakthroughs were easier to come by, because there was so much virgin field to till."

Langmuir's attitude toward the modern scientific scene of the past few years was in direct conflict with such a philosophy. His enthusiasm for the newer achievements remained undiminished, his impatience being directed only toward those he felt were "dragging their feet" and serving as "wet blankets" in the development of new concepts and ideas.

Irving Langmuir on the slopes of Mt. Washington, New Hampshire, on Easter Sunday, 1944.

His research procedures and philosophy were in direct conflict with some of the current attitudes of industrialists and even research directors, who give voice to the idea that the day of the individualist and the "paper-clip, string, and sealing-wax" type of experiment as a basis of scientific achievement is of a bygone era, and that what are needed nowadays are teams of workers using only the most elaborate, expensive, and refined equipment if any degree of progress is to be expected in pushing back the frontiers of scientific knowledge.

It is quite possible that these attitudes have led us into our current predicament. Teamwork is needed for applied research and, in some cases, in operating the great cyclotrons, accelerators, radio telescopes, and satellite launchers whose end result may be the development of new ideas. In the final analysis, however, it is the dreamer, the isolated individual, or the individualist of a research organization who is responsible for the new concept, the radical approach, or the new theory which needs testing.

Langmuir gave wonderful talks on serendipity, which he often discussed with students. I have heard him hold forth at considerable length on the importance of developing an inquiring mind and an active interest in all natural sciences and, when working on a research problem, of trying everything—even the things which apparently will obviously not work! By ranging far and wide in exploring the problem at hand, he stressed the importance of awareness at all times, since it is often at times least expected that the unexpected—the fortunate accident—happens.

Langmuir's concepts of the scientist and his role in society were firm and definite. They were well expressed in his presidential address before the American Association for the Advancement of Science entitled "Science, common sense and decency" [*Science* **97**, 1 (1943)]. He believed that there were some aspects of the world to which the scientific method was not applicable in its commonly accepted framework. These ideas were developed in a talk delivered before the National Academy of Sciences when the new General Electric Research Laboratory was dedicated, and dealt with convergent and divergent phenomena.

It was his conviction that this receptiveness to the unexpected is one of the most important attributes to cultivate if a young student is to become a successful scientist.

Some of his attitudes were undoubtedly acquired from his boss—the beloved and lately deceased Willis R. Whitney. It was "Doc" Whitney who popularized the word *serendipity* and whose daily greeting of "Are you having fun?" and "Have you *tried* it?" undoubtedly served to develop Langmuir's enthusiastic attitude toward his coworkers. It was also Whitney who, when told by the then recently employed Langmuir that he was having a wonderful time but couldn't see how anything he was doing could help the company, retorted that this was *his* (Whitney's) worry, not Langmuir's.

In these days of empire building, conformity, and the organization man, in which the nonconformist, an unorthodox thinker, or an individualist is likely to encounter increased difficulty in finding an environment conducive to living, let alone in carrying out effective research, we should examine the environment which permitted the development of Whitney, Coolidge, Dushman, Hull, and Langmuir. I was privileged to know these men and to be familiar with the environment in which they flourished. It was one permeated with free communication, enthusiastic response to each other's achievements, and sincere helpfulness toward each other's problems. In some respects, the industrial laboratory in which Langmuir spent most of his productive life was an environment perhaps superior to the best universities, since technicians were readily available to cope with problems of fabricating instruments and apparatus, while the new discovery which had practical application could often be followed to its ultimate use. Thus, in addition to enjoying discovery for its own sake, it was often possible to sense the full savor of achievement.

Langmuir's career demonstrates the value of a broad technical education and the importance of presenting intellectual challenges to youngsters at an early age.

I have seen him demonstrate the workings of a slide rule to grammar school students and offer the challenge of underwater swimming and other equally difficult challenges, physical and mental, to preschool youngsters.

He was never happier than when surrounded with youngsters and delighted in getting them to stretch their brains. We need more men like him, and we should devise workable procedures to take advantage of their enthusiastic help wherever programs are under development for leading bright youngsters toward scientific careers. Too little stress has been directed toward drawing the attention of youngsters to the satisfying sense of intellectual achievement which is an integral part of the compensations received by the true scientist. For those who feel that the golden age is past, Langmuir would probably say that it is certainly past for individuals who think this to be true. For the youngsters and the young of heart, he would say that there is no better time than the present, and I am sure he would demonstrate, with many illustrations, the opportunities which abound in all directions for those who have the will to do.

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News of Science

Euratom Agreement

John W. Finney reported in the 8 May *New York Times* that the United States and the European Atomic Energy Community have agreed in principle on a broad-scale cooperative program to promote the development of atomic power in Western Europe. The agreement, which still must be formally approved by both sides, provides for United States technical and financial assistance in the construction of atomic power plants in the six European nations banded together in the atomic energy group known as Euratom. When carried out, the agreement will represent one of the biggest steps yet taken by the United States to implement the policy of atoms-for-peace first proclaimed by President Eisenhower in 1953.

Inspection Issue Solved. In reaching the agreement, the two sides finally succeeded in overcoming the issue of inspection, which had obstructed negotiations in recent months. Previously, Euratom has been insistent that it should perform the inspection to make sure that none of the fissionable materials were diverted to military purposes. The United States, through the Atomic Energy Commission and the State Department, had been demanding inspection rights of its own as a precondition to cooperation.

In the recent negotiations a compromise agreement was reached. The details have not been made public, partly because the issue may still be subject to diplomatic negotiations. The negotiating teams were headed by Max Kohnstamm, special adviser to the Euratom commission, and R. W. Cook, deputy general manager of the Atomic Energy Commission.

Isotope of Element 102

Scientists in the University of California Radiation Laboratory have announced the definite discovery of an isotope of element 102. At the same time they said that in repeated, careful experiments they have been unable to duplicate the work of an international team of scientists who last year reported discovering an isotope of element 102.

The Berkeley research was reported on 5 May in Gatlinburg, Tenn., at a Conference on Reactions between Complex Nuclei, by Albert Ghiorso, a senior nuclear scientist in the Radiation Laboratory. The work was done by Ghiorso, Torbjorn Sikkeland, an exchange scientist from the Joint Establishment for Nuclear Energy Research at Kjeller, Norway; John R. Walton, research chemist; and Glenn T. Seaborg, Nobel laureate and professor of chemistry on the Berkeley campus.

Final identification of the element 102 isotope was achieved early in the morning of April 18, after a sustained 24-hour period of research, climaxing 3 months of experimentation. The element 102 isotope was created by bombarding a rare isotope (mass number 246) of curium (element 96) with carbon-12 nuclei having an energy of 68 million electron volts or carbon-13 nuclei of 75 mev. The new element 102 isotope has a mass number of 254; it decays quickly. Its half-life is 3 seconds. It decays by emitting an alpha particle and turning into fermium-250 (an isotope of element 100). As many as 40 atoms were observed in a single experiment.

The discovery was made by radically new methods of research. As yet the element 102 isotope has not been directly observed—chiefly because of its short half-life. The observations were made on fermium-250, the daughter atom, which has a half-life of 30 minutes. Under the conditions of the experiments, the scientists could deduce that the fermium atoms could arise only from the decay of the isotope of element 102.

In their experiments, the Berkeley scientists deposited curium over an area of less than a square centimeter on a thin nickel foil. This target foil was placed in front of the highly concentrated beam of the heavy ion linear accelerator. The target was enclosed in a container filled with helium gas.

When a curium atom captured a carbon nucleus, a new nucleus was instantaneously formed, four neutrons came off, and the resulting nucleus flew out of the target. This nucleus was slowed down by colliding with the helium atoms, and attracted to a metallic conveyor belt having a negative charge and moving just under the target. The belt passed next to a thin foil plate which had a strong negative charge. As the 102 atoms decayed by emitting an alpha particle, the resulting fermium atoms were kicked off the conveyor belt and attracted to the foil.

The length of foil was cut into five strips, and each was simultaneously analyzed in counters. The distribution of fermium atoms on the foil strips determined the half-life (the fast decay of the atoms of element 102 insured that most of the daughter fermium atoms were deposited on the closest sections of foil to the target, and fewer of them with greater distance). When the speed of the belt was changed, the distribution of fermium atoms varied in conformance with a 3-second half-life for the 102 isotope.

Identification of the atomic number of the element was made by chemically identifying the daughter atoms as fermium in chemical separation experiments with the dissolved foil.

The scientists searched repeatedly for evidence of an isotope of element 102 reported found last year by scientists of the Argonne National Laboratory in Chicago, the Harwell Laboratory in England, and the Nobel Institute in Stockholm, Sweden. These scientists re-