EDWARD LEWIS AND RADIOACTIVE FALLOUT

THE IMPACT OF CALTECH BIOLOGISTS ON THE DEBATE
OVER NUCLEAR WEAPONS TESTING IN THE 1950s AND 60s

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ABSTRACT

The work of Caltech biologists, particularly, Edward Lewis, on leukemia and ionizing radiation transformed the public debate over nuclear weapons testing. The United States began testing hydrogen bombs in 1952, sending radioactive fallout around the globe. Earlier more localized fallout was generated starting in 1945 from tests of atomic weapons at Nevada test sites. The Atomic Energy Commission claimed the tests would not harm human health. Geneticists knew from animal and plant experiments that radiation can cause both illness and gene mutations. They spoke out to warn the policymakers and the public. Edward Lewis used data from four independent populations exposed to radiation to demonstrate that the incidence of leukemia was linearly related to the accumulated dose of radiation. He argued that this implied that leukemia resulted from a somatic gene mutation. Since there was no evidence for the existence of a threshold for the induction of gene mutations down to doses as low as 25 r, there was unlikely to be a threshold for the induction of leukemia. This was the first serious challenge to the concept that there would be a threshold for the induction of cancer by ionizing radiation. Outspoken scientists, including Linus Pauling, used Lewis's risk estimate to inform the public about the danger of nuclear fallout by estimating the number of leukemia deaths that would be caused by the test detonations. In May of 1957 Lewis's analysis of the radiation-induced human leukemia data was published as a lead article in *Science* magazine. In June he presented it before the Joint Committee on Atomic Energy of the US Congress.

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The National Context

Scientists were thrust into the public eye and the political arena after World War II and the development of nuclear weapons. The atomic bombs that devastated the cities of Hiroshima and Nagasaki in August of 1945, although they led to the end of World War II, increased mankind's destructive capabilities by many orders of magnitude. The fear created by the Cold War, McCarthyism, and nuclear weapons pervaded the country and added difficulty to the open discourse that is so important to the pursuit of scientific knowledge. At the same time as many scientists felt a responsibility to educate the American people about the dangers of nuclear weapons and nuclear war, pressure was put on others to reassure the public.

The stakes were raised in 1952 when the destructive technology of nuclear bombs took a thousand-fold leap with the secret explosion of the first thermonuclear or hydrogen bomb on the Eniwetok atoll in the Pacific Ocean. The first publicly known tests began on March 1, 1954 at Bikini. Hydrogen bombs spread radioactive material higher and farther, and deposited it over longer periods of time than the original atomic bombs. This prompted geneticists to warn of the known and suspected dangers of radiation exposure.

The first atomic bombs were powered by nuclear fission and generated several forms of radiation, including radioactive fallout in the local area. Fallout refers to radioactive materials that are sent by the nuclear explosions into the atmosphere and are later deposited on the ground, "falling out" of the contaminated sky; these materials include strontium-90, cesium-137 and carbon-14, along with many other radioactive elements. While the first atomic bombs were powered by nuclear fission, hydrogen bombs are fission-fusion-fission weapons which can generate the same kinds of radioactivity in far greater quantities. Fallout from H-bombs is hurled by the explosion into the troposphere and stratosphere. The particles that stay in the troposphere come to earth over a large area in a time period of months. Those that reach the stratosphere come down all over the globe, sometimes for years [1].

Global fallout presented new moral, ethical, and scientific problems with nuclear weapons testing. The Atomic Energy Commission (AEC) claimed that any risks to human health, if present, would be too small for concern. However, scientific inquiry had taught many that this was not the case. Large doses of radiation could cause radiation burns and illness, as happened to many early researchers who, at the turn of the 20^{th} century, knew little of the danger. Beyond these relatively immediate effects, geneticists knew that X-rays generate deleterious mutations in animals and plants and had shown that x-rays can cause leukemia and other cancers in animals.

The fact that radiation causes biological damage became clear when experimenters experienced radiation burns shortly after the discovery of x-rays by Roentgen in 1895, and of natural and artificial radioactivity a few years later. Many years later researchers began developing malignant tumors in places where they had received large radiation exposures. Radiation was anecdotally, and controversially, linked to leukemia beginning around 1911. When the German Roentgen Society erected a monument in memory of those who died as a result of their pioneering work studying radiation in 1936, one hundred sixty-nine names were recorded. These people died of skin cancer, anemia, leukemia, accidents, and other causes [2].

In their 1952 textbook *General Genetics,* Adrian Srb and Ray Owen noted that X-rays cause mutations both in the somatic cells and in the germ cells [3, 252]. They warned that while mutation "provides the raw material for progress" in evolution and controlled breeding, it is generally a random process which usually results in deleterious changes. "Defective human germ plasm," they said, "must therefore be considered among the recognized hazards of atomic warfare, since the ionizing radiations increase mutation rates" [3, 255].

Starting in 1954, many geneticists began to voice concern about the biological effects of high energy or ionizing radiation. These scientists were motivated by both their sense of social responsibility and their scientific responsibility to asses the hazards. They drew upon H. J. Muller's 1927 discovery[1] that X-rays cause mutations in fruit flies at a rate linearly proportional to the dose of radiation [4]. President Eisenhower's stepped nuclear testing began at Bikini in 1954; the aggressive testing alarmed Muller. He became greatly concerned for the genetic health of humanity because the majority, if not all of the experimentally observed mutations induced by radiation were detrimental to future generations. As an established leader in the field of genetics, Muller encouraged other geneticists speak out about the dangers of fallout to the human germ plasm.

Genetics has changed a great deal since Muller's time. Watson and Crick discovered the chemical structure of DNA in 1953. The implications of this discovery, including the resulting acceptance of DNA, rather than protein, as the genetic material were just beginning to be worked out during the years of the fallout debate. Looking back with current knowledge of DNA's structure and function, pathways by which high energy radiation can cause genetic damage both to the genetic material inside

[1] For which he received the 1946 Nobel Prize in Physiology or Medicine.

reproductive and somatic (body) cells can be understood with relationship to the chemistry of DNA. However, when the issue of hydrogen bomb testing arose, geneticists and biochemists were trying to understand the chemical nature of the hereditary material. At the time genes were units of inheritance located on chromosomes and understood by their relationship with phenotypic characteristics. Geneticists in the 1950s were faced with a pressing need to explain both well established findings and the results of current work to policymakers and the public so that any unnecessary exposure to radiation and consequent health hazard would be avoided.

These tasks were fraught with difficulties. The Atomic Energy Commission was charged both with developing nuclear power for military and peaceful purposes and with safeguarding the public health, missions that were sometimes mutually exclusive. They were quick to assert and defend the position that there was nothing to worry about from nuclear testing, complicating efforts to access the danger.

In the June 1955 issue of the *Bulletin of Atomic Scientists,* Muller explained his motivation for speaking out about the dangers of radiation. He felt it was his social and moral responsibility to warn the public of the risks. Muller wrote,

> And now today, even in our own country, we see certain versions—or is it perversions—of genetics raising their heads, not primarily among geneticists, but among groups who wish to create a semblance of scientific support for some preconceived policy. The matter at issue now [1955] is that of the genetic effects of radiation." [5, 296-302]

Genetic effects were not the only concern, although they received the most attention before 1957. Concerns about radiation-induced cancers were also left almost unrepresented in the 1956 reports on the biological effects of radiation from the National Academy of Sciences and the British Medical Research Council. Scientists aware of the link between radiation and cancers saw these reports as clearly uninformed. Sir Richard Doll of England, who was researching the effects of ionizing radiation in the 1950s, recalls that:

> Further test explosions seemed certain to be carried out by competing powers and determination of the quantitative effects of small doses of radiation became a burning issue. National committees were appointed in the UK and the US to review the evidence. Their reports made it clear that no quantitative estimate of the risks could then be made (Medical Research Council, 1956; National Academy of Sciences, 1956a) and an immense amount of research was initiated. [2]

From his home at Indiana University, Muller wrote letters to dozens of geneticists throughout the United States. Many of the recipients were connected to his mentor, Thomas Hunt Morgan, founder of the Caltech biology department. Among them was fellow student of Morgan, Alfred Sturtevant, a professor at Caltech.

The Fallout Debate at Caltech

Sturtevant was a highly respected, established scientist. He shared Muller's concerns about nuclear testing and the Atomic Energy Commission's claims that there was no danger from the radiation generated, and communicated them with the scientists in his extensive networks. In his June 1954 Presidential address to the Pacific Division of the American Academy for the Advancement of Science (AAAS) on "Social Implications of the Genetics of Man," Sturtevant devoted half of the speech to "the effects of high-energy radiation on the genetic properties of man." He warned that radiation can cause burns and illness, including cancers, but these were not his primary concerns. Like Muller, Sturtevant feared the damage done by the increase in radiation to human genetic material. He explained that radiation caused detrimental, often gross, mutations in experimental organisms. Furthermore, he argued that humanity was in more danger than other organisms from the genetic effects of radiation because our social institutions would inhibit the process of natural selection, which would otherwise eliminate most of the detrimental mutations before the individuals carrying them had a chance to pass them on.

While it is not possible to extrapolate quantitatively from laboratory organisms to humans, Sturtevant put forward five qualitative conclusions that had "now been so widely confirmed that we may confidently assert that they apply to all higher organisms, including man":

1) High-energy irradiation produces mutations.
2) The frequency of induced mutations is directly proportional to the dosage of irradiation. There is almost certainly no threshold value below which irradiation is ineffective.
3) The effects of successive exposures are cumulative.
4) The effects are permanent in the descendants of the affected genes. There is no recovery.
5) The overwhelming majority of these mutations is deleterious—that is, they seriously affect the efficiency of individuals in later generations in which they come to expression. These deleterious genetic effects may lead to early death or to a wide variety of defects, often gross ones.

At the close of his speech, Sturtevant cited an official press release from the White House that angered him. In it Chairman Strauss of the Atomic Energy Commission stated that the radiation generated by the nuclear tests was "far below the levels which could be harmful in any way to human beings" [7].

It is important to understand that Sturtevant's effort was not motivated by an agenda to end nuclear testing. He clearly states that he believed, "It may be that the possible gains are worth the calculated risk," but he felt that the risk and its far reaching effects on the whole of humanity must be acknowledged and considered. This approach was powerful because it had the effect of making the assertions of its adherents difficult to dismiss as biased by a larger political agenda.

Speaking out about the hazards of radiation, which government organizations did not want to acknowledge, sometimes had consequences. H.J. Muller's submission to the 1955 International Conference on the Peaceful Uses of Atomic Energy was excluded. Though he attended, he was not allowed to participate in the discussion because the Atomic Energy Commission prevented him from being an official American delegate. The AEC's explanation for excluding such a prominent scientist was that Muller's mention of the bombing of Hiroshima made his paper inadmissible for a conference on peaceful uses of nuclear power [8].

Muller's exclusion of the conference moved George Beadle, chairman of the Biology Division at Caltech and president of the AAAS, to write an editorial in *Science*. Beadle stressed the need for "free and open discussion of the hazards to man of radiation." While Muller's views on these issues were very different from those stated by the Atomic Energy Commission, they were not so distant from those supported by much of the genetics community. Muller received a standing ovation while he sat silently in the audience of the conference's panel meeting on "Genetic effects of radiation: human implications" [9].

Beadle and Sturtevant were not the only Caltech faculty speaking out about nuclear testing. On October 11th, 1956 they met for lunch with Professors Harrison Brown, Matthew Sands, and Thomas Lauritsen, who were considering making a public statement supporting a unilateral halt to nuclear testing so long as no other nations tested bombs, as proposed by the Democratic presidential candidate, Adlai Stevenson [10].

Each of these men had played a part in the building of the first atomic bombs: Brown had been the Assistant Director of Chemistry, Plutonium Project, Oak Ridge; during the war Sands was a physicist at Los Alamos and Lauritsen was a physicist with the Office of Scientific Research and Development [11]. Bearing the signatures of ten Caltech physicists, their statement was published in the *Los Angles Times* three days after this lunch meeting, October 14, 1956.

These men had many different reasons for wanting nuclear testing stopped. Professor Robert Christy worked at Los Alamos and developed the trigger mechanism for the plutonium bomb that was used on Nagasaki. He was motivated by a desire to see an end to the development of nuclear weapons and world-wide disarmament [12] [13]. The main purpose of a halt to nuclear testing, according to these scientists, would be to "get the negotiations [for international control of nuclear power] out of the deadlock stage." They listed four additional advantages, the first of which was that a halt to testing would "decrease our exposure to radioactive fallout and its associated dangers."

The next day both the president of Caltech, Lee DuBridge, and the chairman of the board of trustees, Albert Ruddock, published statements condemning the physicists' statement. They reiterated that the physicists did not represent Caltech, which supported the government's policies [14]. DuBridge wrote,

> 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 agreements. In my own official government contacts I have become convinced that this is the case. [15]

Additionally, several trustees, including future chairman of the AEC, John McCone, wrote strong letters to the president about the inappropriateness of the physicists' statement. DuBridge's position was unenviable, because on the one hand he had strong government and AEC connections and a conservative board of trustees, and on the other, a majority of the faculty who held liberal political views [16].

The Problem of Cancer and Fallout

Most of the geneticists (including Muller and Sturtevant) who spoke out about fallout from 1954 through 1956 and into 1957 offered cautions about effects of the radioactive substances on later generations. It might have been possible to see if there were more mutations in the progeny of parents who had been irradiated, from medical x-rays or other sources. However, none of the researchers were in positions to do such work. Furthermore, such work could not have been done very quantitatively.

In 1955 Sturtevant published an article entitled "The Genetic Effects of High-Energy Irradiation of Human Populations," in the Caltech magazine *Engineering and Science*. In this article he explained, "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" [17].

In July of 1955 Beadle sent out a memo titled "Possible direct effects on man of low level exposures to ionizing radiation." Direct effects meant effects on the present generation that might be observable. In the memo Beadle questioned the AEC's assumption that doses of radiation below 0.3 r units (Roentgens) per week and 3.9 r units per year would not cause any important effects, these were the doses deemed safe for people living near the Nevada test site. He cited a 1950 study showing that American radiologists died of leukemia at a rate ten times that of non-radiologist MDs as a source of his concern. Then he proposed two ways of getting additional data on leukemia and radiation in people. The first was to do further studies of radiologists and the second was to look at high altitude cities where inhabitants would be exposed to more cosmic radiation than people who lived at lower altitudes [18].

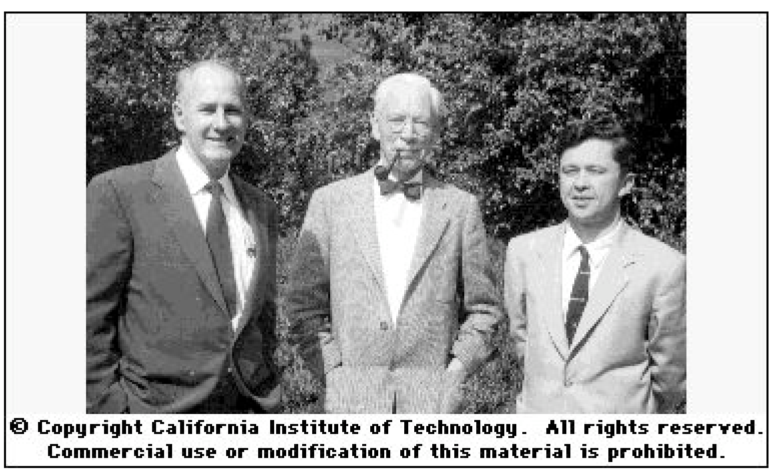
There was no way to predict with much certainty how much radiation exposure would result in how many mutations in human beings. In 1937, a decade after his discovery of X-ray generated mutations, Muller wrote “it is but a logical step to conclude that carcinomas, sarcomas, and leukemias arising after irradiation represent mutations induced by the latter” [4]. Muller and the other outspoken geneticists did not emphasize this conclusion, that radiation could cause cancer. Unlike what were referred to as the genetic effects of radiation, these cancers, referred to then as somatic effects, would manifest themselves within the present generation of people. This made quantitative study of leukemias and other cancers possible, though difficult.

Four months after Beadle’s memo, Edward Lewis wrote a memo to the Caltech geneticists further addressing the problem of getting data on the direct effects of radiation on man. The memo is divided into two sections. In the first section Lewis explains the need for data on the physical measurements of radiation dosage because the information being published by the AEC and other researchers was woefully incomplete. In the second section he laid the groundwork of a study of the available data on human leukemia and ionizing radiation.

Lewis noted that some forms of leukemia might have a mutational origin and that the available data on the atomic bombing survivors showed a highly significant increase in leukemia. He wrote,

> 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 per given population would be if the relationship to dosage is linear and if all forms are considered radiation induced.

Using the linear model Lewis derived a rough estimate of this number from the incidence of leukemia in the population that was within a kilometer of the explosion's hypocenter. This estimate of 2 to 12 cases of leukemia per 100,000 persons per r unit is a full order of magnitude greater than the estimate he would reach after further study and publish a year and a half later. Once it is possible to estimate the radiation exposures of the different groups of Hiroshima and Nagasaki survivors, he wrote, "then the available data on leukemia incidence in these groups becomes available for making the beginnings of estimates of the direct effects of radiation" [19].



George Beadle, Alfred H. Sturtevant, Edward B. Lewis
Courtesy of the Caltech Archives PhotoNet Photo ID 1.47-7 (no date)

Radiation and Leukemia: Lewis's Estimate

In his 1957 paper titled "Leukemia and Ionizing Radiation" Professor Edward Lewis of Caltech used available data on populations that had been exposed to high energy radiation to generate the most widely cited of the first quantitative risk estimates of leukemia caused by radiation[2]. Lewis worked on analyzing the available data on people who had been exposed to radiation and making these estimates throughout 1956. He looked at four data sets: atomic bomb survivors, adults who received radiation therapy for anklosing spondylitis (arthritis of the spine that strikes young people, typically between 17 and 35 years old [20]), infants who were irradiated to treat thymic enlargement, and American radiologists who were occupationally exposed to radiation over many years. From these data Lewis derived a linear dose-response curve and the risk estimate of 2 cases of leukemia per million persons per rad per year.

The debate over the effects of fallout on human beings had reached a point of being one ideologically influenced expert opinion against another. George Beadle would later explain the problem,

> If one takes the position that the probability of war can be reduced most effectively by a build-up of nuclear weapons to the point that no nation will dare to use them, one tends to argue that the biological hazards of bomb-testing are of such relative insignificance that they can be disregarded.
>
> On the other hand, if one is strongly convinced that such a building-up of nuclear weapons, involving ultimately many nations, will greatly increase the chance of nuclear war, there is an almost irresistible tendency to bolster the position with arguments that sound scientific but are not. [21]

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[2] Santosh Kumar Mazumdar and A. Nagartnam estimated the risk to be 3 cases of leukemia per million people per year per roentgen in an article published in the British Medical Journal on March 30, 1957. This paper is reprinted in Part two of the Joint Committee's report on The Nature of Radioactive Fallout and its Effects on Man pages 1684-86.

Lewis's quantitative study shifted the debate by focusing on available data on human beings, rather than extrapolating from animal models or anecdotal evidence. His paper and testimony before the Joint Committee on Atomic Energy transformed the debate over nuclear testing because it raised for the first time the possibility that fallout could result in leukemia. This work made the danger of fallout real and definite; even though the risk estimate predicted only a relatively small increase in the incidence of leukemia due to nuclear testing. Lewis's analysis of human data, and the integrity he brought to it, broke through the ideological divisions between those who argued that testing nuclear weapons would increase national security and those who argued that it would decrease national security and increase the chances of devastating nuclear war.

The most controversial aspect of his analysis was the linear dose-response curve. This relationship made sense to geneticists who had found a linear relationship between radiation and mutations in Drosophila down to 25 rad (Stern and Spencer). Additionally, it fit with the hypothesis of Muller that cancer could result from somatic mutations. This was not the accepted idea in other scientific and medical communities. Rather, as the official voice, the AEC medical doctors and scientists promoted the assumption that there would be a threshold below which radiation would do no harm, just as there is frequently such a threshold in chemical toxicology because the body can process small quantities of toxins like alcohol. The AEC vocally assumed and defended the threshold hypothesis; furthermore, they seem to have assumed that the amount of radiation received by Americans from fallout would be less than the threshold. Lewis found no evidence for such a threshold, and the AEC scientists were unable to offer any.

Lewis was the point-person for the linearity hypothesis at the Joint Committee on Atomic Energy Congressional Hearings in 1957. Both Linus Pauling, who won the 1954 Nobel Prize for chemistry, and Albert Schweitzer, holder of the 1952 Peace Prize, became active opponents of nuclear testing in part due to the information Lewis provided in his paper. With the force of their personalities and the fame generated by their Nobel prizes, they took the statements of many geneticists, including Lewis, to an international audience. Pauling used Lewis's estimate to predict the number of people that would be killed by leukemia as a result of test detonations, and informed the public of the magnitude of health hazards. Lewis's work entered the debate over nuclear testing through several different channels, and it made a crucial contribution to the scientific and public debates that led to the Limited Nuclear Test Ban which halted atmospheric nuclear weapons testing in 1963.

Edward Lewis is now 84 years old and a celebrated man. Mendel worked in his pea garden unraveling secrets of heredity; Lewis has spent his life studying fruit flies and discovering natural rules that are at the foundation of modern genetics. In 1995 he shared the Nobel Prize in Physiology or Medicine for his "discoveries concerning the genetic control of early embryonic development." In addition, he received prestigious awards including the National Medal of Science (1990), and two honorary degrees, one from the University of Umea in Sweden (1981) and the other from his undergraduate alma matter, the University of Minnesota (1993). Lewis's Nobel biography, and Pete Magee's presentation speech at the University of Minnesota, describe his many and foundational contributions to developmental genetics. Nevertheless, they do not mention Lewis's role in the debate over nuclear fallout [22] [23].

In many respects Edward Lewis's personality makes it surprising that he would choose to do scientific work in such a politically charged area. Lewis is a quiet man. Most days he can be found in his office, which looks more like a part of the lab than a separate office. There are fruit flies in small glass bottles on a metal cart, microscopes, a sink, other research equipment and, in the corner nearest the door, a desk with a large computer monitor, bookshelves, and a filing cabinet. A piece of wood, the kind one would hang tools from in the garage, has been attached to the desk and prevents people in the hallway from seeing Lewis at work. He is not fond of much attention; although he has many awards, none hang on the walls of his office.

Lewis did not seek to campaign against nuclear testing. His motivation in researching the biological effects of fallout was not primarily political, he wrote "I was not motivated by hoping the result would argue that weapons testing should cease on biological grounds, namely genetic damage" [24]. Rather, he was intrigued with the opportunity to study Muller's hypothesis that somatic mutations could cause cancer in human beings[25]. Lewis explained his involvement in the fallout debate in an interview:

> I simply planned to publish what I could find out from existing data on somatic effects and never thought of it as a public policy issue….What I was doing was essentially treating radiation risks as a public health problem. I learned that only after being on the PHS radiation committee [1958]. I was often ridiculed for worrying about risks of the magnitude as the one involved in leukemia. *Better to state the risks than to tell people there is simply no danger as the AEC did.* Also I pointed out in my Joint Committee statement that the risk estimates are so low (for leukemia) that an individual receiving even a large dose of irradiation (to cure or alleviate symptoms of a tumor for example) can be reassured that his or her lifetime risk will still be relatively low. This of course showed that there is another side to the making of risk estimates. [26] [emphasis added]

Chapter 2: Lewis's risk estimate

Early work on the biological effects of radiation

In 1954 Ed Lewis established a new method for measuring the biological effects of radiation by using detected chromosomal rearrangements in fruit flies as an index. His paper on the subject was entitled "The Theory and Application of a New Method of Detecting Chromosomal Rearrangements in *Drosophila Melanogaster.*" He called the method the "biothorax" method because it grew out of his work on the biothorax genes. In his lab at Caltech Lewis exposed flies to known doses of X-rays from an X-ray machine. At Argonne National Laboratory he exposed flies to known doses of gamma rays from Cobalt-60 and to fast neutrons from the nuclear reactor (also called "the pile"). Another set of flies was carried by Lewis's colleague, Professor Beadle, to a nuclear test site, where they were exposed to an unknown dose of radiation from the nuclear explosion [27]. Beadle took the flies because Lewis did not receive the security clearance to do so. Lewis believes that he was denied clearance because he visited another academic at his home to play chess. This man was later found to be a Communist ring leader whose group was meeting under the guise of a chess club. Looking back Lewis is thankful that he was not allowed to take the trip and expose himself to the significant dose of radiation that Beadle received. In fact, Lewis was angered by the lack of concern for radiation safety in the handling of the experiment. Lewis considered dangerous both Beadle's exposure and that flies were returned to his laboratory in radioactive metal containers.

Within a day of their exposure, Lewis mated the flies and then looked for biothorax mutations in their progeny. Specifically, he looked for the growth of the metanotum on the fly's metathoractic region. This is a tissue covered by tufts of hair that ranges in the flies from absent to covering about the width of a first abdominal segment. The flies with the widest metanotums, those in the higher grades on Lewis's scale, were determined to have induced mutations.

FIGURE 1. Dorsal (left) and lateral (right) views of the metathoracic region of the bx^{34e} homozygote. (Drawing by E. M. Wallace.)

[27]

The number of flies with this wide band of tissue increased linearly with radiation dosage from the fast neutrons. Lewis explains that this linear relationship, derived from the fast neutron experiments, "served as the best available prediction curve for the unknown dosages received at the nuclear detonation sites" [27]. Using this relationship and his observations of the number of mutated flies from the nuclear detonations, Lewis calculated back to the doses that these flies had received. These calculations were in agreement with the available physical measurements, supporting the validity of the method and the direct correlation between the dose and biological effects of fast neutrons. Another conclusion of this study is that these fast neutrons, generated by nuclear reactions, are more effective than X-rays and gamma rays at producing biothorax rearrangements in fruit flies [27]. This elegant study furthered Lewis's understanding of the biological effects of radiation on fruit flies and his curiosity about what findings would hold for human beings.

The Effects of Radiation on Humans

From the very beginning of the Manhattan Project, radiation safety was a significant problem. During World War II different groups with varying amounts of information took different levels of precaution. Caltech Professor of Physics, Charles Barnes, who worked in the joint Canadian-British Atomic Energy Project in Canada during W.W. II, was very surprised when he moved to the United Kingdom immediately after W.W. II, and later to the United States, to find that most nuclear researchers were much less concerned about the health hazards from radioactivity, and from X-rays and neutrons from accelerators, than those in his wartime laboratory. Some physicists seemed quite oblivious to the possibility of serious radiation damage to their health, such as cancer, cataracts, and immune system damage [28]. In the 1950s, some involved individuals and administrators were ignorant of the dangers, others simply had more important places to put their attention, and some were cautious. There was no real consensus on where to set "worry limits" or safety precautions. AEC spokesmen told the American people that low-levels of radiation were not dangerous. On the other hand, there could be no debate about the effects of high radiation doses. Scientists at Oak Ridge National Laboratory (where the uranium was processed) were trying to find ways to treat people who were injured by large, accidental radiation exposures[3].

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[3] The work of the Oak Ridge scientists, including that of Professor Ray Owen, eventually led to the ability to do bone marrow transplants, and other forms of organ transplants 16.

Owen, R., *Interview 7-9-02*, b.J. Caron, Editor. 2002: Pasadena..

What was at issue was not whether radiation was dangerous, but how much was required to be considered a threat. With most chemical toxins there is a threshold dose below which the body can process the toxin without harm. Also, repeated small exposures to most of these toxins do not create problems. In his 1958 book *No More War!,* Linus Pauling uses the example of sleeping pills, explaining that one a night is not very harmful, but to take a month's supply at once could kill a person. Many people, including the AEC spokesmen, assumed that such a threshold existed for high energy radiation and some people still believe this to be the case. Because of repeated experiments inducing mutations with X-rays that showed a linear correlation between radiation dose and mutation rates, many geneticists did not expect to find a threshold. They expected a linear relationship between radiation and its damaging effects.

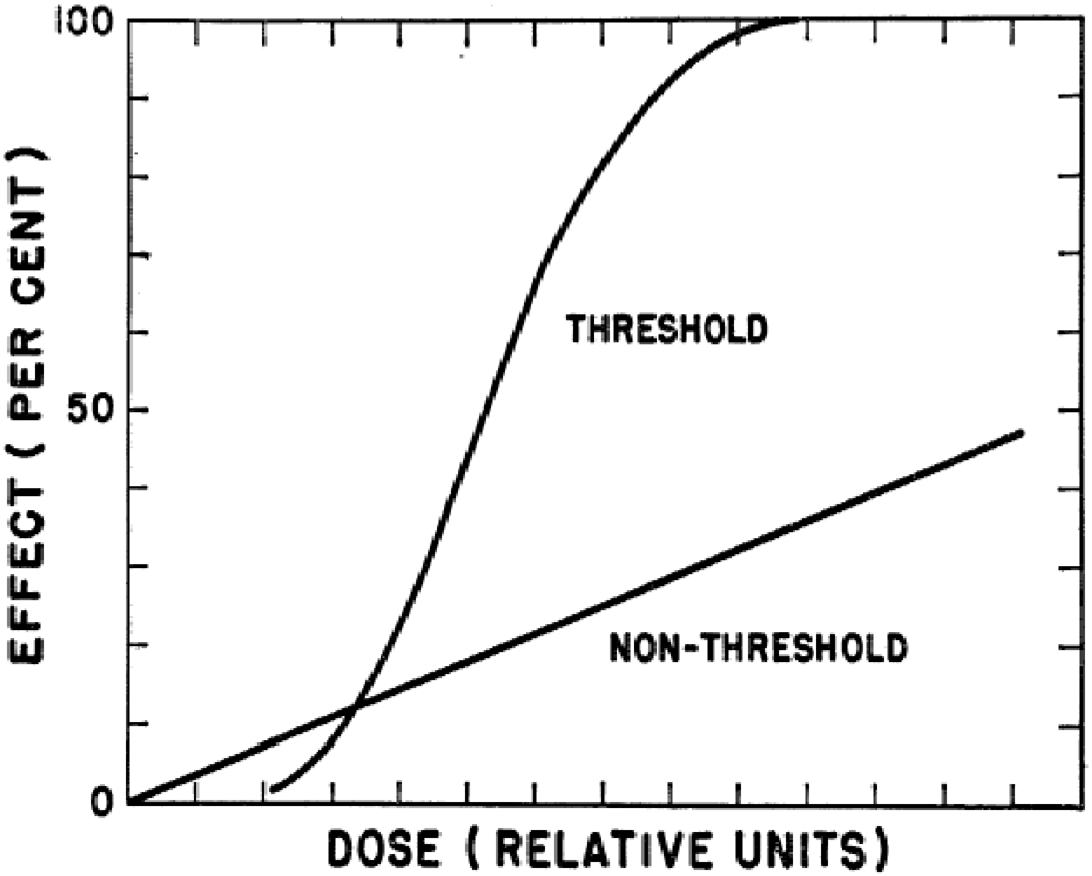

FIGURE 3.—A pictorial representation of the difference between a threshold and a nonthreshold situation. Dose increases to the right. Note that the non-threshold line is a straight line; it needn't be. (See p. 15.) [Figure reprinted from testimony of Drs. Langham and Anderson, Los Alamos Scientific Laboratory.]

From the 1957 *Joint Committee on Atomic Energy Hearings on the Effects of Radiation on Man,* Summary-Analysis, page 14 [29] (Please note that the percentages given on the vertical axis are misrepresented if the dose units are assumed to be comparable to any in use.)

Professor Sturtevant had spoken about the genetic effects of high energy radiation at his presidential address to the AAAS, which was published in the September 10, 1954 issue of *Science* [17]. He continued his discussion of these concerns in an article titled "The Genetic Effects of High-Energy Irradiation of Human Populations," published in Caltech's January 1955 *Engineering and Science* magazine. On July 8th of the same year, Beadle brought up the issue of leukemia caused by radiation. He issued a one-page memo to the Caltech genetics faculty titled “Possible direct effects on man of low level exposures to ionizing radiation.” Beadle pointed out that the “permissible” or “tolerance” dose assumes that low doses of radiation will cause no important effects. Beadle questioned this assumption on the grounds that a study of American radiologists showed them to die of leukemia at 20 times the rate of non-radiologist MDs. Furthermore, Beadle speculated that the AEC’s established “permissible dose” of radiation could mean an increase in leukemia by a factor of one and a half, or five or more for communities receiving the “permissible” dose around the Nevada nuclear testing site. He asked, “Does this speculation make any sense? Is there any reason to believe that low level exposures to radiation do not cause leukemia – and other neoplasms?” In an effort to think of a way to answer the question, he considered getting more data on humans from further studies of radiologists and studies of other exposed medical professionals like x-ray technicians and dentists. What fraction of spontaneous leukemia might be caused by natural radiation was another important question. Beadle speculated that the observed “increased incidence of cancer in general may result at least partly from the widespread use of X-rays in therapy, diagnosis and industry” [18]. This last speculation was borne out by further studies.

Ed Lewis added a memo in a similar vein on November 28th. His cover note to Linus Pauling reads:

> The attached memo was prepared for private circulation at Cal Tech only and has been sent to Dr. Bacher [the provost] and to the geneticists in Kerckhoff. Its purpose is to call attention to the shortcomings of the published information on the physical measurements of fallout. At Dr. Beadle’s suggestion I am considering sending this memo, along with a covering and softening letter, to some of the people in AEC (Dunning and Dunham). Beadle has been assured that

> AEC is prepared to cooperate in providing more information and the point has been made by the AEC that no one has specifically requested information (this was in response to some inquiries Beadle recently made about certain aspects of the physical measurements.)

This memo is divided into two parts. The first part deals with the inadequacies of the available physical measurements of dosage and the consequent inability to estimate genetic damage. The second part deals with the "direct effects of irradiation," specifically, leukemia.

Lewis found the available physical measurements of fallout to be lacking. He explains that the cumulative dosage received by the population would be required for "assessing genetic (and other biological damage)." The most authoritative fallout curves did not include measurements during the times of nuclear testing; furthermore, they only gave detailed information for the northeastern United States. Additionally, they did not address the contributions of beta and gamma radiation from the explosions. Lastly, the methods used to measure fallout were less than ideal. Lewis argued that at least some direct measurements should have been taken with r meters, which measure radiation in Roentgens (r units); instead, the "gummed strip" method was used. One consequence of these shortcomings was that the total average dose received by the citizens of the United States remained unclear. "Finally," Lewis concluded, "an estimate, obviously of the greatest importance for estimating genetic damage, of the dosage extended over all time is needed [19]."

Part II, "Direct Effects of Irradiation," leads directly into Lewis' 1957 paper where he established the linearity hypothesis and estimated the incidence of leukemia induced per radiation dose. He explained that the genetic effects that had been extensively discussed are linked to direct effects because mutations in body cells could be the cause of some cancers.

Lewis discussed data on survivors of Hiroshima and Nagasaki published in 1955 which showed a "highly significant" increase in leukemia for those populations, especially close to the hypocenter over which the bombs exploded. In this draft, Lewis was hesitant about the linear relationship between radiation dose and leukemia incidence:

> It is unlikely that the somatic 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 per given population would be if the relationship to dosage is linear and if all forms are considered radiation induced.

As quoted above, Lewis discussed linearity as a useful inquiry. In the course of the next year and a half his commitment to this hypothesis grew and in 1957 it was a strong, well-reasoned assertion. After ascertaining that more animal work was needed to generalize the finding in mice that leukemia can be radiation-induced, Lewis proposed a course of action. If average dosages could be assigned to the groups of Hiroshima and Nagasaki survivors, then it would be possible to make "the beginnings of estimates on the direct effects of radiation" [19].

In some ways it is surprising that Edward Lewis undertook the politically charged task of making these estimates of the relationship between radiation and leukemia in human beings. Lewis has always been a very quiet and humble man. Patiently finding elegant ways to learn nature's rules of development in his unadorned laboratory, and teaching his students, seems to make Professor Lewis happy; by contrast, he finds large quantities of attention draining. His loyalty is to the truth of experience, and he shows no desire to bend or stretch that truth for political ends. When asked what motivated him to do this work, he answered: "I think I was prompted by a lunch conversation at the Athenaeum in which I became aware that some faculty, possibly physicists, I am not sure, were unaware of the possibility that ionizing radiation, even at low levels, could induce cancer [26]." Later he explained his scientific curiosity in the matter with enthusiasm. Muller had hypothesized that some cancers could be caused by mutations in somatic cells, and radiation exposure from nuclear weapons was an opportunity to collect data on human beings [25]. This research would be valuable both to the study of genetics and to the campaign to end nuclear testing. Lewis's primary motivation was the former and, while his work was very important to it, he tried to keep some distance between himself and the campaign.

His motivation and that of the other geneticists who spoke out about the biological impacts of nuclear weapons testing in the 1950s involved an element of social conscience that took them beyond the scientific curiosity that led them into the field of genetics. In the case of the effects of radiation on people, Lewis was seeking to supply the best available information to policymakers and the public to inform the decision to test or not to test hydrogen bombs. Lewis is proud of this important and far reaching contribution. In his nine-page autobiographical draft, three pages are devoted to his work on radiation. He writes,

> When the US began testing atomic weapons in Nevada, I became intrigued with the possibility that the induction of cancers by ionizing radiation might be linearly related to the dose just as mutations in the germ line of Drosophila had been shown by H. J. Muller, as already mentioned. I was surprised to find that it was generally assumed that there would be a threshold dose below which there would be no induction of cancer. [30]

In his autobiographical sketch Lewis explains that his work on radiation was an extra-curricular activity. At the same time he was teaching, carrying out a research program, and overseeing the Drosophila stock collection [30]. Lewis believes that his lectures suffered in the introduction to genetics course he was teaching while preparing “Leukemia and Ionizing Radiation,” as he spent many late nights on the paper.

The Draft of “Leukemia and Ionizing Radiation”

Lewis circulated drafts of his papers on the Caltech campus. A year after his “Memorandum on Fallout,” in November 1956, he sent out a second draft with a note saying, “Comments and especially criticisms are earnestly solicited” [31]. It would be far better to receive criticism on the draft, at home at Caltech, than on the published version, amidst the growing national debate over nuclear testing. However, his draft paper and its results did reach people outside of the Caltech community. Professor of Geochemistry Harrison Brown had become a full-time activist for international control of nuclear power and disarmament. He either sent a copy of Lewis’ draft to 1953 Nobel Peace Laureate Albert Schweitzer or communicated its content.

Linus Pauling used the risk estimate from the draft before the paper was published. He gave a lecture on abnormal hemoglobins to the Chicago Section of the American Chemical Society in which he mentioned fallout radiation as a small source of genetic mutations. After the talk he was asked about the magnitude of the radiation effect from fallout. He answered that it was relatively small, and added the estimate that 1000 people would die of leukemia if the British were to detonate another hydrogen bomb with

5 megatons of fission. AEC Commissioner W. F. Libby was the scientist spokesman for the AEC and he was quick to write Pauling,

> I am very interested in the details of your calculation of this number. I suppose that we probably know more about radioactive fallout 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. I enclose copies of my most recent speeches on radioactive fallout and I would much appreciate receiving yours. [32]

In his reply Pauling, noted that he was speaking to a small group and did not expect or know that a reporter was present. He cited Lewis's manuscript, a copy of which had already been sent to Libby's office at the AEC, and copied his reply to Professors Beadle, Brown, and Lewis.

In his second draft Lewis begins by connecting the established concern about genetic damage to reproductive cells and the concern that radiation damage to somatic cells would cause cancer. The stated purpose of the paper was to examine the "abundant evidence in man for the induction of leukemia by ionizing radiation" and "to attempt an estimate of the quantitative relation between radiation dose and probability of developing leukemia" [31].

Lewis's confidence about the linear relationship between radiation dose and leukemia incidence had grown since his "Memorandum on Fallout" a year earlier. In that memorandum Lewis expected to be unable to see this linear relationship. However, he found that the data on both the Japanese survivors and the ankylosing spondylitis patients were "compatible with a linear dose curve" [31]. Still, Lewis's assertions about linearity remained cautious. In this second draft he wrote,

> There is insufficient evidence on hand to evaluate the shape of the curve relating dose to incidence of leukemia, especially in the low dose region. The data on leukemia among Japanese survivors and the data on leukemia

> among patients irradiated for ankylosing spondylitis are compatible with a linear dose curve but they by no means prove the point….Since mutation in the germ cells shows a linear relationship to dosage measured in r units, for doses as low as 25 r, somatic mutation rate and dose are probably linearly related.

In this second draft Lewis addresses the assumption that a threshold exists below which leukemia would not be induced by saying, "Although the numbers are small there is no obvious indication of a threshold dose for the induction of leukemia" [31].

"Leukemia and Ionizing Radiation," by E. B. Lewis, published in *Science* on May 17, 1957, is not as soft on the threshold idea. Here Lewis argues first from his data and then backs this up by explaining that the linear dose response curve can be explained by the somatic mutation hypothesis. This is the hypothesis that mutations in the genetic material of body cells can cause cancer. Speaking on the same two sets of data, Lewis stated,

> This is presumptive evidence that the relationship between incidence of induced leukemia and dose of radiation is either linear or approximately linear….these data provide no evidence for a threshold dose for the induction of leukemia. Moreover, chronic irradiation at a relatively low dose rate (perhaps 0.1 rad per day or less) appear to induce leukemia in radiologists at a rate per rad which is comparable to that observed for the Japanese survivors. This finding also fails to support the concept of a threshold dose below which leukemia will not develop.

A linear relationship between dose of radiation and gene mutation in fruit flies had been established more than two decades earlier. The somatic mutation hypothesis gives a possible mechanism to explain why the incidence of leukemia should be linear with respect to dose. Furthermore, since gene mutation had been shown to be directly proportional to cumulative doses, it follows that leukemia would also be directly proportional to the cumulative dose received by the animal. This is a tight argument for linearity because it is founded on multiple sets of independent data and explained by the well established hypothesis that radiation could induce cancer by causing genetic mutations within cells [33].

The list of citations grows from the second draft to the published paper. The draft has 33 notes and citations; there are 57 in the final paper. Most of the additions are explanatory notes and references to statements made by AEC personnel. Among the most important references are those to the 1956 reports on the biological and human effects of nuclear radiation by the US National Academy of Science and the British Medical Research Council. References to Muller's work on the genetic effects of radiation in fruit flies provide some of the scientific grounding. Alice Stewart et. al. had very recently published a study that provided a strong piece of evidence for leukemia induction by low-doses of x-rays. By interviewing mothers of children who died of leukemia and also a matched group of mothers whose children did not develop leukemia, Stewart's team established that those children whose mothers had then-common pelvic x-rays while pregnant had twice the risk of developing childhood leukemia than those whose mothers had not been x-rayed [31] [33].

Lewis's published paper is stronger on the linearity hypothesis than his draft. The draft stated, "there is no obvious indication of a threshold dose for the induction of leukemia." The final paper stated, "these data provide no evidence for a threshold dose for the induction of leukemia." Added to the final version is a section titled "Application to Radiostrontium Exposure" where Lewis predicted that the recommended "safe" limit for the public of 0.1 MPC of strontium 90 "would be expected to increase the present incidence of leukemia (in the United States) by about 5 to 10 percent."

The "Loaded Dice" editorial by Graham DuShane

Science editor Graham DuShane preceded Lewis's paper with an insightful editorial entitled "Loaded Dice" about the debate over the health effects of nuclear testing and the significance of Lewis's paper. He puts Lewis's contribution in political and historical perspective. The health effects of radiation had become a topic of political debate and "linked with questions of national power and prestige," greatly complicating efforts at dispassionate scientific discussion. DuShane wrote,

> Thanks to Lewis, it is now possible to calculate—within narrow limits—how many deaths from leukemia will result in any population from any increase in fallout or other source of radiation….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'. [34]

Echoing Sturtevant's warning two years earlier, DuShane concluded, "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."

DuShane took some heat for this editorial from AEC officials and the President of Caltech, Lee DuBridge[4]. Lewis recalls that the AEC sent some of their Biology Division scientists to the *Science* office demanding that DuShane, "take steps to counter my article" [35]. Lewis met these men in the elevator on his way out the building,

> Graham DuShane told me he had received a very strong letter from DuBridge protesting the loaded dice editorial. I was in his office the day he received it (I was in Washington to testify before the joint committee on atomic energy). He was extremely upset by the letter and had somehow

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[4] Unfortunately it is not possible to confirm this letter because it is not in the DuBridge papers in the Caltech Archives and DuShane's papers were not saved.

> mislaid the letter as he wanted to show it to me. That same day as I was leaving his office several top AEC people came in the building on their way to see him. [26]

A year later, *Science* published a critical letter from A. W. Kimball, a statistician at Oak Ridge National Laboratory, and Austin Brues, Director of the Biology and Medicine Division of Argonne National Laboratory. When asked if he knew anything about the circumstances under which Kimball and Brues wrote their critical articles, Lewis responded, “Yes, the Atomic Energy Commission immediately alerted these people to attack my article” [36]. The year of 1957 was very busy for the fallout debate and a great deal occurred before these critical papers were published.

The 1957 Biology Division Annual Report

George Beadle was more careful than DuShane to acknowledge the limits of available knowledge when he put the questions in context in the introduction to the *1957 Caltech Biology Division Annual Report*:

> Are gene mutations in body cells responsible for some or all malignancies? The answer is not known. The question is important, for if gene mutation is indeed responsible, one might well expect a direct linear relation between exposure of the cells of an individual to ionizing radiation and the chance of developing a malignancy such as leukemia. A linear relation at all levels of exposure would mean that there is a real hazard even at levels as low as those of background. Present radioactive fallout from testing of nuclear weapons is perhaps only one-tenth of background, but if the relation is linear at all levels, this would increase the incidence of malignancy by a small but real amount. On the other hand, if there is a threshold below which no effect is produced and if that threshold level is higher than background plus medical radiation plus fallout, there may be little to worry about in this regard. Presently available data for man are insufficient to answer the question of linearity at all levels. The data are consistent with a linear relationship but they are also consistent with the hypothesis that there is a threshold at low levels. [37]

Lewis's abstract in the *Annual Report* which introduces his work on radiation and leukemia explains that the work was supported by the "General Funds" of the Institute, not by an outside grant. It is interesting to note that the AEC was a funding source on a research project on reverse mutation and gene duplication that he also worked on that year. Lewis wrote,

> It has long been suspected that cancer may in some cases arise as the result of a somatic mutation. Thus, in a malignant disease, a part of the body contains cancerous cells which act as if they were permanently altered in their growth rate compared to normal body cells. Such a cancerous line of cells presumably stems from a mutation in one (or more) of the normal body cells. X-rays and other ionizing radiations are known to be very effective agents in producing mutations in the body cells as well as in the germ cells. Hence, on the somatic mutation hypothesis for the origin of cancer, it is not surprising that ionizing radiations prove to be powerful cancer-producing agents.
>
> Abundant evidence is now at hand that the malignant blood disease, leukemia, can be induced by ionizing radiations. A review of this evidence has been undertaken in order to study how the increase in incidence of this disease after irradiation is related to the exposure dose. The conclusion is that the relation appears to be one of direct proportionality, at least over the range of doses which have been studied. In particular, levels of radiation exposure which have often been claimed to be well below a threshold dose for the induction of leukemia are probably effective in inducing it after all. A detailed account of these studies has been published. [37]

Chapter 3: The Joint Committee Hearings. To the public and scientific press.

Lewis's paper, "Leukemia and Ionizing Radiation," was published in *Science* on May 17, 1957. Beadle and Brown had pushed him to publish, this, he explains, made the writing "a little rushed" [26]. The timing was politically opportune.

The issue of fallout from nuclear testing was pushed front and center by a convergence of forces in 1957. In January, the British government announced its plans to test a hydrogen bomb on Christmas Island, which threatened both the Hawaiians and the Japanese. After great controversy, the bomb was detonated on May 15th, another on May 31st, and a third on June 20th. On April 24th, the Nobel Committee issued Schweitzer's "Declaration of Conscience." Linus Pauling circulated a rapidly successful petition from the world's scientists for an end to nuclear testing [38, 125 and 139].

These forces also brought Representative Chet Holifield, chairman of the Special Congressional Subcommittee on Atomic Energy, to call and orchestrate the Joint Committee on Atomic Energy's hearings on "The Nature of Radioactive Fallout and its Effects on Man." The Joint Committee's staff began their study on fallout had commenced while the pressure was building in the summer of 1956. The hearings occurred, in sync with these other expressions of concern, from May 27th to 29th and June 3rd to 7th. They were the first Congressional investigations into the effects of radiation on public health. They flooded the media and American public with information and expert opinions. The published record is 2000 pages of small print [29].

Schweitzer's Declaration, Libby's Letter, Brown's Response to Libby's Letter

Albert Schweitzer's "Declaration of Conscience" was issued by the Nobel Prize Committee on April 24th and broadcast over the radio from Oslo, Norway. The full text of his statement was published in the *Saturday Review* on May 18th. Three months earlier, Norman Cousins, editor of the *Saturday Review*, visited Dr. Schweitzer at his hospital in French Equatorial Africa. After discussing the problem of nuclear testing and Dr. Schweitzer's careful attention to the development of nuclear power, Cousins asked him to issue a statement. Schweitzer asserted that this problem was in the domain of scientists and that throughout his long life (he was eighty-three), he had "carefully stayed away from making pronouncements on public matters." Later he wrote that he would "get the fullest information from and check his facts with scientists of worldwide repute" and then issue a statement calling for the "right to know." A draft of Ed Lewis's paper on radiation and leukemia was among the scientific studies that reached Schweitzer. Harrison Brown received a copy from Lewis, which Lewis did not expect to be passed on. Brown was an editor for the *Saturday Review* and a professor of both science and government and geochemistry at Caltech [26]. Cousins explains Schweitzer believed "that before anything constructive could be done people had to have full information on the basis of which a moral climate of opinion could be created."

In the Declaration, Schweitzer explained that, like many others, he felt a duty to act "in warning of the danger." His statement covers four pages in the magazine. A small portion of it is devoted to the history of nuclear weapons. From this history, Schweitzer goes on to answer the informative questions: What is radioactivity? Where does it come from and what forms does it take? What is radioactive fallout? How does it enter and impact the human being? What diseases are caused by internal radiation, such as accumulated strontium 90, and how will the effects impact future generations? Schweitzer's argument is based on two premises: First, that nuclear testing is morally wrong because the whole world pays the costs in health and life for the military security of a few nations; and second, that human beings have a "right to know" what is being done to them and their world. Calling radioactive fallout "the greatest and most terrible danger," Schweitzer issued the challenge: "We must muster the insight, the seriousness, and the courage to leave folly and to face reality." How? The nuclear powers, America, Britain, and the Soviet Union, should come to an agreement to cease nuclear testing. Showing his respect for the difficulties of international politics, he wrote: "There must be guarantees preventing the agreement from being signed by anyone intending to win important tactical advantages foreseen only by him." The responsibility of those with the right to know is to hold an informed opinion. Schweitzer holds that the agreement should be the product of, and enforced by, public opinion. He explained:

> When public opinion has been created in the countries concerned and among all nations, an opinion informed of the dangers involved in going on with the tests and led by the reason which this information imposes, then the statesmen may reach an agreement to stop the experiments.
>
> A public opinion of this kind stands in no need of plebiscites or forming of committees to express itself. It works through just being there. [39]

Dr. William F. Libby was a chemist who worked on the Manhattan Project at Columbia during World War II and served on the AEC from 1954 to 1959[5] He replied to Dr. Schweitzer in a widely circulated open letter the day after his declaration. Just as the "Declaration of Conscience," Libby's letter was published in full by the *Saturday Review* [40]. Libby, a scientist himself, contended that the risk from nuclear weapons testing was small, "extremely small compared with other risks which persons everywhere take as a normal part of their lives." He explained that cosmic rays are a part of the natural

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[5] William F. Libby received the 1960 Nobel Prize for Chemistry for "his method to use carbon-14 for age determination in archeology, geology, geophysics, and other branches of science."

background radiation and that living one mile above sea level exposes a person to double the dosage of cosmic rays as living at sea level; therefore, if radiation was such a cancer risk, there would be cancer epidemics in places like Denver. In one of his famous risk comparisons he said, "Living in a brick house, rather than in a wooden house, will, with certain kinds of bricks in certain parts of the world, increase radiation exposure many times over that from test fallout." This is because some clays contain higher amounts of radioactive materials. Libby argued that his standard of concern was "detectable effects." Of course, these effects from varying levels of natural background radiation had not been examined carefully, and when he looked for "any obvious increase in the rate of occurrence of bone cancer or leukemia," he did not find any.

Strontium 90 is a radioactive fission product of atomic bombs and the most dangerous component of fallout. It is chemically similar to calcium and is incorporated into bones, which it irradiates, possibly leading to bone and blood cancers. To evaluate the risk from strontium 90, Libby compared the dosages from fallout to the Maximum Permissible Concentration (MPC) allowed atomic energy workers. Libby asserted that this MPC standard was set far below the concentration which would produce effects that could be detectable by the methods of epidemiology, and that it had built in extra margins of safety. Libby's argument was challenged a month later, when scientists, including Lewis, at the Joint Committee's Hearings on The Nature of Radioactive Fallout and its Effects on Man offered repeated concerns about the safety of the MPC standard.

Libby dismissed the moral argument that it was wrong for the nuclear powers to subject the whole world's people to the dangers of increased radiation without their consent and, in most cases, without their knowledge. He concluded:

> No scientist contends that there is no risk. 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.

Libby held that a "small" risk was acceptable because it was of a similar magnitude to already accepted "normal" risks. What he failed to note is that the fallout danger was an addition to the risk and suffering that were already facts of life for everyone exposed, including people with nothing to gain from testing [41].

Albert Schweitzer and Linus Pauling disagreed and argued for the value of each individual life. If a proponent of nuclear testing argued that the testing would only cause death to a fraction of a percentage of those exposed, Pauling would multiply those two numbers, generating an estimate of the total number of individuals who would be killed.

Harrison Brown replied to Libby's letter in the *Saturday Review*. Also a chemist, Brown was well qualified to engage Libby. He worked on the Plutonium Project at Oak Ridge National Laboratory during World War II. After the war Brown served as President of Einstein's Emergency Committee of Atomic Scientists which worked to educate the public about the atomic bomb and to prevent the further development of nuclear weapons [42]. Brown saw human dignity as a cost of nuclear testing to the nations whose "actions result indiscriminately in the deaths of persons all over the world." Brown explained that Libby had been convinced from the beginning that H-bomb tests were necessary and that his approach to the risks had been simply to assume them to be small, and then find a way to prove it. When Libby spoke to Brown about his activism, Libby challenged Brown to prove that the risks were considerable. Brown believed that, given the possible consequences, the burden of proof should fall on the proponents of testing [43].

In the AEC's efforts to prove the risks of nuclear testing to be small, they missed what Brown calls "a really serious danger": the danger of inducing leukemia with low-dosage exposure to radiation. Brown credited Lewis with uncovering the danger and directed interested readers to the issue of *Science* where "Leukemia and Ionizing Radiation" was published. His summary of the article focused on Lewis's conclusion that natural background radiation must be responsible for a significant fraction of the world's leukemia cases and the conclusion that there is no threshold below which leukemia will not be induced. Carrying out the estimate, Brown concluded that if testing stopped immediately, the strontium-90 already released would increase the incidence of leukemia rate by 0.1 percent; testing continued at the 1957 rate for several decades would increase it by half a percent; and testing increased to the point where the strontium-90 doses received were equal to one tenth the MPC (the dose declared "safe" for the general population by the National Academy of Sciences 1956 report) would increase the leukemia rate by 10 percent. Brown speculated that someone subscribing to the AEC's philosophy might respond with, "This effect is so small that it cannot be detected with certainty in death statistics. Clearly the risk is far less than most other risks which we face as payment for our pleasures, our comfort, or our material progress" [43]. Lewis's estimate was particularly powerful because of how definite it was. An increase in the rate of leukemia of half a percent is arguably small, but it is also inarguably real.

Following Dr. Libby's letter to Dr. Schweitzer and Harrison Brown's response in the May 25th *Saturday Review* was an article by the science editor, John Lear, titled "The

Shrinking Margin." He too emphasized the conclusion that the dose of strontium 90 the AEC considered safe would cause an additional 150 to 3000 Americans to die of leukemia each year. After summarizing the *Science* article, Lear agrees with Graham DuShane's editorial "Loaded Dice." *Science* is the official voice of the American Association for the Advancement of Science and Lear finds it "immensely encouraging that the AAAS…should be the agency of plain speaking" on the issue of the effects of fallout radiation. Lear contends that while the known effects of radiation, including the increased incidence of leukemia shown by Lewis, are proportionally very small, these risks should nevertheless be studied and discussed in the decision-making process. Furthermore, Lear recognized that strontium 90 is only one of many fallout threats, others include cesium 137 and iodine 131.

Lear proceeded to attack Libby's science, foreshadowing strikingly similar attacks on Lewis's work in the Joint Committee hearings that were still a week away. Libby claimed that the danger to a child from a day's fallout was no more than from the cosmic-rays received in walking from a seaside beach to the top of a nearby few hundred foot tall hill. In searching out Libby's reasoning, Lear found that, "It amounted to a series of extrapolations—nothing more positive or definite than that," and he asked whether that method was scientific at all. As if to drive his point home with one final blow, Lear reminded his readers that, based on growing knowledge, the National Committee on Radiation reduced the Maximum Permissible Dose from 0.5 r per week in 1935, to 0.3 in 1946, and then to only 0.096 is 1957. He asked, "Does that threatening procession of figures make exposure to fallout sound as harmless as a walk uphill from the seaside?" [44]

Lewis attended the first meeting of The Committee for a SANE Nuclear Policy in the summer of 1957. This organization, led by Norman Cousins, worked nationwide to mobilize public opinion against nuclear testing. They used the health effects of radioactive fallout as their central argument for a test ban [45]. Lewis was invited as one of several "Leaders of America" and gave a summary of his paper. Lewis believes that Harrison Brown was instrumental in his invitation. When Lewis asked Brown how the travel to New York was to be paid for, Brown covered the expense [26].

The Pauling Bomb-Test Appeal

Linus Pauling also spoke out publicly against nuclear testing. On May 15th he launched a petition titled "Bomb-Test Appeal" which expressed the widespread opinion which had developed within the scientific community that nuclear testing should be stopped by international agreement. This scientists' petition opens,

> We, the scientists whose names are signed below, urge that an international agreement to stop the testing of nuclear bombs be made now.
>
> Each nuclear bomb test spreads an added burden of radioactive elements over every part of the world. Each added amount of radiation causes damage to the health of human beings all over the world and causes damage to the pool of human germ plasma such as to lead to an increase in the number of seriously defective children that will be born in future generations.

The paragraphs which follow address the opportunity to control the spread of nuclear weapons and, ultimately, to destroy them. In the final paragraph the authors express their special motivation as scientists: "we have knowledge of the dangers involved and therefore a special responsibility to make those dangers known" [46].

Within two weeks 2,000 American scientists had signed, and Pauling sent the signed petition to the President on June 4th, 1957. In the covering letter he asserted that there was "essentially unanimous agreement among scientists with experience in the field of the biological effects of radiation as to the general magnitude of these effects." And he explained that few biological scientists asked to sign the appeal abstained, while many physicists did, some on the troubling grounds that they had no personal knowledge of the dangers involved in testing nuclear bombs [47]. In a few months there were 11,021 signatures from forty-nine countries; Pauling presented it to the United Nations believing that "it represented the feelings of the great majority of the scientists of the world" [46]. One third of the signers were biologists, the scientists who would be most aware of the biological effects of radiation, 17 percent were physicists, 15 percent were biochemists, and 14 percent were chemists. Despite Pauling's confidence, Robert Divine explains that the petition did not have the signatures of a majority of leading scientists in the United States. Pauling won many critics of his activism and his lack of scientific care in making estimates of the effects of nuclear weapons testing [38].

Lewis remembers Pauling using his risk estimate for leukemia to extrapolate the effect to much of the world's population when he was reluctant to do so [26]. George Beadle, chairman of the biology division at Caltech, felt that Pauling and those who signed his petition had overstepped the bounds of their expertise when they claimed to be speaking in the name of science. Beadle said that when speaking as regular citizens, scientists should "make it clear that they are speaking not as experts but are expressing private opinions" [38, 128]. Lewis is particularly conscious of this concern and careful to make sure that his public statements can be rigorously defended.

Ray Owen, a biology professor at Caltech and a colleague of Lewis and Pauling, explained that Pauling had a non-standard way of doing things. Unlike many scientists he was willing to run with ideas until they could be disproved, and he wasn't terribly concerned about being wrong. Owen describes Pauling as both freewheeling and a good scientist [16]. Pauling said that where another scientists might ask, “what do these experimental observations force us to believe about the nature of the world?” he would ask, “what is the most simple, general and intellectually satisfying picture of the world that encompasses these observations and is not incompatible with them?" [16].

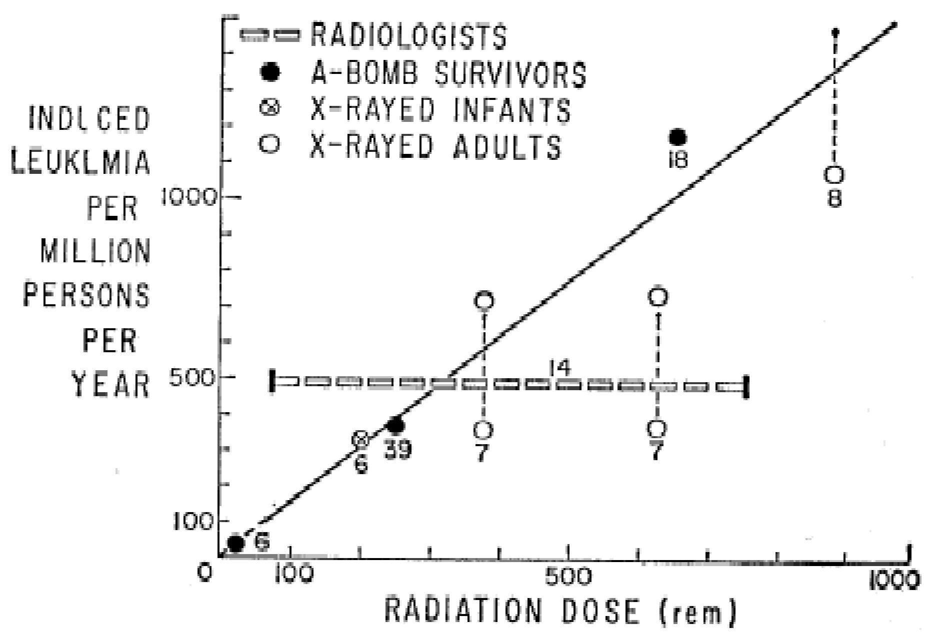
Lewis is also a good scientist, but he is both quiet where Pauling was loud and meticulous where Pauling was freewheeling. Both made crucial contributions to seeing the dangers of nuclear testing addressed to which their personalities made them uniquely suited. It was Pauling’s method to estimate the total number of individuals impacted by each nuclear concern and then to publicize these numbers as the human costs of nuclear testing [48]. From Lewis’s risk estimate he would estimate the number of people who would die of leukemia as a result of a single nuclear test. He could not have generated these powerful numbers without defendable risk estimates to work from.

Pauling was a powerful and articulate spokesman for the cause of ending nuclear testing. Many such outspoken activists who had clear political agendas could not, at the same time, hold the authority of science on related issues. They relied heavily on the credibility of Lewis and other scientists who were careful to keep their statements as much above the political quagmire as possible. Without both contributions the movement to end nuclear testing would have been either without a widely heard voice, or without authority.

The Joint Committee on Atomic Energy Hearings

In the summer of 1956 the Joint Committee on Atomic Energy began a study of fallout and in March 1957 they announced plans for their hearings on "The Nature of Radioactive Fallout and its Effects on Man," which began May 27th and continued for eight days. Unlike most congressional hearings, these were carefully structured to get the facts and opinions out as efficiently as possible. Chairman of the Special Subcommittee on Radiation was Chet Holifield, a liberal Democrat from California. His stated goal was "to delineate those areas where we have knowledge from those where we have little or no knowledge, with a view to determining the areas of research which need more intensive effort" [38, 130].

Robert Divine, author of *Blowing On the Wind: The Nuclear Test Ban Debate 1954-1960*, calls the debate over whether or not there exists a threshold below which radiation does no harm to human beings "the most crucial issue debated at the hearings" [38, 133]. Lewis served as the major spokesperson against the existence of a threshold and for the linearity hypothesis. He was asked to speak to the subject of leukemia and appeared before the committee on Monday, June 3rd. Representative Holifield introduced him and credited him with "a notable scientific background" [29, 955]. In confining his remarks to leukemia, Lewis was careful to explain that he did not believe leukemia is the most important effect of radiation on humans; the genetic effects or other cancers could be more important. He presented the committee with a linear graph of radiation doses in rem (essentially equal to the roentgen unit) versus induced leukemia per million persons per year. Beside the line are numbered circles which represent the number of cases of leukemia attributed to the corresponding dosage. These data points are from the four groups Lewis studied in his paper: A-bomb survivors, radiologists, x-rayed infants (for thymic enlargement), and x-rayed adults (for ankylosing spondylitis). Many researchers had already published tables of the relationship of distance from the atomic explosion to the incidence of leukemia. What Lewis added were dosage estimates.



Summary of incidences of induced leukemia among various groups of persons subjected to ionizing radiations. The numbers under the circles refer to the number of cases of leukemia that are estimated to have resulted from the radiation. "X-rayed infants" refers to children treated for thymic enlargement. "X-rayed adults" refers to patients with ankylosing spondylitis. (References to the original literature and methods of estimating incidence of radiation-induced leukemia and radiation dose are contained in Science, vol. 125, pp. 965–872. May 17, 1957.)

[29, 956]

Lewis pointed out that he had only one small set of data for the low-dose region (less than 100 rem). This, of course, is the region most important to the hearings, as fallout will cause low-dose exposure and the question was whether or not there exists a threshold dose below which radiation exposures will do no harm. The available data for the high dose region supported a linear relationship, but there was not enough data for the low-dose region to draw conclusions there. Lewis explained his point:

> The point here, however, is that in the absence of any other information it seems to me—this is my personal opinion—that the only prudent course is to assume that a straight-line relationship holds here as well as elsewhere in the higher dose region. [29, 959]

He explained that there may be a threshold below which leukemia will not develop, but if so, it must be below 100 rem because you would not expect even six cases beyond natural background levels below the threshold.

Lewis was asked how many people will die of fallout-induced leukemia each year in the United States. Using the conservative estimate of radiation exposure due to fallout of 0.001 r per year, he calculated that there will be 10 deaths from leukemia per year at the 1957 rate of fallout, but only 1 to 3 deaths per year at that time because the fallout had yet to accumulate on the ground, in the food, and in human bodies. These are very small numbers. Lewis still considered them important, "In terms of our population that is a very minute fraction of the population—an exceedingly minute fraction—but after all, it does correspond to somebody" [29, 960].

Following Lewis's testimony were a written statement and his article, "Leukemia and Ionizing Radiation." His statement both summarized the article and carefully related that analysis to the problem of low-dose, chronic radiation exposure cased by fallout. Of the four data sets he analyzed, only radiologists received small doses of radiation over long periods of time. They developed leukemia at five times the rate of non-radiologist MDs with a dose relationship comparable to that of the atomic bomb survivors. This means that one can extrapolate from the other data sets because whether radiation is received all at once or gradually over time is of no consequence to the risk of leukemia which correlates with total dose.

Finally, Lewis evaluated the safety standard for strontium-90 of 100 “sunshine units,” the AEC-named unit for one micromicrocurie of strontium-90 per gram of calcium, at which it has been assumed that the public would not be affected. Using the linearity hypothesis, Lewis calculated that this strontium-90 burden alone will cause between 500 and one thousand cases of leukemia.[6]

Lewis was cited numerous times by other scientists testifying before the Joint Committee. Muller expressed concern about the lack of publicity that had accompanied research showing that radiation exposure could shorten lives and weaken health. He claimed that evidence showing the proportionality, the linear relationship between the effects of radiation and the dose, such as Lewis’s work, received even less publicity [29, 1049].

Dr. Walter Selove, chairman of the Federation of American Scientists’ committee on radiation hazards and associate professor of physics at the University of Pennsylvania, supported Lewis. In his statement he explained that the linear relationship had been shown at high doses of radiation and that it is not certain that the results can be extrapolated to low doses. That said, Selove believed that the extrapolation to low doses

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[6] In the summary-analysis report of the hearings, the Joint Committee’s Subcommittee on Radiation decided to call sunshine units strontium units because the sunshine name appeared to be intentionally misleading [49].Joint Committee on Atomic Energy, R.S., *Summary-analysis of Hearings Held May 27-29 and June 3-7, 1957, on the Nature of Radioactive Fallout and its Effects on Man*. 1957, Joint Committee on Atomic Energy: Washington, D.C..

is “a reasonable one” and that Lewis’s results “strongly support the validity of such an extrapolation in the case of radiation-induced leukemia in man” [29, 1302].

When asked why the safety mark for strontium-90 was set at 100 sunshine units, Dr. Langham of the Los Alamos Laboratory’s Health Division and co-author of a comprehensive report on the hazards of strontium-90, explained that it was based on experiences with radium exposures to researchers. Lewis’s work would now allow one to analyze this standard in a new way [29, 774]. Langham and his co-author Ernest C. Anderson discussed threshold versus non-threshold response in their article titled “Potential Hazard of World-Wide Sr^{90} Fallout from Weapons Testing.” They open with the statement that it was impossible to know whether or not there was a threshold at that time. Lewis is cited as the source for that conclusion, “based on all major sources of human data,” that there was no threshold. Austin Brues, director of the Biological and Medical Research Division of Argonne National Laboratory, is cited for the argument that the lack of a threshold had not been proven by experiment [29, 1363]. From a public health point of view, it is remarkable that the burden of proof was placed on the call for caution, rather than on those who advocated the testing in the face of a lack of information about its health effects.

Lewis’s work was cited in the Armed Forces Institute for Pathology’s statement submitted by the director, Captain W. M. Silliphant. He extrapolates from Lewis’s paper to say that each roentgen of whole-body radiation absorbed by the nation’s 100 million people (100 times the amount Lewis believes that the 1957 level of testing would cause) will eventually lead to 6,000 leukemia cases; and that 100 sunshine or strontium units would lead to 35,000 cases in this population. Dr. L. H. Hempelmann of the University of Rochester, Strong Memorial Hospital, wrote a review paper titled "Irradiation-Induced Cancer in Man" examining the published literature on the same groups of radiation-exposed people as Lewis did his paper. Hempelmann included a table from Lewis's paper showing the summary of his leukemia rate estimates from those populations. His conclusions were that there is a definite relationship between leukemia and radiation at high dosages, but that "the data at hand is insufficient to allow us to conclude that this relationship also holds for low-dose levels" [29, 992-993].

Not everyone put such confidence is Lewis's work. Dr. Jacob Furth, President of the American Association for Cancer Research, had studied leukemia for almost thirty years. He wrote,

> The statement that there is no threshold injurious dose to somatic cells, and every irradiation, no matter how small will cause cancer and leukemia, as is stated by some geneticists, is mere speculation. This applies to the statement that even background irradiation is leukemogenic. The available facts allow argumentation on both sides. In my opinion, the statements that background irradiations will induce leukemia are contrary to observations and the reverse is more likely. [29, 978]

Dr. Shields Warren, who presented Furth's statement in his absence, proved to be one of Lewis's main adversaries. Dr. Warren was Director of the Division of Biology and Medicine of the AEC from 1947 to 1952. In 1957 he was serving on the AEC's Advisory Committee and as a physician pathologist at New Deaconess Hospital in Boston. In his testimony he argued that the results in the low-dose region were not statistically significant. Lewis later explained that they were significant at the two percent level, although there were few data points [29]. Instead of choosing to use them for caution's sake, Warren stated, "They may provide a guide, but I would not want to base any firm conclusions on them" [29, 980].

When Warren said, “I am not at all satisfied that strontium 90 will cause any additional cases of leukemia,” Senators Bricker and Anderson put him in a corner. Anderson reminded Warren of Lewis’s assertion that background radiation was responsible for some fraction of leukemia cases. Warren replied that he knew of no way to “establish or 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 described Lewis’s assumption as nothing more than an educated guess. Anderson followed, asking Warren: “When you say, also, that one microcurie or one-tenth of a microcurie is a safe background, that is also an educated guess, it is not?” Warren’s first reply was no, then he conceded, “I feel—well, yes it is an educated guess” [29, 1327]. This was one of many occasions when those defending nuclear testing demanded a higher level of evidence from those people advising caution than they required to backup their own risk taking.

The Roundtable Discussion

On June 3rd H. L. Friendell of Western Reserve University’s School of Medicine, Austin Brues, Edward Lewis, Hardin Jones of the University of California Radiation Laboratory, Ernest Pollard of Yale’s Biophysics Department, and Shields Warren were invited and participated in a discussion on the day’s testimony at the conference table. Representative Holifield invited Lewis to begin the discussion over the disagreement between his testimony and Dr. Furth’s testimony. Furth’s testimony included the statement that “All reported experiments of leukemia induction by irradiation have pointed to the existence of a threshold and none suggested the lack of it.” But the opening discussion focused on the data on the life spans of radiologists. (Dr. Furth was president of the American Association for Cancer Research and his statement was presented in his absence by Dr. Warren.)

Dr. Brues presented a critical analysis of Lewis's scientific evidence by describing three hypothetical experiments with mice. He finished,

> Then there is the third situation where you do an experiment, having to do with a certain situation, and you transfer the results of that quite a distance. You demonstrate a certain percentage of life shortening at a high level, and you guess from this that you will see a certain amount at the low level which it would be impossible to ever detect. Or you study it in the mouse and you multiply the result by the difference in the life spans, and you come out again with a figure. When this is mixed up with mechanisms that you have no way of looking at, it becomes a little more speculative.
>
> I find personally that Dr. Lewis' figures are extremely interesting and suggestive. I think that probably some of the warmth of the statements that have come out in relation to this are owing to what some people have perhaps done to Dr. Lewis' work, saying that so many leukemias will be produced under certain conditions. I think if we look at it that way, we are perhaps a little less in danger of over weighting our thoughts on the side of radiation hazards and forgetting a lot of other things that are important and related. [29, 1002]

Dr. Jones followed with support for Lewis. Jones called Lewis' work a very good reconstruction of the available data. He agreed with Lewis that "everything we can test critically here suggests the idea of proportionality," and then went on to explain that Lewis' estimate was a conservative one and that the incidence of leukemia caused by radiation could be much higher [29, 1002-1003].

Dr. Friedell contended that there simply was not enough data in the low-dose region to make a threshold impossible and compared the somatic mutation hypothesis, which says that one ray of radiation can damage a cell and cause cancer, to a hypothetical hypothesis for cyanide damage. He claimed that radiation must be like other toxic substances in that the body must have effective ways to nullify small quantities of toxins [29, 1003].

Lewis responded by revisiting the Hiroshima and Nagasaki data, and explaining that Friedell's assumption was simply contrary to the available human data on radiation effects.

Dr. Pollard did not think like a toxicologist. He called the linearity hypothesis both "very reasonable" and "rational." From his perspective the policy on radiation should be based on it until it is proven not to be the case because of the risks involved. He says, "If later on it seems there is a threshold, then we are not too badly off. But if there is not a threshold, and we bet there is one, we are in trouble" [29, 1004].

Dr. Warren thought that policy should not be made so protectively; rather, he argued, it should be based on the most probable situation, which he believed to be the threshold scenario. Warren did not "regard the complete linearity of the induction of leukemia as in the range of reasonable probability."

Lewis brought the group back to the problems of the day; he explained that "the danger comes in legislating a dose that his said to be permissible for the public." He had the last word that day, arguing that the public should be told that a certain number of people would likely still be hurt under a permissible dose.

Finally, for the record, Representative Holifield confirmed that the scientists had all been speaking about the type of radiation associated with fallout and closed the session.

The hearings are printed in two volumes totaling 2000 pages. Accompanying them is a 19-page summary report. The question of a threshold features prominently in this short summary. The report asks if there is a safe dose of radiation or a threshold and concludes that an answer would be difficult to find using experiments. The report discusses possible dose-response curves. A linear relationship is based on the experimental data and on the somatic mutation theory. The testimony for a threshold was based on two contentions. The first was that the ability of biological organisms to repair damage to themselves must create a threshold, below which biological repair would reverse the damage. The second was the assertion that because many different mechanisms can lead to cancer, it is not possible to draw conclusions about the existence of a proportional relationship. The biological effects of low doses of radiation were discussed for two days and little agreement was reached. The report calls the existence of a threshold "the great unknown in the field of nongenetic biological effects of radiation" [49].

Press coverage of the hearings

Before the biological effects of radiation at low doses had been discussed at the hearings, Professor George Beadle of Caltech explained the major disagreements among the some scientists could be traced to their different evaluations of the role of nuclear weapons [21]. Beadle was concerned about the activist positions against nuclear testing of scientists like Pauling and Brown who believed that nuclear weapons were a grave threat to the earth and international security. At the opposite pole, scientists like Edward Teller believed that the Soviet threat to the national security of the United States made developing and testing nuclear weapons a necessity. Neither of these positions could be evaluated scientifically [38, 322]. However, some scientists, including Sturtevant and Lewis, did not take on activist campaigns. They believed that the pressing need was for good information based on scientific work that was not driven by ideology which those elected into politics could use to carefully weigh the costs and benefits of their decisions [26].

On June 3rd, the day after the sessions on the biological effects of fallout, Warren Unna of the *Washington Post* published an article that addressed both genetic and somatic hazards, titled "All Radiation Held Perilous: Nation's Top Geneticists Unanimous in Opinion." Unna pointed out the AEC's history of withholding information, particularly a report on the effects of strontium-90. He quoted Sturtevant's challenge that the AEC should respond to the scientists' careful presentation with a "detailed and objective statement of the reasons for continued testing" [50].

On June 10th *Life* Magazine featured a troubling article on the hearings, titled "A Searching Inquiry Into Nuclear Perils." It opened with photos of manikins wearing gas masks juxtaposed with the worried faces of senators on the radiation subcommittee. Two pages later is a photo spread of scientists who are engaged discussing and researching the fallout question. Lewis sits in front of a blackboard covered in statistical calculations with the caption,

> WARNING OF DANGER was sounded by Dr. E. B. Lewis of Caltech. In an article in *Science* he proved that there is a direct relationship between radiation and leukemia. He predicts a five to 10 percent increase in leukemia if strontium-90 level in humans reaches a figure which the AEC still considers harmless. [51]

In a diagram and a few short paragraphs, the authors explain the path of strontium 90 from nuclear detonations to human beings. The article's dramatic conclusion is a full page photograph of an embattled Nevada rancher who believes the tests are harmful.

Norman Cousins continued to participate in the debate over nuclear testing with his editorials in the *Saturday Review* and as one of the central leaders of SANE. “The Great Debate Opens” was the title of Cousins’ two-page June 15th editorial on the Congressional hearings. He summarized the arguments of those scientists who opposed nuclear testing in terms of the unknown nature of man’s tolerance limits for radiation, the fact that each additional piece of research seemed to show radiation to be “vastly more dangerous than was previously supposed,” and the recent research that “definitely indicates a small increase in the world leukemia rate which is directly attributable to the explosions.” Moving to the argument for nuclear testing, Cousins pointed out that both the American and Russian nuclear arsenals had the capacity to destroy the world. How, under these circumstances, can creating bigger bombs be of use to national security [52]?

On July 6th Cousins wrote “An Open Letter to David Lawrence,” editor of *U.S. News & World Report,* in response to an article titled “What’s Back of the ‘Fall-Out’ Scare” published by his magazine. The article had accused those speaking out against nuclear testing, including Pope Pius XII and Dr. Schweitzer, of being influenced by Communists. Cousins explained that these men held legitimate and sincere concerns for the health of all people and that they were not singling out or attempting to politically disadvantage the United States [53]. A week later he criticized the celebration of the “clean” bomb idea. To him “clean” bombs would only be covering up the immorality of “dirty” wars [54]. Two weeks later, Cousins included those men who were “chronic absentees” from being “supremely aware of and intimately involved in the great issues” of their time in his “Checklist of Enemies” [55].

A mushroom cloud served as the backdrop to the quote “We are dealing with a global health problem. We must face up to it,” on the cover of the August 3rd, 1957 *Saturday Review*. Both the article “Who Should Judge the Atom?” and the quote written by Representative Chet Holifield, who chaired the congressional hearings on radiation. In explaining what the committee learned, he stressed that fallout radiation was a new, manmade hazard. In his discussion of strontium-90, Holifield explained the need for “worry limits” and “yardsticks” which relate to them. The AEC had not been helpful in establishing these markers and measures. Their party line seemed to be to “play it down,” and in discussion they offered only estimates of where to begin to worry, not of what the upper limits might be. Even worse, the AEC had been covering up some of the dangers by not releasing information and by hiding its study of strontium 90 under the cheery name *Project Sunshine*. Holifield called on the president of the United States to ask the advice of scientists. Beyond this he called upon the expert scientists of the world to join together in open discussion and come up with a set of standards for radiation risks [56]. Lewis, whose work was heavily referenced, was an important member of this discussion.

Chapter 4: The responses

Pauling's *No More War!*

In August 1958 Linus Pauling published his book *No More War!*[7] Pauling's thesis was that nuclear weapons have made war prohibitively costly and therefore it must be avoided. The task of the book was to delineate the costs of nuclear war. In his chapter on "Radiation and Disease", Pauling summarized Lewis's "Leukemia and Ionizing Radiation." Pauling credited the analysis as the "most significant direct information about whether or not small doses of radiation produce cancer in the irradiated human being" [57, 90]. Further, he called Lewis's leukemia estimate of 2 _10^{-6} per roentgen per year "the best value available." Additionally, he compares this value with the independent estimate of Mazumdar and Nagaratnam which was 3 _10^{-6} per roentgen per year [29, 1685]. On the question of a threshold, Pauling believed that the geneticists working on the mechanisms of disease had the best information and that they were correct in believing that no threshold exists for the induction by radiation of leukemia and bone cancer. Furthermore, he pointed out that even if there is a threshold it may be low enough to be of no consequence because, in this scenario, the added exposure from bomb testing would push many individuals over that line.

In discussing the hazards of strontium 90, Pauling used Lewis' estimate to make an extrapolation to the world population. Pauling calculated the leukemia deaths per year expected for the whole world due to a steady state of bomb testing at what was then the current rate of tests. According to his extrapolation, 8,000 people on Earth would die of leukemia for each year of nuclear testing [57, 104].

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[7]It is said that Pauling dictated the book while driving to his vacation ranch on the California coast 48. Lewis, E.B., *e-mail*, J. Caron, Editor. 2002: Pasadena..

Lewis was reluctant to make such a broad extrapolation. He thought that by including the entire population of the Earth Pauling had inflated the number of people who were likely to be exposed by the fallout and therefore that his estimates were exaggerated [26]. (In fact, testimony at the Joint Committee hearings had explained that upper atmosphere winds and weather patterns would keep most of the fallout in the northern hemisphere.) Pauling concluded the chapter with the strong statement, "I believe that the nations of the world that are carrying out the tests of nuclear weapons are sacrificing the lives of hundreds of thousands of people now living and of hundreds of thousands of unborn children, and that this sacrifice is unnecessary" [57, 111]

Kimball's "Evaluation of Data Relating Human Leukemia and Ionizing Radiation"

In the August 1958 *Journal of the National Cancer Institute,* A. W. Kimball published an article titled "Evaluation of Data Relating Human Leukemia and Ionizing Radiation" criticizing the strength of Lewis's statistical assertions [58]. Kimball was a statistician at Oak Ridge, the national laboratory where radioactive uranium was processed for the atomic bombs. Lewis wrote Pauling a short and undated memo about another article by Kimball, and in a parenthetical note he discussed Kimball's critical article. He describes it as "a very objectionable criticism of my *Science* article," and says,

> The tone of it is that I have employed statistics incorrectly and so as to give an aura of authenticity to my paper and that this has served to dupe others—the meaning of this being DuShane and yourself—into believing there was something to the linearity hypothesis. There is a long background to this article by Kimball which I will tell you about some time. [59]

Kimball argues that Lewis did not prove the linearity hypothesis because the available data were "insufficient to support any conclusion about the shape of the dose-response curve, particularly in the low-dose region." Only in the second to last paragraph did Kimball note that Lewis never claimed to have proven the hypothesis. Kimball charged that Lewis's analysis must be treated with caution as the data were "selected retrospectively" for radiation exposure and may "be misleading when interpreted without regard for pitfalls that are frequently present" in such evidence. He was, however, comparing this data with what would be gathered in a controlled laboratory experiment on a randomly selected sample of a population, an experiment that would never be possible on human beings. Quoting DuShane's editorial "Loaded Dice," Kimball claims that some scientists had taken Lewis's work as proof of the non-existence of a threshold, and his intention is to establish that the data were "insufficient to support definite conclusions."

"The real point at issue," according to Kimball, is the existence of a threshold dose. Kimball says that the justifiability of the statistical assumptions inherent in Lewis's analysis is susceptible to reasonable doubt. His discussion of "recognizable" sources of error and the statistical techniques involved is "intended to establish such doubt." Kimball is concerned with several categories of errors: errors in the data collection, dosimetry errors, errors due to sampling bias, truncation errors, and random errors. His concerns about dosimetry, sampling bias, and truncation are the most interesting; in contrast, his comments about data collection and random errors amount to little more than the acknowledgement of these general sources of concern in scientific studies.

For both Hiroshima and Nagasaki Lewis used the same estimation of dose based on the distance of each individual from the hypocenter of the atomic explosion. Hiroshima had been hit with a uranium bomb, while the bomb used on Nagasaki was made with plutonium. These two bombs were different and yielded different amounts of neutron and gamma radiation. Furthermore, the two cities were topographically different. Kimball argues that it would have been more accurate to use dose-distance curves constructed separately for each city and to have broken down the neutron and gamma radiation contributions. Kimball criticizes the conclusions Lewis drew from the other data sets by claming that it cannot be assumed that acute and chronic doses have the same effect on the genesis of leukemia. He claims that "if one considers all aspects of the dosimetry problem, it should be clear that the apparent agreement among the calculated leukemia rates per individual per year per rad for the four sets of data may be highly fortuitous."

In his attempt to create doubt about sampling bias, Kimball tells readers that although there is no evidence for a correlation between ankylosing spondylitis or thymic enlargement and leukemia, except for the radiation treatments, "it would be difficult to state categorically that no such correlations exist." The data could also be subject to truncation errors. If irradiated populations die earlier than unirradiated populations, as in animal studies, then looking for the number of leukemia deaths in each population when more irradiated people had died than unirradiated people could lead to a bias. Kimball cites animal studies of leukemia induction by radiation to argue that the incidence of leukemia would be greater in the population that died earlier than it would prove to be once the cause of death was known for the entire exposed population. This bias toward an increased incidence of leukemia would not be present if you could wait to gather data until all members of the population in question had died. While such a study might be of future interest, the immediate need for information to which Lewis was responding would not allow it.

Kimball did find one indisputable error in Lewis's paper. The confidence limits Lewis believed were 95 percent were actually 90 percent limits. Lewis had used a mislabeled reference table to calculate the limits, and he unknowingly carried over the error [26].

Kimball concludes that Lewis's risk estimate is "open to serious question" and that the available evidence is "insufficient" to support either the threshold or linearity hypothesis. He notes, in the second to last paragraph of his very critical paper, that "Lewis has avoided stating the definite conclusion that there is no threshold dose." The last paragraph is very interesting. Kimball attempts to clear himself of advocating a point of view opposite to that of Lewis. He says of his article that,

> In reality its only purpose is to emphasize the shaky grounds on which any definite conclusion would be based. Nothing that is said here should be taken as an argument supporting the hypothesis of a threshold dose for the induction of leukemia by ionizing radiation. An attempt to use the same data to establish a threshold would be open to similar criticism. [58]

After concluding that the available evidence leaves him in the dark about the shape of the dose-response curve for ionizing radiation and leukemia, Kimball ends his paper, "We can only hope that scientists working on this critical problem will soon provide us with adequate evidence." One wonders what evidence Kimball would consider "sufficient" and "adequate" for drawing conclusions. Here we are reminded of Lewis's crucial argument at the Joint Committee Hearings' roundtable. If it is not possible to know for sure what the risks are to the health of large numbers of people, is it not prudent to take the most cautious approach possible?

Brues's "Critique of the Linear Theory of Carcinogenesis"

On April 30, 1958, Graham DuShane wrote Lewis to let him know, among other things, that Austin Brues, Director of Argonne National Laboratory and a radiobiologist, would be submitting a paper criticizing "Leukemia and Ionizing Radiation". This paper, "Critique of the Linear Theory of Carcinogenesis: Present data on human leukemogenesis by radiation indicate that a nonlinear relation is more probable," was published in *Science* on September 26th. The paper is a review of the literature and contains no new data. Brues seeks to cast doubt on the linearity hypothesis by reinterpreting the available data and looking at some of the other mechanisms that could be responsible for cancer.

It is useful to remember Lewis's arguments before approaching the details of Brues's paper. Lewis came to linearity from the data, not from the somatic mutation hypothesis [33], [48]. He considered the finding that the probability of leukemia per individual per rad per year was almost the same over the wide range of dosages received by the atomic bomb survivors and the ankylosing spondylitis patients, "presumptive evidence" that the dose response curve was linear or approximately linear.

In the next paragraph of his paper, "Leukemia and Ionizing Radiation," Lewis said that this linear relationship "suggested by the available data for man, may have its explanation in a somatic mutation hypothesis." Furthermore, he explained that the available hypotheses for radiation-induced cancers were "by no means mutually exclusive." Why did Lewis choose to discuss this hypothesis? Because the data yielded a linear dose-response curve and, as a geneticist, he was aware that gene mutation was known to be linearly proportional to dosage, even when the radiation was received gradually, rather than in one large dose. At no point in his paper does Lewis assume that all cancer, or even all leukemia, is caused by somatic mutations. Nor does he assume that the risk estimate he has derived for radiation-induced leukemia applies equally to everyone. Instead, he explains that it applies to the "average" individual and that some people are likely to be more or less susceptible [33].

Brues sees things differently from square one. Lewis is working from his background in genetics. The first point Brues makes is that the existence of a threshold is usually taken for granted in toxicology. In analyzing the human evidence Brues found that those few individuals who were more than 1625 meters from the hypocenters of the atomic bombs and later developed leukemia were probably exposed to more than the dosage estimated by the distance, because they suffered acute radiation symptoms after the bombings. Therefore, where Lewis estimated that these survivors received doses averaging 50 rem, Brues concluded that they must have received at least 100 rad, which means that Lewis had less low-dose data than he estimated.

Brues also reanalyzed Court-Brown and Doll's research on ankylosing spondylitis patients. These authors concluded that a linear relation without a threshold was a good "working hypothesis." Brues disagreed. In his analysis he found a curvilinear relation from the mean doses to the spinal marrow and an approximately linear relation "only by discarding those cases in which extra spinal irradiation was also given." Therefore, he claims that "present data on human leukemogenesis by radiation fail to indicate a linear relation between dose and effect" [60].

Brues goes on to examine experimental studies of carcinogenesis in animals. At the Joint Committee hearings a year earlier, he expressed what most scientists would consider unreasonable standards for what can be called “scientific.” Among other examples, he said that irradiating one kind of mice and inferring that another species of mouse would behave in the same way is “not quite so scientific of a route” [29, 1002]. In 1958 Brues was less picky about what could disprove a hypothesis. He looked at experiments with carcinogenesis in animals. Some of the studies he cites use radiation, others use chemical carcinogens, and of more than half a dozen studies, none deals with leukemia specifically. Because none of these animal studies, mainly of tumors, shows a linear relationship with dosage, Brues would like to rule out the linear relationship that Lewis and Court-Brown and Doll believe they found in human beings.

Continuing along the same vein, Brues argues that because the somatic mutation hypothesis does not appear to be a plausible explanation of many cancers, mutation somehow cannot be the source of radiation-induced leukemias. Brues says, “I feel, however, that the burden of proof must rest on those who are attracted to the somatic point-mutation hypothesis because of its superficial simplicity.” He proposes five alternate hypotheses for the source of carcinogenesis. But since the purpose of his paper is simply to cast doubt, he is merely throwing alternative out ideas without careful evaluation.

Brues summarizes his claims: 1) that the human data don’t support linearity, 2) that no carcinogenic agent has been shown to have a linear dose-response relation, and leukemia should not be an exception, 3) that a cancer-inducing mutation must, by the numbers, be extremely improbable, and 4) that there cannot be a linear relationship if multiple events or a disordered tissue state are required for leukemogenesis. On these grounds Brues "deduced" that a linear dose-response between radiation and leukemia "seems most improbable."

Why did Brues, director of the Department of Energy's Argonne National Laboratory, write this article? The first sentence of the discussion section may hold the answer: "It has been suggested that strontium-90 from fallout might be linearly responsible for a very low (but in absolute numbers, appreciable) incidence of leukemia." Brues is very defensive when he says that the evidence presented against linearity at low doses is only "illustrative," but, he claims, he has discussed the evidence for linearity "rather completely" [60].

Lewis did not respond to the critical papers

Lewis did not respond to Kimball or Brues. When their articles were published, Lewis was doing research, teaching genetics, managing Caltech's Drosophila collection, and had three sons at home. The journals wanted responses right away and he was too busy, too tired, and too exhausted from all the attention generated by "Leukemia and Ionizing Radiation" and the Joint Committee hearings. Lewis writes,

> I should have answered the letters to Science but as usual the journal wanted an immediate response from me and I don't dash stuff off easily. Aside from using confidence limits from a table in a book that were wrong (90% instead of 95%), there was no substance to any of it and the claim that leukemia deaths would not be a Poisson variable is wrong and papers in the field are now careful to point out that it is Poisson. The number of deaths from leukemia in the USA per month are tabulated in the national data bases and it turns out that it almost perfectly predicts the number of days in the month Feb lowest, 30 and 31 days come out surprisingly well. I did that years ago and should have written a note about it. [35]

More than thirty years later Sir Richard Doll dismissed Brues and supported Lewis in a guest editorial in the *British Journal of Cancer.* In "Hazards of ionizing radiation: 100 years of observations on man" Doll explains that the increased risk of cancer “came gradually to be accepted as due to one or more somatic mutations partly as the result of epidemiological observations in the mid 1950s (Court Brown and Doll, 1957; Lewis 1957) but even as late as 1960, it continued to be resisted by some distinguished radiobiologists (Brues, 1960)” [2].

Chapter 5: Conclusions

Lewis's later work on radiation

After the Joint Committee hearings, Lewis was asked to serve on the National Advisory Committee on Radiation. The committee was established by Dr. LeRoy E. Burney, the Surgeon General. According to his son, Abel Wolman, a sanitary engineer [a public health specialist in sanitation] from Johns Hopkins University, initiated the formation of the committee. Wolman saw a need for an expert committee that brought together diverse experts who were not part of the radiation establishment. The committee reported to the Surgeon General and was under the umbrella of the Public Health Service; it had no statutory authority [61, 250-251]. The first meeting was held in Washington DC on March 13, 1958 [62]. On the committee were 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. Russell H. Morgan, chairman of the committee, was a professor of radiology at Johns Hopkins Medical School and radiologist-in-chief at Johns Hopkins Hospital [61, 251]. Members of the committee included Wolman, Lewis, and James Crow, an outspoken geneticist from the University of Wisconsin. Arnold Beckman, president of Beckman Instruments and a Caltech alumnus, was on the committee for the purpose of representing the radiation instruments industry; according to Lewis's memory, he never said a word [63].

National Advisory Committee on Radiation, first meeting, Washington, DC. Front row: far left Edward Lewis, far right Arnold Beckman, Back row: far left, Abel Wolman. Mar. 13, 1958.
Courtesy of the Caltech Archives PhotoNet Photo ID 1.2.02-9

A year after its formation, the Committee suggested that the "ultimate authority" for protecting the public from nuclear radiation be removed from the AEC and vested in the Public Health Service. The Committee recognized that the AEC had been given the dual responsibilities of regulating and promoting nuclear power and called this structure "unwise." Promotion was clearly winning at the expense of public health and this organizational structure was unwise. The next month President Eisenhower ordered a study by “high Federal officials to determine which Government body shall be responsible for protecting the public against atomic radiation” [64, 308-309] [61, 251-253].

In 1959 Lewis found reason to challenge another AEC assumption. It had been assumed that absorbed doses of radiation averaged over yearly periods and large populations would be significantly below the natural background doses. Lewis found this to be far from the case for radioactive iodine, predominantly iodine-131, in infants and children in the United States. Lewis used data on the radioiodine content in milk for five major US milk sheds from March 1957 to September 1958, estimates of milk consumption, and estimates of the fraction of radioiodine taken up by the thyroid by age group. Infants received about 18 times the thyroid dose of radiation received by adults. Lewis found that infants and children received an average dose from radioiodine generated by nuclear tests equal to one to two times the corresponding natural background radiation dose [65].

Lewis worried that this paper would “meet review problems in *Science*” because it was such a charged topic and the AEC had put pressure on the editors after “Leukemia and Ionizing Radiation” in 1957. Instead of trying to publish in *Science*, Sturtevant submitted it to the *Proceedings of the National Academy of Sciences*; which, at that time, accepted articles directly from NAS members without further review. Looking back, Lewis said, “Probably a mistake, but by then I was not sure *Science* would take it and I felt it needed publication to counter some of the AEC claims about fallout levels” [26].

Edward B. Lewis with Drosophila, 1960
Courtesy of the Caltech Archives PhotoNet Photo ID 10.24-181

In 1962 Lewis again offered a statement at Joint Committee on Atomic Energy Hearings. In his statement he focused on the danger of thyroid cancer in children from fallout exposure, estimating that 1600 United States children would develop thyroid cancer as a product of the nuclear testing. He explains this estimate:

> Over the last five years it may be surmised that about 40,000,000 children (under ten) in the U.S. have experienced an average total accumulated dose from the radioiodines in fallout that is equal to about 0.2 to 0.4 rad. If such individuals experience the same probability of thyroid cancer per year per rad as the infants in the thymus-irradiated series [those treated for enlarged thymus glands with radiation], then some 80 to 1600 cases of thyroid cancer might be expected to develop over the lifetimes of these 40,000,000 individuals. The number of cases predicted in this way is seen to be a small percentage of the total number of individuals involved. *However, neither total number of cases nor the percentage they represent of the total population are adequate measures of the extent of human suffering which would be involved.* These numerical estimates have been presented merely in order to give some idea of the magnitude of the damage which might result in the U.S. from the radioiodine release in past weapons tests. [66] [emphasis in original]

The linear versus threshold debate was continued at these Joint Committee Hearings, so Lewis evaluated the radioiodine risk in both scenarios. He concluded that in this case a linear relationship to dose might yield a lower estimate of the number of individuals affected than a threshold relationship.

> If there is a threshold for the induction of thyroid cancer and if this threshold has not yet been exceeded, then no cases of thyroid cancer may trace to fallout from past weapons tests. On the other hand, there have been extremely wide variations in radioiodine levels, with time and with locality, which will have to be taken into account before it can be said even on the threshold hypothesis that no damage could have resulted from past tests. Moreover, many children receive doses of medical X-rays that are near if not over the threshold dose for the induction of thyroid malignancy and on the threshold hypothesis these individuals are those most sensitive to the added radiation from fallout. On the linear hypothesis it is the average dose over the entire population of the U.S. which is important and local hot spots do not then have the alarming significance that is often attributed to them nor, from the linear hypothesis, does the individual who receives a large dose of radiation need to be alarmed, since the individual's probability of developing a malignancy remains relatively low even after heavy dose exposures. [66]

With this last scenario, that of individuals receiving radiation in the course of medical treatment, Lewis demonstrated that risk estimates can provide reason for alarm or for confidence, and sometimes for both.

On December 13, 1963 Lewis published a more in-depth study of leukemia among radiologists in *Science,* which built on the one in his 1957 paper "Leukemia and Ionizing Radiation." Lewis looked at the death certificates of 425 radiologists who died between 1948 and 1961 and found increased incidences of leukemia, multiple myeloma, and aplastic anemia when compared to the incidences among the larger population of white males in the United States [67]. Furthermore, he established for the first time that these increased incidences were not the result of radiologists receiving better diagnosis than other Americans. To do this he used the discovery by Court-Brown and Doll that one common form of leukemia, chronic lymphatic leukemia (CLL), was not induced by ionizing radiation. If the increased incidence of leukemia in radiologists was an artifact of diagnosis, then one would expect to see a proportional rise in CLL cases, which Lewis did not find [30].

In 1998 Lewis presented a review paper titled "Ionizing Radiation, Cancer Induction and Radioactive Fallout" at the international conference *The Discovery of Polonium and Radium—its scientific and philosophical consequences, benefits, and threats to mankind.* In this paper he discussed,

a) how important discoveries over the last 100 years help to quantify the risk of cancer in populations exposed to man-made sources of ionizing radiation, and
b) how periodic episodes of contamination of the environment with radioactive elements have created public health problems

Looking back on the years of nuclear testing with his knowledge of the cancer-inducing effect of radioiodine on the thyroid glands of children, Lewis wrote:

> In some areas of the US, it would probably have been wise to try to reduce the thyroid dose by limiting the intake of contaminated milk. However, the hazard was not recognized by the US Atomic Energy Commission, which assured the public that fallout doses were far below natural background levels (0.1 rem per year).

Lewis warned that more could have been done to protect the victims of Chernobyl from fallout, especially the infants and children from radioiodine. He concluded that, in this nuclear age, governments and societies need to be better prepared to deal with future releases of radioactive fallout [4].

The threshold debate remains unresolved. Lewis discussed the evidence for linearity in the "Epidemiology of cancer induction" subsection of his 1998 review and notes that the United States National Academy of Science (1990) and UN (1994) committees on radiation found cancers in addition to leukemia with approximately linear dose-response curves. Apparently no firm conclusions about the effects of low doses of radiation can be established. In the summary of this review, Lewis simply stated that "certain cancers are induced by relatively high doses at a rate that is linearly proportional to the dose," citing Muller's 1937 paper on the issue [4]. He explained:

> Science cannot claim absolute truth and this allows people to make extreme statements that a threshold dose can never be ruled out. In practice it can be a moot point if everyone exceeds the threshold dose if that dose is below that received from natural background sources of ionizing radiation. [48]

While the scientific debate on whether the induction of leukemia by radiation has a linear or threshold relationship to dose remains uncertain, Lewis is confident that the relationship is linear. One reason he gives is that usually in biology if there is a threshold below which a biological system can compensate for a damaging agent, then once the threshold is met, the incidence of damage or disease increases exponentially, not linearly. In the case of leukemia and radiation it clearly increases linearly into the high dose range. Even if the relationship is not linear, Lewis argues, the threshold has been exceeded [25].

Watson and Crick published the structure of DNA in 1953. Molecular biology was in its infancy during the fallout debate of the late fifties. Almost half a century later, a great deal has been discovered and it is a well developed field of study. Lewis is further convinced that the relationship between leukemia and radiation is linear because of the action of radiation on DNA.

> The reason I am convinced that there is no threshold is that cancers such as leukemia are known to be the result of somatic mutations. The absorption of a single quantum of radiation results in a track of ionizing particles that is long enough to delete up to several thousands DNA base pairs. Such lesions can therefore lead to a gene mutation and if in a bone marrow cell can transform it into a leukemic cell. Such lesions also cannot be easily repaired nor is there any known way that such repair can be 100% effective. Obviously in the case of induced cancers (namely those significantly in excess of the expected number), the DNA repair process must have failed. [48]

Although the biological effects of radiation are not the predominant focus of Lewis's scientific career, he continues to be concerned with the impact of radiation exposure on human health. Lewis has convinced several members of the Caltech faculty to accept dental x-rays less frequently than suggested by their dentists. In addition, he has pushed for an increase in the suggested age at which women should have mammogram screenings because his calculations show that the risks associated with the x-rays outweigh the expected benefits of the early detection of breast cancer at 40 years of age.

The Limited Nuclear Test Ban

A voluntary moratorium on atmospheric testing was initiated by the Soviet government in 1958 and lasted for three years. Intense efforts of diplomats, scientists, and activists were underway during this time to create an enforceable ban on all nuclear testing. The Soviets resumed testing on September 1, 1961 and the United States followed suit two weeks later. 1962 was the most intense year of testing for both countries. Finally, the pursuit of a detection system which could observe all underground and outer space tests was abandoned and the compromise solution was to ban atmospheric testing of nuclear weapons and consequently end the creation of nuclear fallout.

The Limited Nuclear Test Ban was signed into law on Aug. 5, 1963 by the US, Great Britain, and the Soviet Union. The agreement banned nuclear tests in the oceans, in the atmosphere, and in outer space [38]. The Committee for a SANE Nuclear Policy was credited with building a substantial grassroots movement to end nuclear testing. They chose to use the health effects of fallout as their central argument for a test ban. Included in their campaign of full paged advertisements were "Is this what it's coming to?" with a photo of a milk bottle labeled with poison cross bones, and "Your children's teeth contain Strontium-90" with a photo of smiling kids [45]. Their approach would not have been viable without the work of scientists like Lewis who researched the hazards of radioactive elements.

Edward B. Lewis (no date)
Courtesy of the Caltech Archives PhotoNet Photo ID 10.24-82

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TIMELINE

1945

July 16
Trinity, the first atomic detonation

August 6
The bombing of Hiroshima

August 9
The bombing of Nagasaki

1946

Harrison Brown, professor of geochemistry at Caltech, published *Must Destruction Be Our Destiny? A Scientist Speaks as a Citizen* arguing for international control of nuclear weapons.

1950

The Los Alamos Scientific Laboratory published *The Effects of Atomic Weapons: Prepared for and in cooperation with the U.S. Department of Defense and the U.S. Atomic Energy Commission*. While this document includes significant discussion of the immediate effects of radiation exposure, the discussion and index fail to mention both leukemia and cancer.

1952

October 13
Britain tested its first atomic bomb

November 1
The first hydrogen or thermonuclear device, MIKE, was secretly detonated at Eniwetok in the Pacific.

1954

March 1
BRAVO hydrogen bomb test by the AEC begins the AEC CASTLE series.

July-August
Lewis published “The Theory and Application of a New Method of Detecting Chromosomal Rearrangements in Drosophila Melanogaster” in the *American Naturalist*.

September and October
Soviet H-bomb tests

September 10
Sturtevant’s Pacific Division of the AAAS Presidential speech on the “Social implications of the genetics of man.”

1955

January
Sturtevant published “The Genetic Effects of High Energy Irradiation of human populations” in the Caltech magazine, *Engineering and Science (E&S)*.

February 15
The AEC released its report on fallout from the March 1st, 1954 H-Bomb test, BRAVO.

February 18-May 25
Operation TEACUP tests in Nevada

July 8
Beadle sent a memo on “Possible direct effects on man of low level exposures to ionizing radiation” to the Caltech biology faculty.

October 4
New Soviet H-bomb test series begun

October
At the last minute, the AEC prevented Muller from being an American delegate to the UN Atoms for Peace Conference and prevent him from presenting his warning about fallout radiation and genes

October 28
George Beadle’s Science Editorial “Liquidating Unpopular Opinion” responds to the AEC’s exclusion of Muller’s paper from the UN Peaceful Uses of the Atom conference

November 28
Lewis replied to Beadle and the biology faculty with his “Memorandum on Fallout.”

November 30
The New York Times reported on the findings of the Atom Bomb Casualty Commission.

December
Gordon Dunning of the AEC published the “Effects of Nuclear Weapons Testing” in the *Scientific Monthly*. He claimed that “the highest measured radiation exposure to the thyroid of human beings has been far below that needed to produce any detectable effects.”

December 3
A scientific committee to study radiation hazards was created by the UN General Assembly.

1956

April
AEC Commissioner Murray makes public call for moratorium, endorsed by Democratic Presidential candidate Adlai Stevenson.

May 21-July 21
Operation REDWING tests in the Marshall Islands

June 12
The National Academy of Sciences released its report on “The Biological Effects of Atomic Radiation” (BEIR).

October 14
Ten Caltech physicists who had participated in the building of the original atomic bombs published and advertisement in the Los Angles Times in support of Democratic Presidential candidate Adalai Stevenson and cessation of nuclear weapons testing. The biological effects of radioactive fallout were among their reasons for opposing testing.

October 15
Caltech President DuBridge and Chairman of the Board of Trustees Ruddock both publicly responded to the physicists’ advertisement.

October 25
Pauling wrote Beadle and carbon copied Lewis and Sturtevant about a case of leukemia that a reported from Tonopah, Nevada called him about.

October 26
Sturtevant published a Letter to the Editor in *The Washington Post* countering an October 15^{th} article headed “Tenfold Rise in A-Tests Seen as Safe.” He explained that he had sat on the National Academy of Sciences BEIR Committee and that the Committee was falsely credited with this conclusion. Furthermore, Libby, who chaired the AEC Division of Biology and Medicine, had recently indicated that the Sr-90 danger was greater than

previously reported to that committee. Consequently, their conclusions about the danger from fallout would need "revision upward."

November 30
Lewis circulated a draft of his "Leukemia and Ionizing Radiation" paper to Caltech faculty members including Linus Pauling and Harrison Brown. Brown sent it (or a summary) to Schweitzer, probably via Norman Cousins, editor of the Saturday Review and founder of SANE.

1957

January 19-April 26
Soviet nuclear tests in Siberia

February 18
Beadle addressed the American Pharmaceutical Manufactures Association, Mid-Winter Conference on the topic of "Chemical Genetics and Radiation Effects." He compared the hazard posed by fallout to that of medical x-rays and stressed the need to minimize x-radiation exposure.

April 24
Albert Schweitzer released his open letter on nuclear bomb testing through the Nobel Committee.

April 25
W. F. Libby published an open letter to Schweitzer arguing that his own standard of concern was "detectable effects" and that the risks caused by radioactive fallout were small.

May 2
W. F. Libby of the AEC wrote Pauling a critical letter regarding his estimation that 1,000 people would die of leukemia as a result from an upcoming British Hydrogen bomb tests.

May 10
Pauling replied to Libby's letter, explaining that he had made his estimation using Lewis's as yet unpublished estimate among a small group after a lecture on abnormal hemoglobin.

May 15
Britain's first H-bomb test at Christmas Island

Scientists' Bomb-test Appeal initiated by Pauling

May 17
Lewis published "Leukemia and Ionizing Radiation" in *Science.*

May 25
President Eisenhower approved a temporary test ban

Brown published an article in the *Saturday Review* in its "Forum on the Schweitzer Declaration: What is a "Small" Risk?" He explained that the risk of increased incidence of leukemia from low doses of radiation "was uncovered by a lone geneticist, Professor E. B. Lewis."

May 27 - June 7
The Joint Committee on Atomic Energy held hearings on the "Nature of Radioactive Fallout and Its Effects on Man."

June 3
Pauling presented the Scientist's Test Ban Petition to Eisenhower.

June 10
Lewis appeared in the *Life Magazine* article "Nuclear Worries: The nation begins to worry in earnest about its nuclear tests as scientists explain their fallout warnings to a congressional committee"

June 21
Lewis gave a summary of his paper at the organizing meeting in New York for what became The Committee for a SANE Nuclear Policy.

July 16
Beadle wrote Dr. Sterling Emerson of the AEC's Division of Biology and Medicine regarding several articles by Elizabeth Coulson printed in the El Monte Herald which misrepresented the estimates of fallout risks generated by Caltech faculty.

September 19
First underground nuclear weapons test in Nevada.

October 3
Beadle moderated a panel discussion on the "Health Hazards of Radiation" at the California Division of the American Cancer Society's Annual Meeting.

October 4
The launch of Sputnik launch intensified Cold War fears of the Soviet Union.

October 20
The New York Times reported that the AEC's Advisory Committee on Biology and Medicine had considered the dangers of radioactive fallout from nuclear testing and concluded that they were "well within tolerable limits" and would continue to be so if the global rate of testing did not increase from that of the preceding five years.

In a separate article on leukemia they reported that the testing was estimated to produce 196 cases of leukemia in the United States beyond the 11,400 per year that were "not attributable to test radiation."

1958

Pauling publishes his book *No More War!*

January 13
Pauling presented the Scientists' Test Ban Petition to the UN

March 13
The first meeting of the Surgeon General's National Advisory Committee on Radiation; Lewis was a founding member.

April 28-August 12
HARDTACK I H-bomb test series in the Pacific.

June 30
Admiral Lewis Strauss resigns as AEC Chairman; former member of the Caltech Board of Trustees, John McCone is appointed by Eisenhower.

August
A. W. Kimball publishes "Evaluation of Data Relating Human Leukemia and Ionizing Radiation" in the *Journal of the National Cancer Institute* criticizing Lewis's statistical analysis.

August
The Soviet government announced that they would stop all tests. On August 22nd President Eisenhower announced a moratorium on US nuclear-weapons tests.

September 12-October 30
HARDTACK II atomic tests in Nevada

1959

March 15
A letter written by General Loper and released by Senator Anderson states that Sr-90 reaches the earth more quickly than expected; this information created renewed fear of fallout.

March 26
The Surgeon General's National Advisory Committee on Radiation recommended that primary authority for radiation safety be vested in the U.S. Public Health Service, rather than the AEC.

June
Lewis published "Thyroid Radiation Doses from Fallout" in the *Proceedings of the National Academy of Sciences*.

May 5-8
The Joint Committee on Atomic Energy held hearings on "Fallout from Nuclear Weapons Tests."

May 7
Lewis reported on radioiodine and leukemia at the congressional hearings.

June 22-26
Hearings before the Special Subcommittee on Radiation of the Joint Congressional Committee on Atomic Energy on the "Biological and Environmental Effects of Nuclear War"

August 14
Eisenhower created the Federal Radiation Council "to provide advice on radiation safety and to reassure the public about the federal government's objectivity in evaluating fallout hazards."

1959-61

Voluntary atmospheric-testing cessation by the United States and the Soviet Union which ended with a Soviet test on September 1, 1961

1961

September 15
The United States resumed underground nuclear testing.

September 20
President Kennedy approved Federal Radiation Council's proposal to change guidelines for population exposure to strontium 89, strontium 90, iodine 131, and radium 226. AEC subsequently modified its regulations.

1962

April 25
The United States resumed atmospheric testing in the Pacific.

June 1
The Federal Radiation Council released its report on the "Health Implications of Fallout from Nuclear Weapons Testing through 1961."

1963

December
Lewis published "Leukemia, Multiple Myeloma, and Aplastic Anemia in American Radiologists" in Science.

August 5
The Limited Test Ban Treaty was signed by the US, Great Britain, and the Soviet Union. This treaty banned nuclear tests in the oceans, in the atmosphere, and in outer space.

October 10
The Test Ban Treaty went into effect.

And the Nobel Committee announced that it would award the 1962 Peace Prize to Linus Pauling.

1970

Lewis published "Ionizing radiation and tumor production" in *Genetic Concepts and Neoplasia.*

1971

October 29
Lewis published a letter on "Leukemia, Radiation, and Hyperthyrodism" in *Science.*

1976

Lewis prepared an "Analysis of lung tumor mortality in the Batelle Beagle Lifespan experiment" which became part of the Ad Hoc Committee on "Hot Particles" of the Advisory Committee on the Biological Effects of Ionizing Radiations of the NAS and National Research Council's report on the *Health Effects of Alpha-Emitting Particles in the Respiratory Tract*. This report was published by the Environmental Protection Agency.

1992

President George Bush Sr. ended all nuclear weapons testing in the United States and instructed US laboratories to use computer models and other methods to asses the national nuclear stockpile without test detonations.

1995

Sir Richard Doll of England published "Hazards of ionizing radiation: 100 years of observations on man" in the British *Journal of Cancer*. In this review article he supported the linearity hypothesis as articulated by Lewis in 1957, ending, in the minds of some, the threshold debate.

1998

September 17-20
Lewis presented a paper titled "Ionizing Radiation, Cancer Induction and Radioactive Fallout" at the *Curie Symposium: The Discovery of Polonium and Radium—its scientific and philosophical consequences, benefits and threats to mankind.*

2002

The Bush administration began taking steps to enable the resumption of underground nuclear weapons testing.

SOURCES REVIEWED IN CHRONOLOGICAL ORDER

Reference Type: Journal Article
Record Number: 47
Author: Muller, H. J.
Title: Potential Hazards of Radiation
Call Number: Sturtevant 13.5

Reference Type: Book
Record Number: 59
Author: Snyder, Laurence H. Sc.D.
Year: 1941
Title: Medical Genetics: A Series of Lectures Presented to the Medical Schools of Duke University, Wake Forest College, and the University of North Carolina
City: Durham, NC
Publisher: Duke University Press
Number of Pages: 130

Reference Type: Journal Article
Record Number: 51
Author: Oppenheimer, J. R.
Year: 1945
Title: Atomic Weapons and the Crisis in Science
Journal: delivered at the Joint Meeting of the American Philosophical Society and The National Academy of Sciences in Philadelphia
Date: Nov. 16, 1945
Call Number: DuBridge 168.1

Reference Type: Book
Record Number: 57
Author: Brown, Harrison
Year: 1946
Title: Must Destruction Be Our Destiny? A Scientist Speaks as a Citizen
City: New York
Publisher: Simon and Schuster
Number of Pages: 157

Reference Type: Report
Record Number: 60
Year: 1950
Title: The Effects of Atomic Weapons: Prepared for and in cooperation with the U.S. Department of Defense and the U.S. Atomic Energy Commission
Institution: Los Alamos Scientific Laboratory
Pages: 456
Date: Revised September 1950
Call Number: UF 767 U594 1950a

Reference Type: Book
Record Number: 91

Author: Srb, Adrian and Owen, Ray
Year: 1952
Title: General Genetics
City: San Francisco, California
Publisher: W. H. Freeman and Company
Number of Pages: 561
Edition: 1st

Reference Type: Journal Article
Record Number: 70
Author: Lewis, E.B.
Year: 1954
Title: The Theory and Application of a New Method of Detecting Chromosomal Rearrangements in Drosophila Melanogaster
Journal: The American Naturalist
Volume: LXXXVIII
Issue: 841
Pages: 225-239
Date: July-August, 1954

Reference Type: Journal Article
Record Number: 49
Author: Sturtevant, A. H.
Year: 1954
Title: Social Implications of the Genetics of Man
Journal: Science
Pages: 406-407
Date: September 10, 1954

Reference Type: Journal Article
Record Number: 55
Author: Sturtevant, A. H.
Year: 1955
Title: The Genetic Effects of High-Energy Irradiation of Human Populations
Journal: Engineering and Science
Volume: XVIII
Issue: 4
Pages: 9-12
Date: January 1955

Reference Type: Journal Article
Record Number: 54
Author: Beadle, George W.
Year: 1955
Title: Possible direct effects on man of low level exposures to ionizing radiation
Pages: 1
Date: July 8, 1955
Call Number: Pauling Archive

Reference Type: Personal Communication
Record Number: 71

Author: Lewis, E.B.
Year: 1955
Title: Memoradum on Fallout
Recipient: Pauling, Linus Carl and Caltech faculty
City: Pasadena, CA
Date: Nov. 17, 1955, send to L.P. Nov. 28
Type: memo

Reference Type: Newspaper Article
Record Number: 46
Year: 1955
Title: GENE MUTATION DOUBTED Scientist Discloses Findings on Hiroshima Survivors
Newspaper: NY Times
City: Tokyo, Nov. 29
Issue Date: Nov. 30, 1955
Call Number: Sturtevant 13.5

Reference Type: Journal Article
Record Number: 92
Year: 1955
Title: News of Science
Journal: Science
Date: October 28, 1955

Reference Type: Journal Article
Record Number: 50
Author: Beadle, George W.
Year: 1955
Title: "Liquidating Unpopular Opinion
Journal: Science
Pages: 813
Date: October 28, 1955

Reference Type: Manuscript
Record Number: 75
Author: Lewis, E.B.
Year: 1956
Title: Second Draft of Leukemia and Ionizing Radiation
Collection Title Eva and Linus Pauling Papers
Date: November 30, 1956
Type of Work: second draft of a Science article

Reference Type: Generic
Record Number: 40
Author: DuBridge, Dr. Lee A
Year: 1956
Title: Statement responding to Lauritsen/Chrsity statement
Date: Oct. 15, 1956

Reference Type: Generic

Record Number: 39
Author: Ruddock, Chairman of the Board of Trustees
Year: 1956
Title: Statement responding to Oct. 14, 1956 advertisement
Date: Oct. 15, 1956

Reference Type: Personal Communication
Record Number: 43
Author: Lauritsen, Thomas
Year: 1956
Title: H-Bomb Release
Recipient: Watson, E. C.
Date: Oct. 23, 1956
Type: inter-office memo

Reference Type: Personal Communication
Record Number: 41
Author: Lauritsen, Thomas
Year: 1956
Title: Lauritsen to Board member J.A. McCone
Recipient: McCone, J. A.
Date: Oct. 24, 1956
Type: letter

Reference Type: Personal Communication
Record Number: 38
Author: Lauritsen, Thomas
Year: 1956
Recipient: Dahle, Mr. T. K.
City: Alhambra, CA
Date: Oct. 30, 1956
Type: letter

Reference Type: Generic
Record Number: 94
Author: Anderson, Carl et al.
Year: 1956
Title: H-Bomb Release
Place Published: Los Angles Times
Date: October 14, 1956
Type of Work: Advertisement, Statement for an end to nuclear testing by 10 Caltech scientists
Call Number: Caltech Archives DuBridge 190.5

Reference Type: Book
Record Number: 30
Author: Biology Division, Caltech
Year: 1957
Title: Biology 1957 At the California Institute of Technology: A report for the year 1956-1957 on the research and other activities of the Division of Biology
Number of Pages: 126

Reference Type: Book
Record Number: 26
Author: Dolan, Glasstone and
Year: 1957
Title: The Effects of Nuclear Weapons
Call Number: Archives and EERL U1282.A8.1957

Reference Type: Report
Record Number: 42
Author: Selove, Walter
Year: 1957
Title: Not for Release: Statement on radioactive fallout prepared for submission to the joint committee on Atomic Energy at its open hearings May-June 1957
Pages: 8
Call Number: T Lauritsen 13.8

Reference Type: Report
Record Number: 80
Author: Joint Committee on Atomic Energy, Radiation Subcommittee
Year: 1957
Title: Summary-analysis of Hearings Held May 27-29 and June 3-7, 1957, on the Nature of Radioactive Fallout and its Effects on Man
City: Washington, D.C.
Institution: Joint Committee on Atomic Energy
Date: 1957

Reference Type: Journal Article
Record Number: 48
Author: Muller, H. J.
Year: 1957
Title: Damage from point mutations in relation to radiation dose and biological conditions
Journal: WHO report (published 1957) of a study on _Effect of Radiaiton on Human Genetics_
Date: 1957
Call Number: Sturtevant 13.5

Reference Type: Report
Record Number: 36
Author: Libby, W. F. Dr.
Year: 1957
Title: Open Letter to Dr. Albert Schweitzer
Pages: 7
Date: April 25, 1957
Type: letter

Reference Type: Report
Record Number: 37
Author: Libby, W. F. Dr.
Year: 1957
Title: Remarks Prepared by Dr. Willard F. Libby, Commissioner US AEC For Delivery before the Spring Meeting of The American Physical Society, Washington, D. C. April 26, 1957

Pages: 24 + figures
Date: April 26, 1957

Reference Type: Journal Article
Record Number: 66
Author: Holifield, Chet
Year: 1957
Title: "We are dealing with a global health problem. We must face up to it." Who Should Judge the Atom?
Journal: The Saturday Review
Pages: cover, 34-38
Date: August 3, 1957

Reference Type: Generic
Record Number: 63
Author: Beadle, George W.
Year: 1957
Title: Chemical Genetics and Radiation Effects
Pages: 18
Date: February 18, 1957
Type of Work: address before the American Pharmaceutical Manufacturers Association, Mid-Winter Conference

Reference Type: Magazine Article
Record Number: 69
Author: Cousins, Norman
Year: 1957
Title: An Open Letter to David Lawrence
Magazine: The Saturday Review
Pages: 20-21
Date: July 6, 1957

Reference Type: Magazine Article
Record Number: 82
Author: Cousins, Norman
Year: 1957
Title: Clean Bombs and Dirty Wars
Magazine: Saturday Review
Pages: 20
Date: July 13, 1957

Reference Type: Magazine Article
Record Number: 83
Author: Cousins, Norman
Year: 1957
Title: Checklist of Enemies
Magazine: Saturday Review
Pages: 20
Date: July 27, 1957

Reference Type: Newspaper Article
Record Number: 44
Reporter: Laurence, William L.
Year: 1957
Title: Science in Review: Facts on the Effects of Atomic Fall-Out Are Being Presented for Public Decision
Newspaper: ? Washington Post or NY Times
Pages: E11
Section: E
Issue Date: June 2, 1957
Call Number: Sturtevant 13.3

Reference Type: Newspaper Article
Record Number: 81
Reporter: Unna, Warren
Year: 1957
Title: All Radiation Held Perilous: Nation's Top Geneticists Unanimous In Opinion, Fallout Produced Now Will Shorten Lives in Future, Congress is Told
Newspaper: Washington Post
City: Washington D.C.
Pages: A1 and A6
Section: A
Issue Date: June 3, 1957
Type of Article: news

Reference Type: Personal Communication
Record Number: 85
Author: Pauling, Linus Carl
Year: 1957
Recipient: States, The President of the United
City: Pasadena, CA
Publisher: Pauling Archives Online
Date: June 4, 1957
Type: letter

Reference Type: Journal Article
Record Number: 15
Year: 1957
Title: Nuclear Worries: The nation begins to worry in earnest about its nuclear tests as scientists explain their fallout warnings to a congressional committee.
Journal: Life Magazine
Volume: 42
Issue: 23
Pages: 24-29
Date: June 10, 1957

Reference Type: Magazine Article
Record Number: 68
Author: Cousins, Norman
Year: 1957
Title: The Great Debate Opens
Magazine: The Saturday Review
Pages: 24-25

Date: June 15, 1957

Reference Type: Personal Communication
Record Number: 76
Author: Libby, W. F. Dr.
Year: 1957
Title: Letter to Pauling about his estimate of leukemia deaths from a nuclear test
Recipient: Pauling, Linus Carl
City: Washington D. C.
Publisher: Pauling archives on the web
Date: May 2, 1957
Type: letter

Reference Type: Personal Communication
Record Number: 77
Author: Pauling, Linus Carl
Year: 1957
Title: Letter replying to Libby about using Lewis' estimate
Recipient: Libby, W. F. Dr.
City: Pasadena, CA
Publisher: Pauling Archives on line
Date: May 10, 1957
Type: letter
Abstract: Pauling's letter replying to Libby and explaining the situation.

Reference Type: Generic
Record Number: 100
Author: DuShane, Graham
Year: 1957
Title: Loaded Dice
Place Published: Science
Publisher: AAAS
Volume: 125
Pages: on page 964
Date: May 17, 1957
Type of Work: editorial

Reference Type: Journal Article
Record Number: 6
Author: Lewis, Ed, Ph.D.
Year: 1957
Title: Leukemia and Ionizing Radiation
Journal: Science
Volume: 125
Issue: 3255
Pages: 964 (Loaded Dice editorial) and 965-972
Date: May 17, 1957

Reference Type: Journal Article
Record Number: 65
Author: Schweitzer, Albert
Year: 1957

Title: The Schweitzer Declaration
Journal: The Saturday Review
Pages: 13-20
Date: May 18, 1957

Reference Type: Journal Article
Record Number: 64
Author: Brown, Harrison
Year: 1957
Title: Forum on the Schweitzer Declaration: What is a "Small" Risk?
Journal: Saturday Review
Pages: 9-10 and entire forum is 8-13, 35-37
Date: May 25, 1957

Reference Type: Magazine Article
Record Number: 84
Author: Lear, John
Year: 1957
Title: The Shrinking Margin
Magazine: Saturday Review
Pages: 11-13, 35-36
Date: May 25, 1957

Reference Type: Magazine Article
Record Number: 79
Author: Libby, W. F. Dr.
Year: 1957
Title: An Open Letter to Dr. Schweitzer
Magazine: Saturday Review
Pages: 8-9, 36-37
Date: May 25, 1957
Original Publication: April 25, 1957

Reference Type: Magazine Article
Record Number: 67
Author: Titterton, E. W.
Year: 1957
Title: Science and Conscience, A Reminder to Modern Scientists: Power Is a Responsibility
Magazine: The Saturday Review
Pages: 46
Date: May 25, 1957

Reference Type: Hearing
Record Number: 78
Year: 1957
Title: Hearings on The Nature of Radioactive Fallout and its Effects on Man
Committee: Joint Committee on Atomic Energy
City: Washington D.C.
Publisher: United States Government Printing Office
Number of Volumes: 2
Pages: 2000

Legislative Body: Congress
Date: May 27-29 and June 3-7, 1957

Reference Type: Newspaper Article
Record Number: 45
Reporter: Press, The United
Year: 1957
Title: Radiation Experts Back Atomic Tests, But Call for Limit
Newspaper: NY Times
Pages: 2
Issue Date: Oct. 20, 1957
Call Number: Sturtevant 13.3

Reference Type: Book
Record Number: 33
Author: Pauling, Linus Carl
Year: 1958
Title: No More War!
City: New York
Publisher: Dodd, Mead & Company
Number of Pages: 254
ISBN: 58-11741

Reference Type: Personal Communication
Record Number: 87
Author: Lewis, E.B.
Year: 1958
Title: memo
Recipient: Pauling, Linus Carl
City: Pasadena
Publisher: Pauling Archives
Date: 1958, between March and August
Type: memo

Reference Type: Journal Article
Record Number: 56
Author: Kimball, A. W.
Year: 1958
Title: Evaluation of Data Relating Human Leukemia and Ionizing Radiation
Journal: Journal of the National Cancer Institute
Volume: 21
Issue: 2
Pages: 383-391
Date: August 1958

Reference Type: Audiovisual Material
Record Number: 103
Year: 1958
Title: First Meeting of the National Advisory Committee on Radiation
City: Washington DC
Publisher: Caltech Archives

Extent of Work: photo
Number: negative 1.202-9, ID 50.2-3
Date: March 13, 1958

Reference Type: Journal Article
Record Number: 86
Author: Brues, Austin M.
Year: 1958
Title: Critique of Linear Theory of Carcinogenesis
Journal: Science
Volume: 128
Issue: 3326
Pages: 693-699
Date: September 26, 1958

Reference Type: Journal Article
Record Number: 8
Author: Lewis, E.B.
Year: 1959
Title: Thyroid Radiation Doses From Fallout
Journal: Proceedings of the National Academy of Sciences
Volume: 45, No. 6
Pages: 894-897
Date: June 1959

Reference Type: Generic
Record Number: 53
Author: Murray, Thomas E.
Year: 1960
Title: The Case for Resuming Nuclear Tests
Secondary Title: Remarks Prepared by Thomas E. Murray for Delivery before the Combined Senior Classes Yale University
Date: Dec. 5, 1960
Type of Work: address
Call Number: DuBridge 168.11

Reference Type: Personal Communication
Record Number: 52
Author: Murray, Thomas E.
Year: 1960
Title: An Open Letter to the Presidential Candidates
Recipient: Kennedy, Vice President Nixon and Senator
Date: Sept. 6, 1960
Type: letter
Accession Number: DuBridge 168.11

Reference Type: Generic
Record Number: 13
Author: Jahn, Gunnar
Year: 1962
Title: The Nobel Peace Prize for 1962

Place Published: Noble website
Date: 1962
Type of Work: Presentation speech for Nobel Peace Prize
URL: http://www.nobel.se/peace/laureates/1962/press.html

Reference Type: Report
Record Number: 32
Author: Lewis, E.B.
Year: 1962
Title: Statement by E. B. Lewis for Fallout Hearings May 7
Pages: 10
Date: May 7 1962
Type: report for congressional hearings

Reference Type: Edited Book
Record Number: 62
Editor: Grodzins, Morton and Rabinowitch, Eugene
Year: 1963
Title: The Atomic Age: Scientists in National and World Affairs, Aricles from the Bulletin of the Atomic Scientists 1945-1962
Publisher: Basic Books, Inc. Publishers

Reference Type: Generic
Record Number: 14
Author: Pauling, Linus Carl
Year: 1963
Title: Science and Peace-Nobel lecture
Date: December 11, 1963
URL: http://www.nobel.se/peace/laureates/1962/pauling-lecture.html

Reference Type: Journal Article
Record Number: 11
Author: Lewis, E.B.
Year: 1963
Title: Leukemia, Multiple Myeloma, and Aplastic Anemia in American Radiologists
Journal: Science
Volume: 142
Pages: 1492-1494
Date: December 1963

Reference Type: Book
Record Number: 58
Author: Knudson, Jr., Alfred G.
Year: 1965
Title: Genetics and Disease
Publisher: McGraw-Hill
Number of Pages: 294
Notes: borrowed from Ray Owen

Reference Type: Book

Record Number: 35
Author: McBride, Hubert James
Year: 1967
Title: the test ban treaty: military, technological, and political implications
City: Chicago
Publisher: Henry Regency Company
Number of Pages: 197
ISBN: 67-14660

Reference Type: Book
Record Number: 61
Author: Roberts, Chalmers M.
Year: 1970
Title: The Nuclear Years: The Arms Race and Arms Control, 1945-70
City: New York
Publisher: Praeger Publishers
Number of Pages: 159

Reference Type: Book
Record Number: 24
Author: Divine, Robert
Year: 1978
Title: Blowing on the Wind: The Nuclear Test Ban Debate 1954-1960
City: New York
Publisher: Oxford University Press
Number of Pages: 393
ISBN: 0195023900
Call Number: E835.D53

Reference Type: Book
Record Number: 20
Author: Wasserman, Harvey and Solomon, Norman with Alvarez, Robert and Walters, Eleanor
Year: 1982
Title: Killing Our Own: The Disaster of America's Experience with Atomic Radiation
City: New York
Publisher: Dell Publishing Co., Inc.
ISBN: 0-440-54566-6

Reference Type: Book
Record Number: 22
Author: Mazuzan, George T. and Walker, Samuel J.
Year: 1985
Title: Controlling the Atom: The Beginnings of Nuclear Regulation 1946-1962
City: Berkeley
Publisher: University of California Press
Number of Pages: 530
ISBN: 0-520-05182-3
Call Number: KF2138.M39.1985

Reference Type: Book
Record Number: 34

Author: Katz, Milton S.
Year: 1986
Title: Ban the Bomb: A History of SANE, the Committee for a Sane Nuclear Policy, 1957-1985
City: New York
Publisher: Greenwood Press
Number of Pages: 215
ISBN: 0-313-24167-8
Call Number: JX 1974.7.K274

Reference Type: Book
Record Number: 18
Author: Miller, Richard L.
Year: 1986
Title: Under the Cloud: The Decades of Nuclear Testing
City: New York
Publisher: The Free Press, A Division of Macmillan, Inc.
Number of Pages: 547
ISBN: 0-02-921620-6
Call Number: U264. M55 1986

Reference Type: Book
Record Number: 27
Author: Prud'homme, Interview by Rachel
Year: 1987
Title: Interview with John D. Roberts
Series Title: California Institute of Technology Oral History Project
City: Pasadena, CA
Publisher: Caltech Archives
Number of Pages: 161

Reference Type: Book
Record Number: 1
Author: Weart, Spencer R.
Year: 1988
Title: Nuclear Fear: A History of Images
City: Cambridge, MA and London, England
Publisher: Harvard University Press
Number of Pages: 535
Edition: 1
ISBN: 0-674-62835-7
Call Number: QC773.W43 1988 Hums
Abstract: Traces images and myths of nuclear power from 1902-1988.
Part 1: Years of Fantasy 1902-1938
Part 2: Confronting Reality 1939-1952
Part 3: New Hopes and Horrors 1953-1963
Part 4: Suspect Technology 1956-1986
Part 5: The Search for Renewal

Reference Type: Book
Record Number: 16
Author: Fradkin, Philip L.
Year: 1989

Title: Fallout: An American Nuclear Tragedy
City: Tucson
Publisher: The University of Arizona Press
Number of Pages: 300
ISBN: 0-8165-1143-8
Call Number: U264.F72 1989

Reference Type: Journal Article
Record Number: 2
Author: Seidel, Robert
Year: 1990
Title: Books on the Bomb
Journal: ISIS
Issue: 81 : 3 :306
Pages: 519-537
Date: 1990

Reference Type: Book
Record Number: 21
Author: Cantelon, Philip L.; Hewlett, Richard G.; and Williams, Robert C, editors.
Year: 1991
Title: The American Atom: A Documentary History of Nuclear Policies from the Discovery of Fission to the Present
City: Philadelphia
Publisher: University of Pennsylvania Press
Number of Pages: 369
Edition: 2nd
ISBN: 0-8122-3096-5
Original Publication: 1984
Call Number: U 264.A44.1991

Reference Type: Journal Article
Record Number: 10
Author: Upton, Arthur C.
Year: 1991
Title: Health Effects of Low-level Ionizing Radiation: BEIR V--the National Research Council's fifth committee on the biological effects of ionizing radiation--found the population's risk of injury to be somewhat larger than estimated previously
Journal: Physics Today
Issue: August 1991
Pages: 34-39
Date: August 1991

Reference Type: Book
Record Number: 23
Author: Walker, Samuel
Year: 1992
Title: Containing the Atom: Nuclear Regulation in a Changing Environment
City: Berkeley
Publisher: University of California Press
Number of Pages: 533
ISBN: 0-520-07913-2

Call Number: KF2138.W35.1992

Reference Type: Generic
Record Number: 4
Author: Magee, Pete
Year: 1993
Title: The Career of Dr. Ed Lewis
Place Published: Speech awarding Dr. Lewis an honorary degree from the University of Minnesota
Pages: 3
Date: 1993
Type of Work: speech

Reference Type: Book Section
Record Number: 99
Author: Revelle, Roger
Year: 1994
Title: Harrison Brown: September 26, 1917-December 8, 1986
Book Title: Biographical Memoirs of the National Academy of Sciences
Publisher: National Academy Press
Volume: 65
Pages: 41-55
URL: www.nap.edu/openbook/0309050375/html/40.html

Reference Type: Journal Article
Record Number: 3
Author: Walker, Samuel
Year: 1994
Title: The Atomic Energy Commission and the Politics of Radiation Protection, 1967-1971
Journal: ISIS
Volume: 85
Pages: 57-78
Date: 1994

Reference Type: Report
Record Number: 98
Year: 1995
Title: Edward B. Lewis Nobel Biography, From Les Prix Nobel
Institution: Nobel Foundation
Pages: 2
URL: http://www.nobel.se/medicine/laureates/1995/lewis-bio.html

Reference Type: Book
Record Number: 19
Author: Goertzel, Ted and Goertzel, Ben
Year: 1995
Title: Linus Pauling: A Life in Science and Politics
Publisher: Basic Books
Number of Pages: 300
ISBN: 0-465-00672-8
Call Number: Q143.P25G64 1995

Reference Type: Book
Record Number: 17
Author: Pauling, Linus Carl Edited by Barbara Marinacci
Year: 1995
Title: Linus Pauling: In His Own Words, Selections from his Writings, Speeches, and Interviews
City: New York
Publisher: Simon & Schuster
Number of Pages: 320
ISBN: 0-684-81387-4
Call Number: Q143.P25A3 1995

Reference Type: Journal Article
Record Number: 73
Author: Doll, Sir Richard
Year: 1995
Title: Hazards of Ionizing Radiation: 100 years of observations on man
Journal: British Journal of Cancer
Volume: 72
Pages: 1339-1349
Date: 1995

Reference Type: Journal Article
Record Number: 12
Author: Lewis, E.B.
Year: 1995
Title: Nobel Lecture: The Bithorax Complex: The First Fifty Years
Journal: Nobel Lecture
Issue: 1995
Pages: 247-272
Date: December 8, 1995
URL: http://www.nobel.se/medicine/laureates/1995/lewis-lecture.html

Reference Type: Journal Article
Record Number: 28
Author: Christy, Robert: Interview by Sara Lippincott
Year: 1998
Title: Interview with Robert Christy
Pages: 100

Reference Type: Journal Article
Record Number: 7
Author: Lewis, E.B.
Year: 1998
Title: Ionizing Radiation, Cancer Induction and Radioactive Fallout
Journal: Bulletin of the Polish Academy of Sciences, Biological Sciences
Volume: 46
Issue: 3-4
Pages: 185-191
Date: 1998

Reference Type: Book
Record Number: 108
Author: Greene, Gayle
Year: 1999
Title: The Woman Who Knew Too Much: Alice Stewart and the Secrets of Radiation
City: Ann Arbor
Publisher: The University of Michigan Press
Number of Pages: 321
ISBN: 0-472-11107-8

Reference Type: Generic
Record Number: 9
Author: Lewis, E.B.
Year: 2000
Title: Letters: 'Radiation Risk and Ethics': Health Hazards, Prevention Costs, and Radiophobia
Place Published: Physics Today
Pages: 13
Date: April 2000
Type of Work: letter to the editor

Reference Type: Journal Article
Record Number: 31
Author: Owen, Ray
Year: 2000
Title: Perspectives: Anecdotal, Historical and Critical Commentaries on Genetics, Edited by James F. Crow and William F. Dove
Karl Landsteiner and the First Human Marker Locus
Journal: Genetics
Volume: 155
Issue: July 2000
Pages: 995-998
Date: July 2000

Reference Type: Book Section
Record Number: 89
Year: 2002
Title: Fallout and Atomic Bombs
Book Title: Encyclopedia Britannica
URL: http://search.eb.com/eb

Reference Type: Electronic Source
Record Number: 102
Year: 2002
Title: What is Spondylitis?
Producer: Spondylitis Association of America
Access Year: 2002
Access Date: November 28, 2002
Type of Medium: website
URL: http://www.spondylitis.org/html/htmlpages.asp?load=whatisas.htm

Reference Type: Personal Communication

Record Number: 90
Author: Lewis, E.B.
Year: 2002
Title: e-mail
Recipient: Caron, Jennifer
Date: August 13, 2002
Type: e-mail

Reference Type: Personal Communication
Record Number: 97
Author: Barnes, Charles
Year: 2002
Title: interview
Recipient: Caron, Jennifer
Date: August 16, 2002
Type: interview

Reference Type: Personal Communication
Record Number: 96
Author: Christy, Robert
Year: 2002
Title: interview
Recipient: Caron, Jennifer
Date: August 16, 2002

Reference Type: Personal Communication
Record Number: 106
Author: Lewis, E.B.
Year: 2002
Title: Dec. 1 e-mail
Recipient: Caron, Jennifer
Date: December 1, 2002
Type: e-mail

Reference Type: Personal Communication
Record Number: 104
Author: Lewis, E.B.
Year: 2002
Title: personal interview, Dec. 9
Recipient: Caron, Jennifer
City: Pasadena
Date: December 9, 2002
Type: personal interview

Reference Type: Personal Communication
Record Number: 107
Author: Lewis, E.B.
Year: 2002
Title: Professor of Biology
Recipient: Caron, Jennifer
Date: December 12, 2002

Type: personal interview, Dec. 12

Reference Type: Personal Communication
Record Number: 29
Author: Owen, Ray
Year: 2002
Title: Interview 7-9-02
Recipient: Caron, Jennifer
City: Pasadena
Date: July 9, 2002
Type: personal interview

Reference Type: Personal Communication
Record Number: 95
Author: Christy, Robert
Year: 2002
Title: phone interview
Recipient: Caron, Jennifer
Date: July 12, 2002
Type: phone interview

Reference Type: Personal Communication
Record Number: 74
Author: Lewis, E.B.
Year: 2002
Title: Interview
Recipient: Caron, Jennifer
City: Pasadena
Date: July 12, 2002
Type: interview

Reference Type: Manuscript
Record Number: 5
Author: Lewis, Ed, Ph.D.
Year: ?
Title: Edward B. Lewis
Pages: 10
Date: ?
Type of Work: Autobiography (draft)