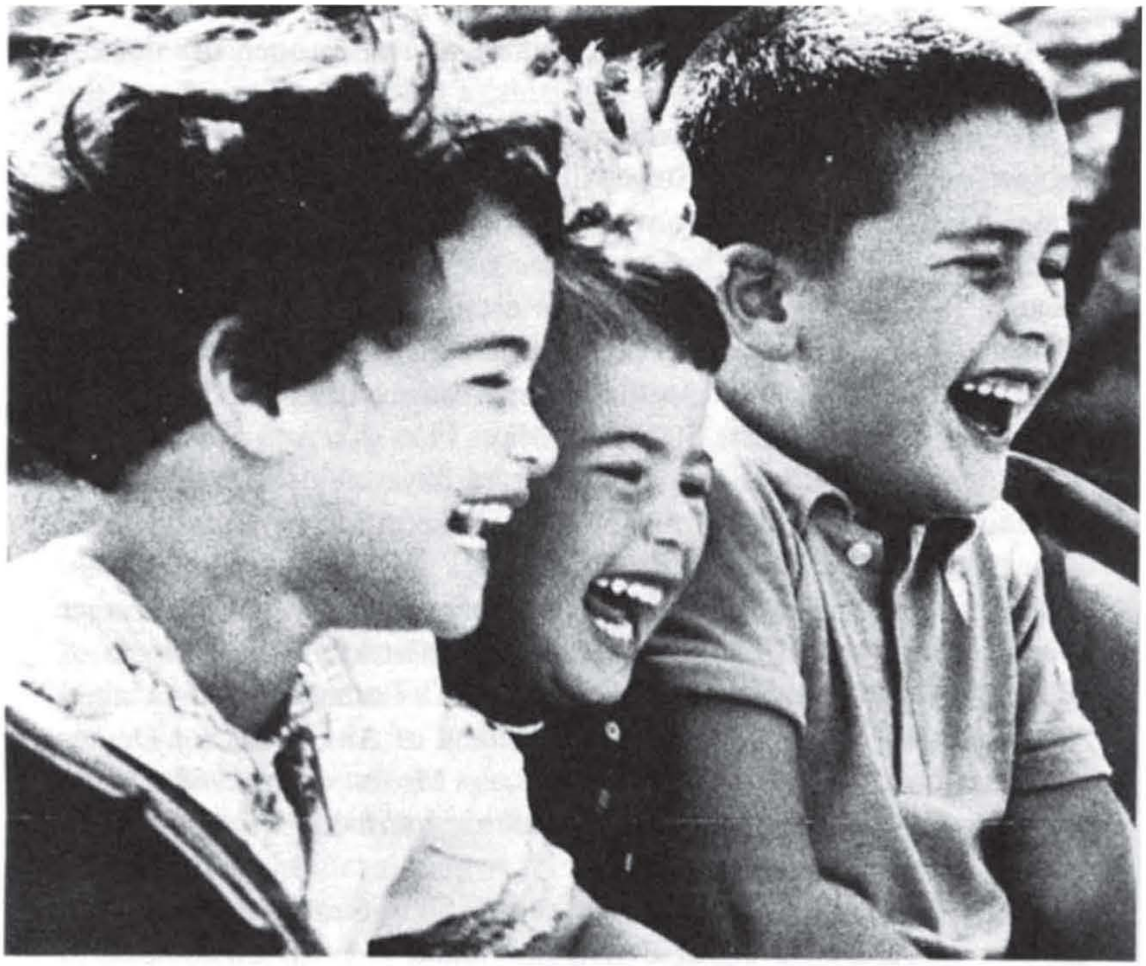

Your children's teeth contain Strontium-90

All children's teeth now contain radioactive Strontium-90 from nuclear weapons tests.

Radioactive Strontium is a potential cause of leukemia, as pointed out in the United Nations report on radiation. Early signs of leukemia appear in the mouth, and dentists are familiar with them.

Scientists can tell how much radioactive Strontium-90 is in children's bones by measuring the radioactive material in their teeth. A recent analysis of baby teeth shows a 16-fold increase in Strontium-90 over the past five years.* Unlike baby teeth, however, the permanent teeth and bones retain Strontium-90 throughout their existence.

As dentists, we deplore the buildup of radioactive Strontium-90 in children's teeth and bones. It is a measure of the sickness of our times. Even if nuclear weapons tests cease today, the accumulation of Strontium-90 will continue for years.

We oppose nuclear weapons testing by all nations not only because of the contamination of bones and teeth of our children and patients, but because it is a direct stimulus to the runaway arms race. The testing race only multiplies mistrust and tension, and increases the chances of nuclear war.

Therefore, as dentists, our responsibility to promote life and health compels us to make this public appeal to all governments to cease nuclear weapons tests and to develop those international agreements which would eliminate the nuclear arms race.

*Committee for Nuclear Information St. Louis Baby Tooth Survey

David Abramson, Norman E. Alderman, Seymour Algus, Maurice B. Atkin, Mark August, Morris Berger, Harold L. Berk, Meyer F. Berkelhammer, Milton Berman, Frank Bisk, Frank F. Beube, Carl Blacharsh, Milton Bloch, Daniel H. Bloom, Bertram Blum, Daniel W. Borkin, Lee Botwinick, Robert S. Breakstone, Raymond M. Bristol, Benjamin R. Bronstein, Louis J. Budner, Jack Budowsky, Harold J. Canter, Murray A. Canter, Andrew F. Catania, George Cohen, Louis M. Cohen, Maxwell B. Colton, Eugene M. Coven, Ralph S. Crapanzano, Stanley Darrow, Zalmen A. Dunn, Irving I. Eckman, Robert S. Eisenberg, Manasseh Elson, Sol Engel, Ulysses Erdreich, Sol Ewen, M. Marvin Fader, Alan Feinstein, Leon Feinstein, Samuel Feinstein, William B. Feldman, Stanley Feuer, Lester Fineman, Stanley Finkelstein, Julius Fox, H. William Frankel, Eugene Fried, Abraham Friedman, Charles Gargle, Milton Garnett, Arnold M. Geiger, Morton F. Geiger, Abraham Geisner, Leon H. Gerbee, Seymour A. Gladstone, Sidney Glatter, Raymond Glauhinger, Philip Gold, Burton Goldberger, Sol M. Goldin, Irving Goldman, David Goldstein, Martin Goldwasser, Leonard Gorelick, Manuel Gottlieb, John Graziano, Albert Green, Lewis L. Greene, Howard Grindlinger, Paul Grindlinger, Henry Hack, Charles Handelman, Henry Hausen, Murray M. Hilton, George A. Hindes, Jack Hirsch, Robert Hoffman, Norman Horowitz, Irving Jaffee, Nathan Janiger, Ilse Jansen, Paul Jarman, Herman Kasten, L. Paul Kaufman, Stanley L. Kent, Joseph Kessler, Nathan Kobrin, Benjamin S. Koplik, Ralph Krainin, Seymour Krauth, Louis Kroll, Paul A. Krooks, Morton Lauter, Nathan M. Leben, J. Lewis Lebov, Harold A. Leegant, Joseph M. Leiberman, Robert R. Lemkin, Emil W. Lentchner, Philip H. Levin, M. Robert Levine, Wilfred Levine, Frederick Levy, Jacob M. Levy, Benjamin Lieberman, Lawrence Lieberman, Victor O. Lucia, Alvin V. Lyons, Samuel Mamlet, Irwin D. Mandel, William I. Margolies, Ralph Margulies, John Oppie McCall, Mortimer Messing, Roger H. Miller, Soloman Mink, Richard M. Moodnik, Melvin L. Morris, Samuel D. Moskowitz, Sidney Moses, Abraham I. Mulson, Hirsch Mullman, Seymour L. Nash, Bernard Nathanson, Samuel E. Neikrug, Leonard M. Nevins, Irving Nussenbaum, Benjamin Ogman, Judah M. Orkin, Jack C. Orzach, Herbert I. Oshrain, Elliot Ossenberg, Irving J. Panken, Leon Pentel, Irving Peress, Arthur L. Phillips, Eugene R. Pinto, Nathan Platt, William Rakower, Benjamin S. Recant, Robert M. Reiss, Lewis Rice, Lee H. Roper, Aaron Rosenbaum, Theodore Rosebury, Emanuel Rosenberg, Martin Rosencrans, Harold Rosenman, Mitchell L. Rosenson, Withal Rosstein, Ephraim A. Rothenberg, A. Allen Rothman, Bernard Rudin, Irving Rumack, Robert W. Sabin, Alexander M. Samuels, Daniel Samuels, Harry Sardell, Donald Sasankin, Solomon J. Satine, Harold Scheiten, Paul Schoman, Marvin Jay Schissel, Don Jay Schlossman, Richard M. Schneer, Walter Z. Schuman, Elias Schwartz, Louis Schwartz, Louis Laszlo Schwartz, Samuel Schwartz, Ben Seidler, Martin Seiger, Paul W. Selden, Abbe J. Selman, A. J. Shapiro, Bernard Shapiro, Gerald I. Shapiro, Earl H. Shatzkin, Alfred R. Shepard, Max Siegel, Samuel R. Siegel, Stanley Siegel, Sidney Silverman, Paul Singer, Simon Solovey, Nathan Sonnerman, Robert Spalten, Clifford N. Stern, Irwin Steuer, Arthur W. Stulbaum, Irving K. Tayner, Harold J. Tennen, Earl G. Thompson, Michael I. Uris, Maurice S. Varon, Allan Wallshein, Bernard Weber, Seymour R. Weinstein, Arthur Burton Weiss, Robert V. Weissman, Jacob J. Weksler, Bernard L. Winter, Louis Wolf, Harold Yachnes, Maurice Yarkow, Harry Zweig.

SPACE FOR THIS STATEMENT HAS BEEN PAID FOR BY THE DENTISTS WHOSE NAMES APPEAR ABOVE. FOR FURTHER INFORMATION WRITE TO DENTISTS' COMMITTEE FOR A SANE NUCLEAR POLICY, 17 EAST 45TH STREET, NEW YORK 17, N. Y. GIFTS TO FURTHER THE AIMS OF THE ORGANIZATION ARE WELCOME.

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18 – U.S. Army, National Atomic Museum; 27 – Bob Paz

Biology and "The Bomb"

by Jennifer Caron

Strontium belongs to the same chemical family as calcium, and like calcium, it concentrates in the teeth and bones, especially of growing children. Strontium-90, or Sr-90, has a half-life of 29 years, meaning that half of it will have decayed during that time. Until it does, however, it exposes the body to beta rays from within, damaging cellular DNA. In 1957, Caltech geneticist Edward Lewis published a calculation of radiation-induced leukemia risks to humans that included Sr-90 as an example. His work was exploited by organizations like SANE, which ran this full-page ad in the *New York Times* on April 7, 1963.

"We have made a thing," J. Robert Oppenheimer told a joint meeting of the American Philosophical Society and the National Academy of Sciences three months after the bombings of Hiroshima and Nagasaki, "a most terrible weapon, that has altered abruptly and profoundly the nature of the world. We have made a thing that by all the standards of the world we grew up in is an evil thing. And by so doing . . . we have raised again the question of whether science is good for man." Among the men who participated in the development of the atomic bomb were Caltech faculty members, as well as scientists who would come to Caltech after the war.

Physicists Robert Christy, Richard Feynman, and Robert Bacher worked on the Manhattan Project. Feynman worked on bomb theory and Christy helped design the trigger mechanism. Bacher was at various times in charge of the nuclear physics division and the bomb division. Physicists Thomas Lauritsen [BS '36, PhD '39] and Jesse DuMond [BS '16, PhD '29] and electrical engineer Robert Langmuir [PhD '43] worked for the Office of Scientific Research and Defense; geochemist Harrison Brown worked on the isolation of plutonium at the Oak Ridge National Laboratory.

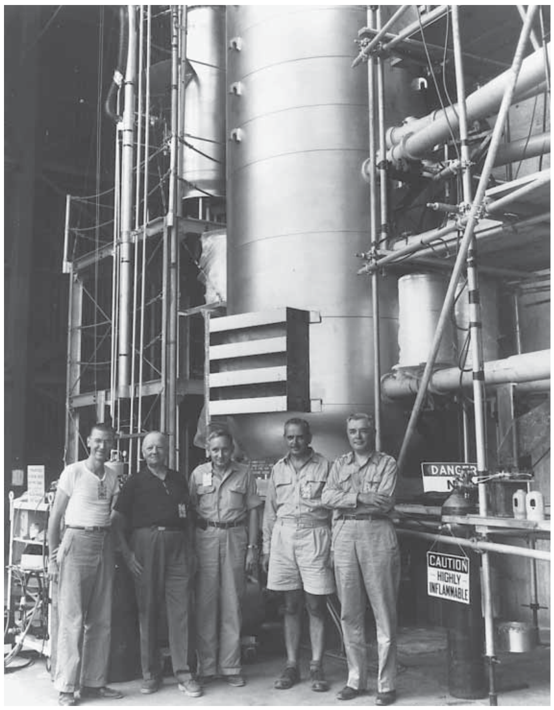
After the war, Brown returned to the University of Chicago and served as executive vice chairman of Einstein's Emergency Committee of Atomic Scientists, working to educate the public about the threat of nuclear weapons. Within a year he published a 160-page book arguing for international control of nuclear power, *Must Destruction Be Our Destiny?* Brown came to Caltech in 1951; because of his growing activism he was given a joint appointment as professor of geochemistry and of science and government in 1967. Chemist Linus Pauling [PhD '25], though he was not involved in the bomb project, also served on Einstein's Emergency Committee.

Christy, Brown, and Pauling all opposed the further development of nuclear weapons. But despite their efforts, and those of like-minded people, the hydrogen bomb was developed under the leadership of Edward Teller and the Atomic Energy Commission (AEC). At least three members of the Caltech faculty had AEC connections. President Lee DuBridge served on its General Advisory Committee, Provost Bacher served on the commission, and George Beadle, chairman of the Division of Biology, served as a science consultant.

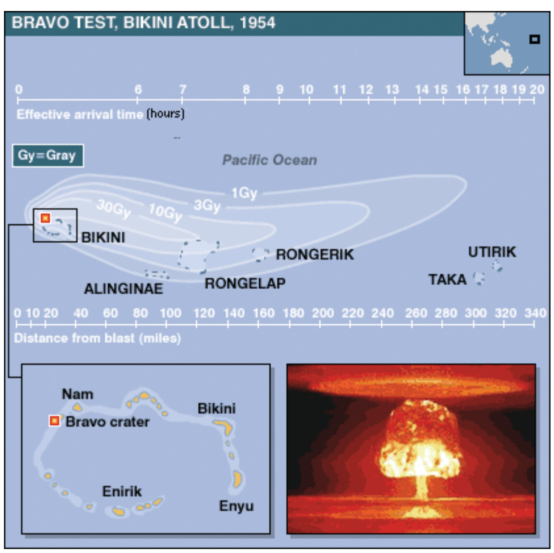
The first hydrogen-fusion device, Mike, was secretly detonated at Eniwetok atoll on November 1, 1952, destroying the mile-wide island of Elugelab and leaving a crater in the ocean floor. The public was told nothing of the power released—only that the AEC had successfully detonated a fusion device in the Pacific.

The AEC planned to secretly test six hydrogen bombs in March and April of 1954. The might of Bravo, the first one, surprised everyone, including the scientists and engineers who built it. The first news of these tests to reach the American press was a brief notice that residents of the Marshall Islands had been evacuated due to radioactive fallout. Two weeks later a Japanese tuna boat, the *Lucky Dragon*, which had been about 85 miles downwind, returned to its home port of Yaizu with its crew of 23 suffering from severe radiation sickness. Panic spread from Japan to the United States.

The H-bomb made it possible to obliterate even the largest cities with a single weapon, and, with a large number of such bombs, to end human life on Earth. Such potential for catastrophe was beyond the grasp of most people. So, in an attempt to communicate the dangers of nuclear war, the *Bulletin of the Atomic Scientists* had earlier created the "Doomsday Clock." When first published in 1947, it read seven minutes to midnight. After the Soviet Union detonated their first atomic bomb in 1949 it was moved to three minutes. In 1953, after both the United States and the Soviet



Mike, the first fusion "device," created a mushroom cloud (above) that rose to 135,000 feet—the top of the stratosphere—in five minutes and lofted 80 million tons of freshly radioactive soil into the air. Mike wasn't exactly portable (right)—it was about 20 feet tall and weighed 82 tons, including 12 tons of cryogenic apparatus to keep its deuterium fuel liquid. The first "real" bomb, Bravo, used solid lithium deuteride, making it a manageable 15 × $4\frac{1}{2}$-foot cylinder. Unexpectedly large amounts of tritium produced by the fast-neutron fission of lithium-7 more than doubled Bravo's predicted yield—to 15 megatons, some 1,000 times the power of the Hiroshima blast. The inhabited atolls downwind (below right) were blanketed with a layer of ash-like fallout up to two inches deep. (The gray is a unit of absorbed radiation dosage.)



Courtesy of www.bikiniatoll.com

Union exploded their first hydrogen-fusion devices, the hands read two minutes to midnight, the closest to Armageddon they have ever been.

While atomic bombs created local fallout for a short time, H-bombs sent radioactive debris into the stratosphere. From there it spread over the globe, descending to Earth for up to two years afterward. On March 31, 1954, nearly a month after Bravo, the chairman of the AEC, Admiral Lewis Strauss, stated that nuclear tests had resulted in a small increase in radiation in some places in the United States. He claimed that this increase was "far below the levels which could be harmful in any way to human beings."

Strauss assumed that, as in the case of many chemical toxins, there existed a threshold dose below which radiation did no harm and that the low dose to which the public was exposed did not exceed this threshold. The threshold assumption was widely held—in fact, shoe stores of the day routinely contained X-ray boxes so that patrons could see the bones in their feet.

Only a select community of biologists understood that the United States and Soviet governments were killing people without realizing it. In the late 1920s, geneticist Hermann Muller had discovered that high-energy radiation caused genetic mutations in fruit flies at a rate proportional to the dosage received. (He won the Nobel Prize for this in 1946.) After the H-bomb tests became public knowledge, he felt morally obligated to warn policymakers and the public about the risk of mutations in the germ line—the reproductive cells in the testes and ovaries—from radioactive fallout.

Muller and Caltech genetics professor Alfred Sturtevant had been graduate students of Thomas Hunt Morgan—founder of Caltech's biology division—at Columbia University. Both Muller and Sturtevant were alarmed by the AEC's assurances that no harm was occurring. In his September 1954 presidential address to the Pacific Division of the American Association for the Advancement of Science (AAAS), Sturtevant enumerated five conclusions that had "now been so widely confirmed that we may confidently assert that they apply to all higher organisms, including man." These were that high-energy irradiation produced mutations at a rate that was directly proportional to dosage, that the existence of a threshold dosage was extremely unlikely, that the effects of successive exposures were cumulative, that children born with a mutation would carry it permanently, and that the overwhelming majority of mutations were deleterious.

At the close of his speech Sturtevant made it clear that he was not taking a political stand. He said, "I do not wish to be understood as arguing that the benefits ultimately to be derived from atomic explosions are outweighed by the biological damage they do. It may be that the possible gains are worth the calculated risk."

Sturtevant as he appeared on the January 1955 cover of *E&S*. Morgan, Muller, Sturtevant, and Lewis all used fruit flies as their experimental organism of choice.

Data on genetic effects takes generations to acquire—a matter of days for fruit flies, but decades for human beings. Clearly some other way was needed to estimate the risks of radiation exposure. In January 1955, Sturtevant published an article in *E&S* titled "The Genetic Effects of High Energy Irradiation of Human Populations." He concluded, "No scientist interested in exact quantitative results would touch the subject, were it not that its social significance leaves us no alternative. We must, like it or not, try to get some sort of idea as to how much, of what, is happening to how many people."

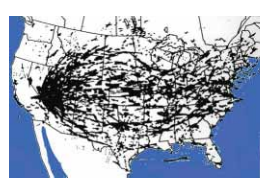
A study of American radiologists published in 1950 had shown that they died of leukemia at a rate 10 times that of nonradiologist MDs. Beadle realized that radiation-induced cancers would be visible in the present generation, making them more available to quantitative analysis than genetic damage to the germ line. In July 1955 he sent a memo headed "Possible Direct Effects on Man of Low Level Exposures to Ionizing Radiation" to the biology faculty. Citing the radiologist study, he questioned the assumption that low-dose exposures were "of negligible importance." Furthermore, he suggested that natural background radiation might cause some leukemias. He identified two ways of pursuing human risk estimates: First, doing further research on those occupationally exposed; and second, studying people exposed to different levels of natural radiation, including increased solar radiation in high-altitude communities. Also, he speculated that the observed increase in cancer rates in the U.S. might be due, at least in part, to heavy cigarette smoking and the increased use of synthetic organic compounds, some of which Sturtevant had pointed out might be carcinogenic.

Edward Lewis was one of the younger members of the biology faculty. After studying with Sturtevant, he had received his PhD from Caltech in 1942. The war under way, Lewis then went through Caltech's meteorology program and became the weather officer for the G2 (intelligence) section of the Tenth Army. He arrived at Okinawa shortly after U.S. troops landed, and stayed on the command ship there until the end of World War II. Returning to Caltech as an instructor in 1946, by 1955 he had worked his way up to associate professor. He responded to Beadle's memo with his own "Memorandum on Fallout," which he circulated to Caltech's geneticists and to Bacher, the division chairman for physics, math, and astronomy, in late November. Sharing the goal of quantitative risk estimates, Lewis summarized the available literature on the biological effects of high-energy radiation and argued the necessity of more accurate measurements of radioactive fallout.

The memorandum went on to say, "It is unlikely that direct radiation effects will show the simple linear relationship to dosage that the genetic effect shows and that the direct effects will be as independent of the time over which the dosage is administered as the genetic effects are. Nevertheless for discussion purposes it may be useful to inquire what the rate of leukemia per R unit [Roentgen] per given population would be if the relationship to dosage is linear and if all forms are considered radiation induced." He concluded that when it became possible to estimate the exposures of survivors from Hiroshima and Nagasaki, and when data on their leukemia rates became available, it would be possible to make "the beginnings of estimates of the direct effects of radiation."

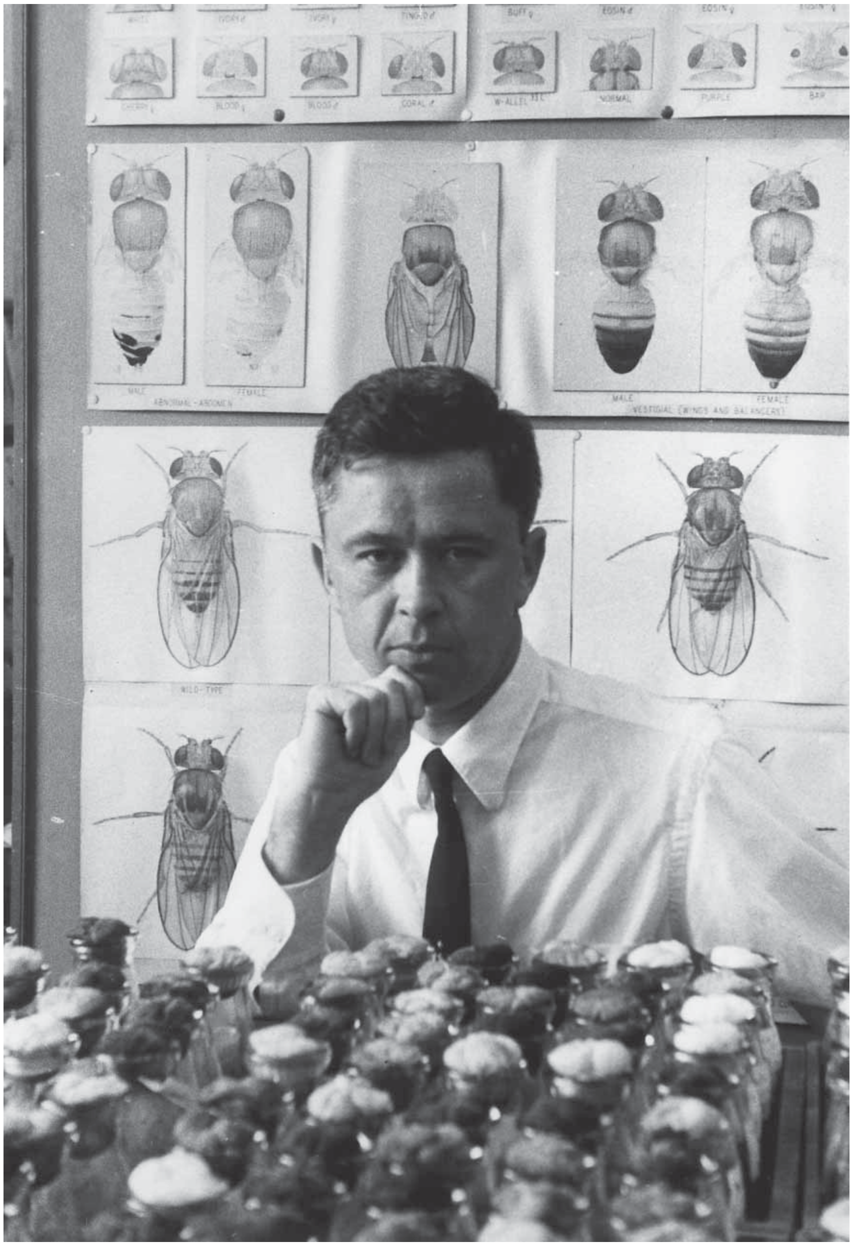
Two days after Lewis's memo, the *New York Times* reported that the Atomic Bomb Casualty Commission had discovered increased incidences of leukemia and cataracts among their study group of 30,000 bomb survivors; however, while it had been feared that the radiation might create previously unknown diseases, none were found. Beadle used his AEC connections to get Lewis the commission's unpublished data.

Lewis told me that several forces motivated him to pursue this research. Over lunch at the Athenaeum—Caltech's faculty club—with members of the physics faculty, he had learned that some of them "were unaware of the possibility that ionizing radiation even at low levels could induce cancer." He was also concerned about the communities around the Nevada Test Site—even the Geiger counter on the roof of Kerckhoff, Caltech's biology building, was recording increased radioac-



After *Under the Cloud*, Richard L. Miller

Fallout from the Nevada Test Site was carried eastward across the entire United States by the prevailing high-altitude winds.



Above: Lewis's fly work was *E&S*'s cover story in November 1957. Above, right: Beadle in 1950 in a three-acre field in nearby Temple City, where Caltech geneticists grew corn from seeds irradiated by nuclear tests. Beadle would share the Nobel Prize in 1958 for his part in the discovery that genes act by regulating specific chemical events.

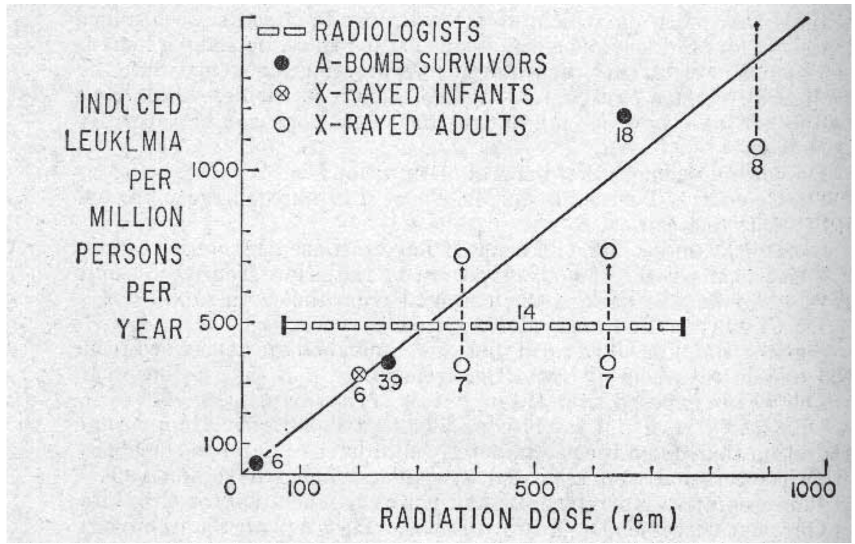
tivity after some of the tests. And of course the curiosity that drove his lifelong career in science also played a role: Muller had proposed the somatic-mutation theory of carcinogenesis in 1937, but it had never been further researched. (Somatic cells are all the cells in the body that aren't germ cells.) Fallout presented an opportunity to examine this theory in the light of human data.

Nationally, 1956 was an exciting year in the debate over nuclear testing. In April, AEC commissioner Thomas Murray called for a unilateral moratorium; he was endorsed by Democratic presidential candidate Adlai Stevenson. In June, the National Academy of Sciences (NAS) issued a report that offered mixed messages on the dangers of radioactive fallout. The AEC was quick to reassure the public.

In the September 1 issue of the *Lancet*, Alice Stewart, M.D., and her coworkers published a study that found that a single, low-dose, obstetric X-ray doubled a child's chances of dying from leukemia or other cancers.

In early October Beadle, Lauritsen, Brown, physicist Matthew Sands, and Sturtevant met over lunch at the Athenaeum. According to Lauritsen they agreed that "a useful purpose could be served by an intelligent statement emphasizing the need for public discussion." This statement was framed by Brown, Lauritsen, Sands, and Christy. On October 14, bearing the signatures of 10 Caltech physicists who had participated in building the original atomic bombs, the statement supporting Stevenson and the cessation of nuclear-weapons testing was published as an advertisement (paid for by the physicists) in the *Los Angeles Times*. The biological effects were among the reasons advanced.

The following day, both DuBridge and Albert Ruddock, chairman of Caltech's Board of Trustees, responded publicly to the ad. DuBridge wrote, "I regret that a partisan stand on the continuation of H-bomb tests has been made by a scientific group because there is no disagreement among American citizens on their desire for peace and for avoidance of nuclear war through enforceable international agreements. . . . The question of the best diplomatic methods of achieving these agreements is not a subject on which scientists are especially competent to render advice. The principal technical question involved in the present debate is whether large-scale tests are an important part of our weapons-research program. Those in responsible charge of that program assure us that they are and that their discontinuance, therefore, should follow and not precede enforceable international



Lewis compiled data from four classes of people exposed to high-energy radiation. "X-Rayed Infants" had been treated for an enlarged thymus—a gland in the neck that is part of the immune system—and "X-Rayed Adults" were patients with ankylosing spondylitis, a crippling, arthritis-like disease. The number below each circle is the number of excess leukemia cases in each population, all of which Lewis assumed to have been radiation-induced. The radiologists were plotted as an elongated bar because the dosages they received were unknown, but the important thing is that a straight line can be drawn through the data points.

agreements. In my own official government contacts I have become convinced that this is the case." Ruddock criticized the ad as "clearly political in character" and warned that it "must not be taken to represent any official position by the Institute, its officers, Trustees, or faculty as a whole." Institute leaders had, for years, provided advice and aid to the government on matters of national defense and disarmament "without the slightest reference to political motivation," he said, and "the Institute stands squarely behind the policies of its government."

Harrison Brown's involvement went beyond drafting the statement. As author Robert Divine explains in his history of the national fallout debate, *Blowing on the Wind*, it was Brown who first encouraged Stevenson to take on the test-ban issue. Brown spent the weekend that the ad was published at Stevenson's Illinois farm working on the candidate's first test-ban speech.

Chemistry professor Linus Pauling had become an opponent of nuclear-weapons development shortly after the war. By 1956 he was a well-known advocate for ending nuclear testing and for international control of nuclear power. At the end of October he wrote to Beadle and carbon-copied Lewis and Sturtevant about a case that a reporter in Nevada had called him about. A seven-year-old boy had died of leukemia in a small town an hour and a half from the Nevada Test Site. The boy and his family had been exposed to fallout intense enough to result in eye irritation, which AEC doctors had told them not to worry about. Pauling informed the reporter "that there was no way of saying what had caused the leukemia" but agreed that the circumstances were suspicious.

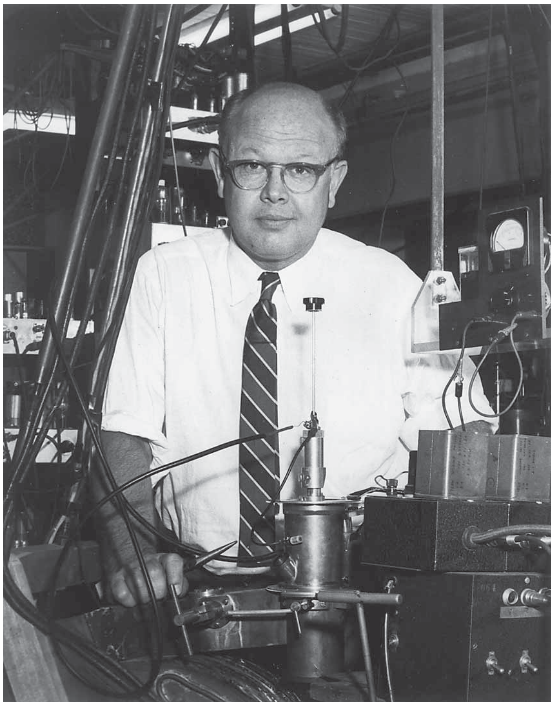
Meanwhile, the *Washington Post* ran an article headed "Tenfold Rise in A-Tests Seen as Safe." This prompted a rebuttal from Sturtevant, run as a letter to the editor on October 26, in which he explained that he was on the NAS committee that had been falsely credited with this conclusion. Furthermore, he said, the AEC's Willard Libby, who was known for downplaying radiation risks, had recently indicated that the strontium-90 danger was greater than previously reported, so that the committee's findings would need "revision upward." (Libby would win the 1960 Nobel Prize in chemistry for the invention of carbon-14 dating.)

Radioactive strontium-90, or Sr-90, is chemically similar to calcium and gets absorbed into the teeth and bones. Not found in nature, it is a byproduct of uranium and plutonium fission—which can be used alone in an atomic bomb, or to trigger the fusion reactions in a hydrogen bomb. It was primarily ingested by eating fallout-dusted crops or the products of the animals that ate them, but could also be absorbed by drinking contaminated water or, in some cases, by inhalation. Once in the bones, it irradiated the body from within, causing leukemia, a cancer of the white blood cells (white blood cells are produced in the bone marrow), as well as other cancers.

Meanwhile, Lewis had been analyzing the AEC data. On November 30, he circulated a draft of a paper, titled "Leukemia and Ionizing Radiation," to several Caltech faculty members, including Pauling and Brown. The covering note concluded, "Comments and especially criticisms are earnestly solicited." DuBridge was convinced that Lewis did not know what he was talking about and sent him to see "a radiologist friend," whom Lewis remembers as "unbelievably ignorant" of the genetic and somatic effects that radiation might cause.

Lewis used data from four independent populations—atomic bomb survivors, ankylosing spondylitis and thymic-enlargement patients (both of whom had been treated with X-rays), and occupationally exposed radiologists—to demonstrate the linear relationship between dosage and leukemia, and argued that this implied that the leukemias resulted from a somatic-cell gene mutation. Furthermore, since the data showed no sign

Fowler in his lab in 1956. He would win the Nobel Prize in 1983 for showing how stars transmute hydrogen and helium into the rest of the periodic table.



of a threshold dose below which mutations did not occur—even at doses as low as 25 R—he concluded that there was no evidence supporting the existence of a threshold for leukemia induction. He estimated that the probability of radiation-induced leukemia was 2×10^{-6} per individual per rad (or rem) per year. This means that a person exposed to one rad and then living for another 60 years without additional exposure would have a total risk of 12 in 100,000, or 12×10^{-5}. (For an explanation of rads, rems, and Roentgens, see the table on page 24.)

Added to the paper's final version was an application of this estimate to strontium-90 exposure, for which Lauritsen and fellow physics professor William "Willy" Fowler {PhD '36} helped Lewis calculate the cumulative doses one would receive as the Sr-90 decayed into radioactive yttrium-90 and thence into stable zirconium-90. Lewis predicted that the AEC's recommended "safe" limit for the public—one-tenth the Maximum Permissible Concentration for workers with radioisotopes—"would be expected to increase the present incidence of leukemia in the United States by about 5 to 10 percent."

Brown was an editor for the *Saturday Review*, a prestigious weekly magazine. The chief editor was Norman Cousins, a national leader in the test-ban movement. Through these men Lewis's manuscript, or a summary thereof, reached Albert Schweitzer, the Nobel Peace laureate for 1952, at his bush hospital in French Equatorial Africa around March 1957.

On April 24, 1957, Dr. Schweitzer issued his "Declaration of Conscience" under the auspices of the Nobel Committee. In it, he called the effects of radioactive fallout "the greatest and most terrible danger" and concluded that nuclear testing is wrong because the whole world pays the costs in health and lives for the military security of a few nations. Furthermore, he argued, people have a "right to know" what is being done to them and to their world.

The following day, Libby wrote an open letter to Schweitzer, in the form of an AEC press release that was widely reprinted, arguing that the proper standard of concern was "detectable effects." He contended that the risks were "extremely small compared with other risks which persons everywhere take as a normal part of their lives." He claimed that the risk of cancer from fallout was less than that from wearing a luminous-dial wristwatch (the hands and numerals were painted with radium to make them glow in the dark) and that "living in a brick house . . . in certain parts of the world, increase[s] radiation exposure many times over that from test fallout." Libby dismissed the moral argument out of hand and concluded, "We accept risk as payment for our pleasures, our comforts, and our material progress. Here the choice seems much clearer—the terrible risk of abandoning the defense effort which is so essential under present conditions to the survival of the free world against the small controlled risk from weapons testing."

On May 1, Pauling gave a speech on the molecular structure of abnormal hemoglobin to the Chicago Section of the American Chemical Society. When the talk ended, a small group surrounded him asking about the effects of fallout. He estimated that 1,000 people would die of leukemia due to the upcoming British test of their first H-bomb. A reporter was in the group and the estimate ended up in the newspaper. Again Libby replied the next day. It seems that they were on a first-name basis, because Libby wrote, "Dear Linus . . . I am very interested in the details of your calculation of this number. I suppose that we probably know more about radioactive fallout

IMAGE NOT LICENSED FOR WEB USE

Edward Clark/*Life*/Getty Images

Congress's fallout hearings got extensive press coverage, including a six-page photo essay titled "A Searching Inquiry into Nuclear Perils" in the June 10, 1957 issue of *Life* magazine. This picture was captioned, "Worried senators, hearing testimony from scientists, are John W. Bricker of Ohio, John Pastore of Rhode Island and Clinton Anderson of New Mexico. Anderson closely questioned witnesses, once corrected a scientist's arithmetic." Another shot showed Lewis in front of a calculation-filled blackboard.

than you do, but I am quite certain that none of us here knows as much about leukemia, so I would like very much to see your calculation."

In a letter that was cc'd to Brown, Beadle, and Lewis, Pauling explained that he had derived the number from Lewis's still-unpublished paper. Lewis had estimated that a dose of radiation from Sr-90 of 0.002 R per year could give an individual a 5:1,000,000 risk of leukemia. Pauling assumed that this dose would be generated for the world's population of 2.5 billion if 50 megatons' worth of fission products were uniformly distributed over the globe. The upcoming test was to be approximately five megatons, yielding his result of 1,000 leukemia deaths.

Privately, Lewis took issue with Pauling's extrapolation to the whole world's population. It was known that fallout was not uniformly distributed—the stratospheric wind called the jet stream brought the vast majority of it to the northern hemisphere and concentrated it along the 40th parallel. Lewis had been careful and conservative in generating his risk estimates; Pauling was being far less careful in his use of them. It is important to understand that Pauling and Brown were motivated not only on health grounds, but also because they believed that ending testing would be a first step to disarmament. In contrast, Lewis and Sturtevant simply wanted the risks to public health acknowledged, and decisions made on the best available information.

On May 15 the British went ahead, against much public opposition, with the H-bomb test at Christmas Island. The same day, Pauling initiated the "Scientists' Bomb-test Appeal," gathering signatures from scientists all over the country.

Fallout was in the news. The Special Subcommittee on Radiation of the congressional Joint Committee on Atomic Energy scheduled hearings on "The Nature of Radioactive Fallout and Its Effects on Man" for June. Beadle and Brown pushed Lewis to publish, which, he told me, made the writing rushed.

"Leukemia and Ionizing Radiation" was the lead article in *Science* on May 17, 1957. In his front-page commentary, "Loaded Dice," editor Graham DuShane put Lewis's contribution in political and historical perspective. He reminded readers of Schweitzer's declaration, Libby's reassurances, Pauling's estimate, and the Earl of Home's response that "we have no information that any deaths have been caused by the Russian and American explosions during 1956–1957." DuShane acknowledged that the issue had become a political debate, greatly complicating efforts at dispassionate scientific discussion, and wrote, "Thanks to Lewis . . . we are approaching the point at which it will be possible to make the phrase 'calculated risk' mean something a good deal more precise than the 'best guess.' . . . It is apparent that the atomic dice are loaded. The percentages are against us and we ought not play unless we must to assure other victories."

A week after the publication of Lewis's paper (and following months of negotiations with the Soviet, British, and French governments), President Eisenhower approved a temporary test ban. On the same day Brown published "What Is a 'Small Risk'?" in the *Saturday Review*, in which he stated that the risk of increased incidence of leukemia from low doses of radiation "was uncovered by a lone geneticist, Professor E. B. Lewis."

Congress invited Lewis to testify. When he arrived in Washington, he visited DuShane at *Science*'s editorial offices, where DuShane said that he had received a "very strong letter from DuBridge protesting the 'Loaded Dice' editorial." (Unfortunately, DuShane could not find the letter while Lewis was there, and it does not appear to have been archived.) As Lewis left the building, several AEC officials entered, apparently to pressure DuShane further. These pressures did not reach Lewis directly; he assured me that the AEC never interfered with his work and that he was not bothered by the House Un-American Activities Committee.

Lewis testified on June 3, the same day that Pauling presented his "Appeal" to Eisenhower. Having been asked to confine his testimony to leukemia and radiation, Lewis explained that "I do not wish to imply that I think that leukemia is the most important effect of radiation on man," and that the genetic, i.e. germ-line effects, or other malignant diseases, might be more important. He had simply chosen leukemia because good data were available. He then explained the threshold-versus-linear controversy and argued for the linear view.

"For three days the scientists testified," *Life* reported, "interspersing their well-ordered presentations with a brain-taxing assortment of figures measured in unfamiliar units like milliroentgens and microcuries. (At one point, Senator Anderson was moved to ask plaintively, 'Can you keep it to pecks, quarts, and bushels?')" Those units might not help today's reader, but perhaps this glossary will.

In his testimony, Lewis used the conservative estimate that Americans were being exposed to 0.001 R, one milliroentgen, of radiation per year from fallout. From this he derived a long-term estimate of 10 leukemia deaths per year, though he explained, "We have not had this exposure long enough to make it 10 per year as yet . . . I do not think it would be higher than 1 to 3 deaths per year at the present time from the fallout that has accumulated so far. In terms of our population [172 million] that is a very minute fraction of the population—an exceedingly minute fraction—but, after all, it does correspond to somebody."

Finally, Lewis evaluated the AEC's safety standard for the general public of 100 "sunshine units," the AEC-named unit for one picocurie of radioactivity from Sr-90 per gram of calcium (as, for example, in the body). The AEC asserted that this dose would not affect the public. Using the linearity hypothesis, Lewis calculated that this dose would cause between 500 and 1,000 cases of leukemia in the U.S. each year, and noted that constant exposure to even one "sunshine unit" would lead to five to 10 cases annually.

Later that afternoon, Lewis participated in a "roundtable discussion" before the committee, centered around the linear-vs-threshold debate. Dr. Jacob Furth, president of the American Association for Cancer Research, who had been studying leukemia for nearly 30 years, posited that there must exist a "reparative force" that would "counteract the effect of very low level radiation." While linearity could not be ruled out as a possibility, he did not consider complete linearity to be "a reasonable probability."

Dr. Hardin Jones of the University of California Radiation Laboratory (now part of Lawrence Berkeley National Laboratory) homed in on the conflict, noting that "part of the difference is in the way people look at small quantities. In very small doses, you get very small effects. It is very easy to say that very small effects are zero, and then you have the threshold concept. If very small effects are just that—'very small'—then you do not have a threshold phenomenon." That day Lewis was given the last word. The danger, as he saw it, came "in legislating a dose that is said to be permissible for the public." Echoing Sturtevant from three years earlier, Lewis argued that, whatever the standards were, "the percentage or the number who are expected to be damaged should be stated, instead of implying that there is no danger from fallout or that the permissible dose will cause no damage."

Three days later, Lewis's work was debated in another roundtable, where Dr. Shields Warren proved to be one of his main adversaries. Warren had been director of the AEC's Division of Biology and Medicine from 1947 to 1952, and was now on the AEC's Advisory Committee and a physician-

Unit	Measures	Definition	Conversions
Curie (Ci)	Radioactivity	1 curie = 37,000,000 atomic nucleus disintegrations per second (dps)	1 microcurie = 10^{-6} Ci = 3.7×10^4 dps 1 picocurie = 10^{-12} Ci = 0.037 dps = 2.2 disintegrations per minute
Rad	Absorbed dose	1 rad = 100 ergs of energy absorbed per gram of irradiated material	1 gray (Gy) = 100 rads = 1 joule per kilogram
Rem, for Roentgen equivalent man	Biological effect	1 rem = the dose equivalent* that gives the biological effect of 1 Roentgen's worth of X-rays	1 sievert (Sv) = 100 rem
Roentgen (R)	Exposure	1 Roentgen of X- or gamma rays produces 1 electrostatic unit's worth of ions in 1 kilogram of dry air	
Sunshine Unit	Sr-90 concentration	1 sunshine unit = 1 picocurie's worth of Sr-90 per gram of calcium (the average adult contains 1 kilogram of calcium)	

*Dose equivalent = absorbed dose × quality factor, which depends on the type of radiation. For X-rays, gamma rays, and beta rays (electrons), the quality factor is 1. For alpha rays, it is 10. Alpha rays are helium nuclei, which can be stopped by a sheet of paper and therefore do not contribute significantly to fallout exposure. Thus, for our purposes, a rad and a rem are essentially equivalent.

pathologist at New Deaconess Hospital in Boston. When Warren said, "I am not at all satisfied that strontium-90 will cause any additional cases of leukemia," Senators John Bricker (R-Ohio) and Clinton Anderson (D-New Mexico) put him in a corner. Anderson reminded him of Lewis's assertion that background radiation was responsible for some fraction of leukemia cases. Warren replied that he knew of no way to prove that assertion. When pushed, he conceded that it was "a fair and reasonable assumption," but added, "I do not think we are warranted in accepting it as an established fact." Bricker noted that Lewis's assumption was an educated guess. Anderson followed, "When you say, also, that one microcurie or one-tenth of a microcurie is a safe background, that is also an educated guess, is it not?" Warren's first reply was no, but then he conceded, "I feel—well, yes it is an educated guess." This was one of many occasions when those defending nuclear testing demanded a higher level of evidence from people advising caution than they required of themselves.

Later that month, Beadle published a letter in *Science* saying that, when speaking as regular citizens, scientists should "make it clear that they are speaking not as experts but are expressing private opinions." This made the biologists unique: At no point did Beadle, Lewis, or Sturtevant make known the personal beliefs that, as engaged and thoughtful men, they surely held. Rather, they always confined their public statements to their field of expertise. For example, on June 21 Lewis gave a summary of his paper at the New York organizing meeting for what became the Committee for a Sane Nuclear Policy (SANE). Both Brown and DuShane attended the meeting. When the group decided that ending nuclear testing was their goal and that the biological effects were a major argument for this, Lewis declined to sign the ad they ran in the *New York Times*, nor did he participate in the group beyond making his presentation.

"I do not think it would be higher than 1 to 3 deaths per year at the present time. . . . That is a very minute fraction of the population—an exceedingly minute fraction—but, after all, it does correspond to somebody."

On October 4, Sputnik was launched, intensifying America's Cold War fears of the Soviet Union.

On January 13, 1958, Pauling presented the "Scientists' Test Ban Petition," signed by over 9,000 scientists internationally, to the United Nations. In May 1958 he published his book, *No More War!*, which included a chapter called "Radiation and Disease" that relied heavily on Lewis's paper.

After the hearings, Lewis was asked to serve on the National Advisory Committee on Radiation, which reported to the Surgeon General under the umbrella of the Public Health Service; it had no statutory authority, but brought together scientists from outside the radiation establishment. It included physicians, public-health officials, geneticists, a scientist from the AEC's Brookhaven National Laboratory, and Lauriston Taylor of the National Bureau of Standards and the National Council on Radiation Protection. Arnold Beckman [PhD '28], president of Beckman Instruments, represented the radiation-instruments industry; according to Lewis, he never said a word. The first meeting was held in Washington, D.C., on March 13, 1958.

In August, A. W. Kimball published a paper in the *Journal of the National Cancer Institute* criticizing Lewis's work. Kimball was a statistician at Oak Ridge National Laboratory, where uranium was processed for atomic bombs. He attempted to create doubt about Lewis's methodology, but found only one error—the confidence limits that Lewis believed were 95 percent were actually 90 percent. This insignificant error had unknowingly been carried over from a published table that Lewis had used in his calculations. The following month Austin Brues, director of the biological and medical research division of the Argonne National Laboratory, which was in charge of the peaceful development of atomic power, published a review article in *Science*. Brues sought to cast doubt on the linearity hypothesis by reinterpreting the available data and looking at other mechanisms that could be responsible for cancer. Lewis did not respond to either paper—he was doing research, teaching genetics, managing Caltech's *Drosophila* collection, working on the Surgeon General's committee, and helping raise three sons at home. The journals wanted responses right away and he was too busy—and exhausted, he told me, from all the attention.

In March 1959, a year after its formation, the Surgeon General's committee suggested that the "ultimate authority" for protecting the public from nuclear radiation be removed from the AEC. The committee called giving the AEC the dual responsibilities of regulating and promoting nuclear power "unwise"—promotion was clearly winning at the expense of public health. Eisenhower agreed, and that August he created the Federal Radiation Council to set safety standards and oversee public-health protection.

In addition to his genetics research, Lewis continued to study the effects of fallout. In June 1959, fearing that the article might meet review problems in *Science*, he published "Thyroid Radiation Doses from Fallout" in the *Proceedings of the National Academy of Sciences*. Sturtevant sponsored the paper on Lewis's behalf; at the time a member of the Academy could submit a paper without further review. In it, Lewis showed that iodine-131, in fresh milk from cows grazed in contami-

SANE ran this full-page ad in the *New York Times* on July 5, 1962.

nated pastures, exposed the thyroid glands of infants and young children to radiation levels approximately equal to that of the natural background, in effect doubling their dose. (The thyroid concentrates iodine, especially in children.) This hazard had previously been overlooked, largely because I-131 has a half-life of only eight days. Just as had Lewis's work on Sr-90, this work provided fuel for SANE's campaign.

The Joint Committee on Atomic Energy held another round of hearings in May 1959, this time on "Fallout from Nuclear Weapons Tests." Representative Chester "Chet" Holifield (D-California) convened the hearings, but unlike the 1957 hearings, which he also organized, these were designed to show the public that fear of fallout was unfounded. Like the AEC, Holifield argued that winning the arms race was worth the small risks of nuclear testing. Lewis was not invited to appear, but presented his findings on both radioiodine and leukemia in a written statement. This time the hearings did not make front-page headlines. The panel concluded that the Sr-90 hazard was slight by comparison to other, normal radiation exposure, but nonetheless present.

Throughout this time diplomats, pushed by public fear of fallout and the more overwhelming, but less discussed, possibility of nuclear war, worked nonstop to find ways to limit the nuclear threat. Soviet officials repeatedly called for a halt in testing, but they refused to consider on-site inspections or other enforcement methods. Thankfully, from 1959 until the Soviet Union detonated an H-bomb on September 1, 1961, the U.S. and the U.S.S.R. voluntarily ceased atmospheric testing. During this time, both the Public Heath Service and the AEC reported that Sr-90 concentrations in American milk dropped rapidly, and the fallout scare subsided. On September 15, the U.S. also resumed testing—but underground, for the first time ever, to avoid generating atmospheric fallout.

Five days later, President Kennedy approved the Federal Radiation Council's proposal to change the guidelines for population exposure to strontium-89, strontium-90, iodine-131, and radium-226. The AEC subsequently modified its regulations. Atmospheric testing, however, was not yet over—on April 25, 1962, the United States resumed it in the Pacific.

On August 5, 1963, more than a decade after the first thermonuclear explosion, the nuclear powers of that time—the United States, Great Britain, and the Soviet Union—signed the Limited Test Ban Treaty banning nuclear tests in the oceans, in the atmosphere, and in outer space. This treaty went into effect on October 10, at which time the Nobel Committee announced that it would award the held-over 1962 Peace Prize to Linus Pauling for his continuous efforts, beginning in 1946, to end nuclear-weapons tests and

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Pauling, who had won the Nobel Prize in 1954 for his work on the chemical bond, was invited to dinner with President Kennedy at the White House with other Nobelists on April 29, 1962. He took the opportunity to picket his host the preceding day, joining a demonstration protesting the American resumption of nuclear testing.

Lewis shared the 1995 Nobel Prize with Christiane Nüsslein-Volhard and Eric Wieschaus for the discovery of "master" genes that control other genes in early embryonic development. These genes, in turn, control other genes that control still more genes, allowing the creation of limbs and even entire body segments to be directed by a handful of genes being turned on in the proper order. Using X-rays to manipulate the genes of the bithorax complex, Lewis created a mutant fruit fly (above) with an extra set of wings. A bithorax fly of real fruit (or at least, vegetable matter) decorated a cake (below) at a campus celebration in his honor.

"against all warfare as a means of solving international conflicts."

Many outspoken activists who had clear political agendas could not, at the same time, speak with the authority of science on related issues. One of Pauling's most powerful tactics was to employ Lewis's risk estimates to show the costs in human lives. Similarly, SANE used the health effects of fallout as their central argument. These activists relied heavily on the credibility of Lewis and other scientists who were careful to limit their statements to their areas of expertise and to remain as much outside the political quagmire as possible. Without both the sensational and the scientific, the movement to end nuclear testing would have been either without a widely heard voice or without authority. □

Jennifer Caron (BS '03, Science, Ethics, and Society) wrote her senior thesis on Lewis's role in the national fallout debate. She will be attending the Johns Hopkins School of Nursing this fall.

For further reading, see :

Blowing on the Wind: The Nuclear Test Ban Debate, 1954–1960*, Robert Divine, Oxford University Press, 1978;*

Genes, Development and Cancer: The Life and Work of Edward B. Lewis*, edited with commentary by Howard Lipshitz, Kluwer Academic Publishers, 2004;*

Under the Cloud: The Decades of Nuclear Testing*, Richard Miller, Two-Sixty Press, 1986; and*

"Edward Lewis and Radioactive Fallout: The Impact of Caltech Biologists on the Debate over Nuclear Weapons Testing in the 1950s and 1960s," *Jennifer Caron, 2003, http://resolver.caltech.edu/CaltechETD:etd-03292004-111416*

On July 21, as *E&S* was going to press, Ed Lewis died after a long battle with cancer. He was 86. An obituary will appear in a subsequent issue.