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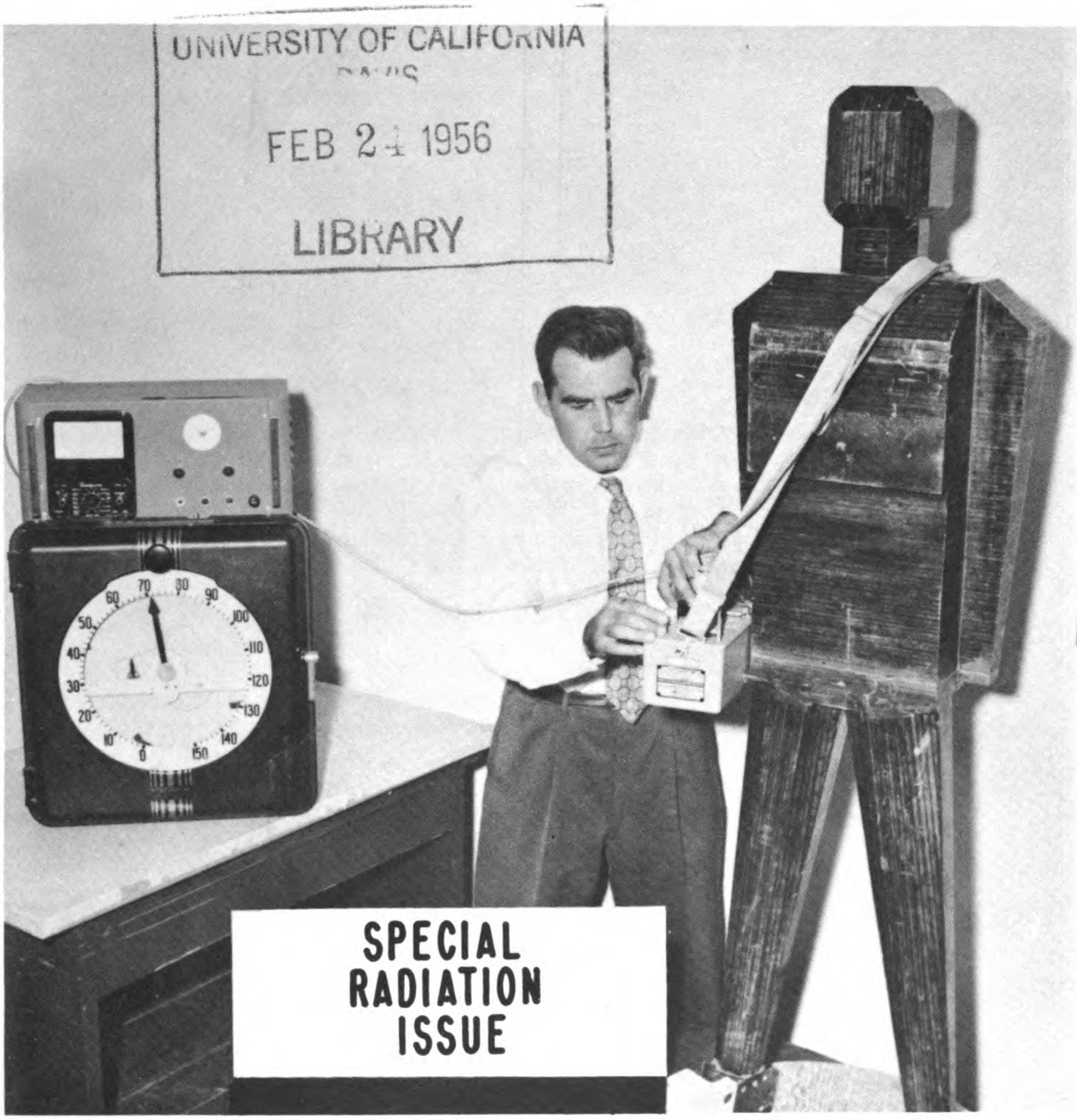
RESEARCH REVIEWS



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WASHINGTON, D. C.

COVER PHOTO: The masonite dummy, designed by the Naval Medical Research Institute, is a valued employee of the U. S. Naval Radiological Defense Laboratory. "He" wears the radiation dosimeters, film badges, and other protective devices that are tested in the Laboratory's radiac analysis program.

Research Reviews endeavors to report briefly highlights of technical progress in research by Navy laboratories and contractors and the development of important naval research facilities. Articles which meet these broad criteria and possess a good degree of readability are welcomed. Manuscripts and changes of address should be sent to Code 740, Office of Naval Research, Washington, D. C.

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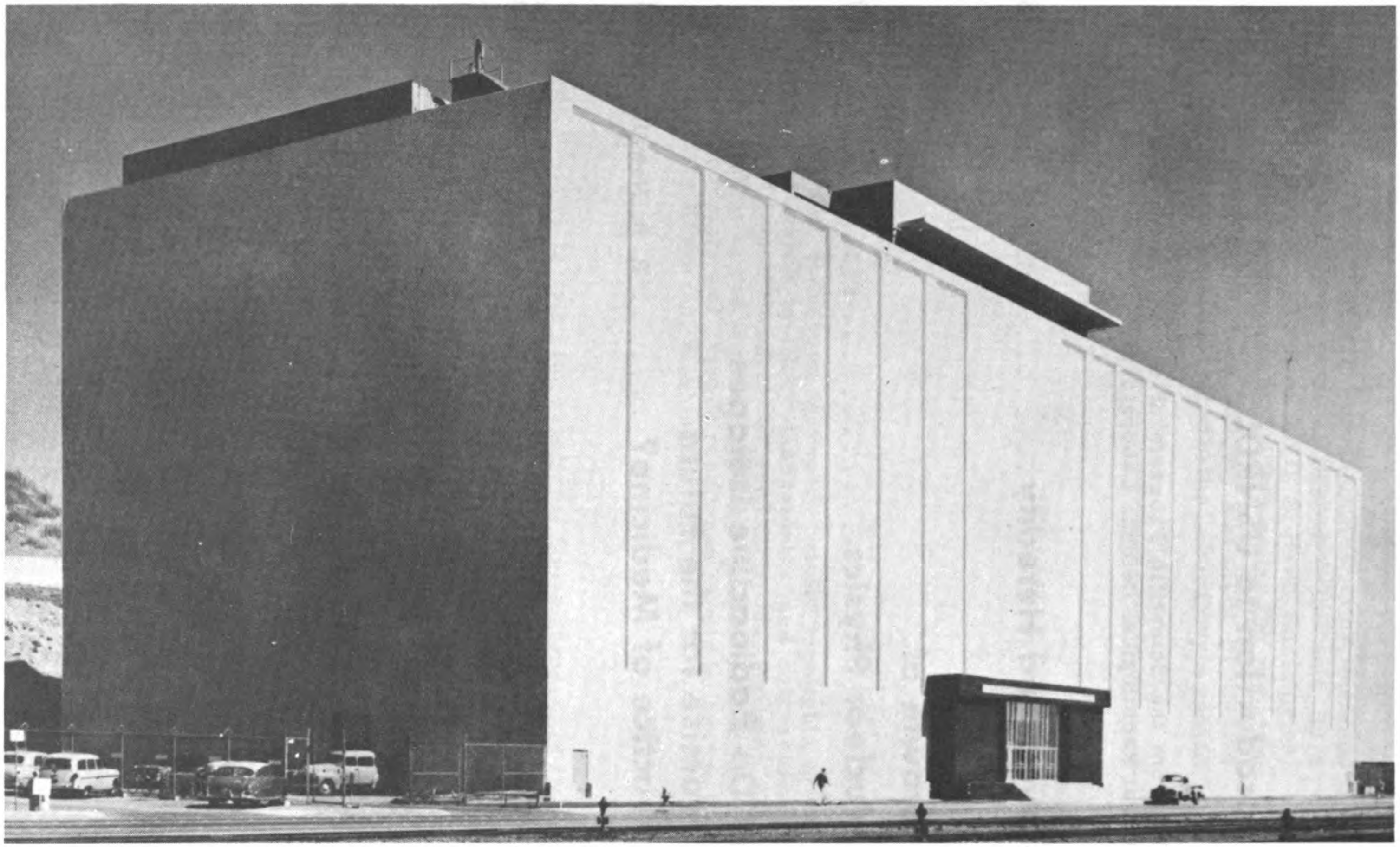

The new $8,000,000 building of the U.S. Naval Radiological Defense Laboratory at San Francisco

An Introduction to USNRDL

What is now the U. S. Naval Radiological Defense Laboratory, a major Navy research and development facility, came into being in 1946 as a "by-product" of Operation CROSSROADS at Bikini. Born of the necessity to decontaminate the target ships used in the tests, the embryonic Laboratory was made up of a handful of junior naval officers who had served as radiological monitors at Bikini, to whom were shortly added a few radiation chemists, physicists and technicians. Initially, it occupied two small rooms as a part of the San Francisco Naval Shipyard. Little was known at the time of the complexities or full potentialities of atomic energy, or the means of accomplishing the laborious decontamination task at hand. Even less was known of protection against the harmful effects of this new and overwhelmingly devastating agent.

From so modest a beginning, the applied endeavor was progressively augmented by research from which has evolved a separate and increasingly important armed forces activity, the U. S. Naval Radiological Defense Laboratory, the only laboratory in the country solely devoted to the study of defense against the harmful effects of the radiations resulting from nuclear reactions and to the development of means of preventing or minimizing the hazards of those effects.

USNRDL is a naval command under a senior engineering officer with the title of Commanding Officer and Director. It is within the military structure of the Twelfth Naval District and under the management control of the Bureau of Ships. Organizationally, it is divided into three departments: Scientific, Medical, and Administrative.

The Scientific Department is headed by a civilian Scientific Director, who administers the scientific program covering the study of radiation characteristics and hazards, the development of means of radiation detection, prevention of radiation injury, and decontamination. The scientific program of the Laboratory is carried out by four technical divisions of this department:

1. The Biological and Medical Sciences Division is concerned with the effects of nuclear and thermal radiations on people, and means of preventing or minimizing the unfavorable effects.

2. The Chemical Technology Division investigates problems of radioactive contamination of objects such as ships, planes, and equipment; and develops methods of decontamination. This requires extensive study of the basic chemical and physical nature of radioactive substances.

3. The Nucleonics Division conducts investigations concerning the characteristics of nuclear and electromagnetic radiations, and designs and develops instrumentation for their detection and measurement.

4. The Military Evaluations Group, a part of the Scientific Director's staff, interprets and adapts scientific knowledge of nuclear effects to the needs of the Armed Forces.

The Medical Department is responsible for the Laboratory's health program including radiological safety. It also controls the use of radioactive sources.

The Administrative Department provides a variety of services in support of the Laboratory program including engineering services; security and communications; technical information; logistic support; civilian personnel, employment, and training.

In addition to the foregoing departmental organizations, there are located directly under the Director's office several important staff groups concerned with such functions as management planning, financial control, and liaison with other armed forces agencies. This latter function is discharged by a group of projects and liaison officers which includes officers representing the Army and Air Force as well as several Navy Department technical bureaus.

It's a far cry from the few precursory young naval officers in 1946 to the 600-name roster of USNRDL in 1956 which includes more than 300 scientific or technical personnel.

Drawn from almost every field of scientific endeavor, the scientific staff now includes many specialists from both the physical and medical sciences such as chemists, physicists, biologists, engineers, medical doctors, physiologists, psychologists, mathematicians, and metallurgists. Appropriate laboratory technicians contribute significantly to the undertaking.

Among those in the support capacity are administrators, clerical workers, technical editors and illustrators, librarians, photographers, mechanics, electricians, glass blowers, draftsmen, laborers, and specialists in communications, information, training, and transportation.

Academically, the standing of this Laboratory is very high, with members of the staff holding nearly 250 degrees including approximately 40 Ph.D., 10 M.D., and 50 M.S. or M.A.

From the two small rooms allotted by the Shipyard in 1946, the Laboratory gradually spread out until in 1954 it occupied twenty widely separated buildings. Hope of relief from this dispersion handicap began with the ground-breaking for the new $8,000,000 main Laboratory building in 1952. In the spring of 1955, this ultra-modern structure was completed and, one by one, Laboratory units took up their residence under one roof. Another smaller building, adjacent to the main building, was completed in June 1954 and houses the Laboratory's two-million-electron-volt Van de Graaff generator, a primary source of radiation equipped for acceleration of both electrons and nuclear particles used for diverse studies connected with radiation effects.

Both of these buildings are designed without windows for maximum protection from possible atomic attack, more usable wall space, and reduced construction and maintenance costs.

The main building is a six-story concrete structure with total floor space of 282,000 square feet. It has many utilitarian and attractive features, including movable inside partitions to provide flexibility; a specially designed ventilation system with separate intake and exhaust on each floor so that the air is never re-circulated; escalators that expedite traffic; soft, morale-building color treatment of walls, different on each floor to avoid monotony; and a penthouse cafeteria with an immense picture window framing a magnificent view of San Francisco Bay against a backdrop of gently rolling hills.

Facilities and equipment for scientific research and other uses are of the latest design for maximum utility. In addition to the Van de Graaff atom-smasher already mentioned, other radiation sources include a number of large X-ray machines and an eight-curie cobalt source.

Several climatic simulating chambers, ranging from small eight-foot units to walk-in types, provide extremes in temperature for important experiments. For work with high levels of radioactivity, a change house and a hot cell with special shielding and waste disposal provisions are available. Thermal radiation investigations are conducted with three carbon-arc sources—a 36-inch reflector, a 60-inch reflector, and a modified Mitchell background projector. Among the other items are: calorimeters and radiometers, a high time-resolution bolometer system, a high time-resolution spectrometer, a mass-recording spectrometer; an optical spectrograph, an X-ray diffraction unit, and an electron microscope.

The foregoing has touched upon some of the important aspects of USNRDL's mission and program. Commensurate with the rapid developments in the Laboratory, which have paralleled the growth of knowledge in the field of atomic energy, is a program of broad range to cope with the multitudinous new radiological problems which today present an intensified challenge to military operations and installations.

This Laboratory is dedicated to its basic mission of providing protection against the harmful effects of nuclear radiations, regardless of their origin. Thus, it is also equipped to participate in the development of the peacetime applications of nuclear energy for the benefit of all mankind.

In mid-October 1955, the new Laboratory was dedicated with ceremonies that were highlighted by talks from the heads of two agencies very close to USNRDL: RADM B. W. Hogan (MC), Chief of the Bureau of Medicine and Surgery, and RADM Frederick R. Furth, Chief of Naval Research. The dedication speech was given by RADM Albert G. Mumma, Chief of the Bureau of Ships.

Following the ceremonies, a scientific symposium, sponsored by the Office of Naval Research, was held at the Laboratory. Talks were given by seven of the foremost radiation specialists in the nation. Research Reviews has been fortunate enough to obtain, through the courtesy of USNRDL's Commanding Officer and Director, CAPT Robert A. Hinners, five of these papers. They are presented, in some cases abridged, in this Special Radiation Issue.

These papers, of course, do not represent the research program or policies of the Navy in this field, but they are comments considered by the speakers to be appropriate to the dedication of this Laboratory.

Radiation and Heredity

Dr. George W. Beadle
Professor and Chairman, Division of Biology
California Institute of Technology
President, American Association for the Advancement of Science

Genes are the agents by which all living things transmit heredity from one generation to another. Knowledge of them, especially that acquired in the past decade, constitutes an impressive part of our knowledge of the basic nature of living systems. Genes are altered—mutated—by high-energy radiation. It is therefore appropriate to discuss some of the problems of radiation genetics.

Let us begin by asking what genes are from the standpoint of a geneticist. They are units of inheritance, they are carried in the chromosomes of higher plants and animals, and they are transmitted from one generation to another through the gametes. This knowledge is a part of so-called classical genetics, a well developed and a well understood branch of biology. Our understanding of what genes are chemically and how they operate in the development and functioning of organisms is much less complete but is growing rapidly at the present time.

Significant information about genes has come from a study of viruses. These simple organisms have genes like higher organisms and they lend themselves to the study of the units of inheritance in ways that higher organisms do not.

GENETICS OF VIRUSES

Viruses vary in shape. A few are roughly box-shaped, many are spherical, some are rod-shaped, and others are tadpole-shaped. All are small, ranging from about 3000 Å in the longest dimension down to approximately 100 Å.* They multiply only inside an appropriate living host cell. One group of viruses infects higher plants, another multiplies in the cells of higher animals, and a third group infects bacteria.

The bacterial viruses (also known as bacteriophages or simply as phages) have been particularly important from a genetic point of view. Recent work has been focused especially on a group of bacterial viruses,

*One centimeter = 100,000,000 Ångstrom units.

called coliphages, that infect Escherichia coli and related species. Some of these coliphages have polygonal heads about 800 Å in length and tails about equally long. They are readily studied quantitatively by plating them with suitable host bacteria on solid media. Under proper conditions virus colonies descended from single virus particles are readily identified, counted, and subcultured.

Osmotic shock or decompression shock can lead to separation of virus particles into coats, which are largely protein, and cores consisting mainly or wholly of desoxyribonucleic acid (DNA). These components are identifiable chemically and can be further characterized by electron microscopy.

Within 20 to 30 minutes after the initial infection, the host cell is disrupted (lysed) with the release of 100 to 300 daughter viruses. This is the most rapid biological reproduction known. If one virus particle were started on its cycle now, and if all the progeny could be saved, they would be sufficient in number within 24 hours to pack the universe solid with virus particles.

If one infects a large number of bacteria with an equally large number of viruses, it turns out that occasionally a bacterial cell resists infection. Through gene mutation the pattern of electrostatic charges in its protein surface is modified. This mutation does not occur in response to a need. Rather it occurs at random and is selected preferentially because of its resistance. Such mutations occur with a frequency of perhaps once in a million cell generations.

Through such selection a new virus-resistant strain of bacteria can be established. If this new strain is now grown in large numbers, and infected with an equally large number of viruses to which it is resistant, then it is found that the virus, too, has the ability to mutate. It occasionally changes the pattern of electrostatic charges on its tail to fit the pattern on the new bacteria. This is a spectacular example of evolution in a test tube, for obviously if the virus could not undergo this type of mutational change, it could not survive. Again this is not a directed mutation. It occurs spontaneously and is selected from the population by the fact that it is the only virus that will survive. Such mutant types are known as host-range mutants.

In the same way in which frequency of recombination is used as a measure of linear order and spacing of genes in the chromosomes of higher plants and animals, the genes of viruses can be "mapped." In specific types of coliphages some forty or so genes have been mapped. It is estimated that the total genetic material in these viruses is about 200 units long in a system in which map units are defined in essentially the same way as in higher forms.

It is believed that for about a ten-minute period following infection, viral DNA somehow repeatedly duplicates until there are 100 to 300 units of it per host cell. Then the bacterial host cell manufactures protein of the kind characteristic of the virus coat that did not enter the cell. Clearly the virus DNA must have carried to the host cell the information necessary to direct the synthesis of virus protein—a type of protein not made by an uninfected bacterial cell.

Important evidence that only DNA enters the host cell comes from radioactive tracer experiments of Hershey and Chase and others. If coliphages with radio sulfur (S^{35}) in their protein coats—made by growing them on bacteria that have in turn been grown on S^{35} sulfate—are used to infect non-radioactive bacteria, it can be shown that the protein coat of the virus remains outside the cell. Immediately after infection, the virus coats can be separated from the bacterial cells by knocking them off in a Waring blendor followed by fractionation in a centrifuge. The radioactivity remains with the coats. The bacterial cells show essentially no radioactivity but produce normal virus crops.

If the DNA cores of the viruses are labeled with radiophosphorous (P^{32}) in a similar way, the radioactivity enters the host cell at the time of infection and the virus coats that remain outside are not radioactive. Since proteins contain sulfur and not phosphorous, whereas DNA contains phosphorous and no sulfur, such experiments show that the virus injects its DNA core into the bacterial host cell at the time of infection but leaves its protein coat outside. Obviously, then, the genetic material that is transmitted from one virus generation to the next is DNA.

On the basis of evidence of the kind I have reviewed, many geneticists currently accept, as a working hypothesis, the view that the primary genetic information in all organisms is carried in the form of DNA. Even if the hypothesis should prove to be incorrect, it will have had a most significant part in the development of modern biology for it has and will continue to stimulate the kind of investigations that are necessary to give the correct answers.

RADIATION AND GENETICS

The effects of high-energy radiation on genes have been studied for some time. The sensitivity of genes to high-energy radiation was discovered independently in the late twenties by H. J. Muller and L. J. Stadler. We now know that every organism that has been adequately studied experimentally shows mutation in response to high-energy radiation.

There is currently found among the public and in the press a great deal of confusion about this subject. This is partly because different persons emphasize different aspects of the problem and partly because emotions play such an unusually large part in considerations of the effects on man of radiation, especially if they come from military weapons.

Actually there is reasonable general agreement among qualified scientists as to probable genetic effects, even though quantitative predictions are subject to large errors that can be reduced only if we have more basic information.

Why, then, all the fuss? There are several reasons for the wide disagreement.

Let us first consider the question of difference in emphasis. Medical men who make use of X-rays in diagnosis and in therapy, and engineers responsible for the production and use of radioactive materials, tend to emphasize direct effects to exposed individuals. Here large doses are required to produce immediately noticeable effects. It takes about 100 r units or more of X-rays or gamma rays over the entire body to produce serious radiation sickness in man. Genetic damage, on the other hand, can result from very low exposure. An exposure of many individuals to only one r unit will almost surely increase hereditary damage by a small amount. This type of damage is also much more subtle in that it is largely hidden. It may not show in the exposed individual and may not be easily detectable in his children or even in his grandchildren. It is therefore not easy to demonstrate its presence in man, even though we can be almost certain of its occurrence by analogy with experimental animals.

On the question of the long-range genetic effects of radiation on the human species, predictions have an even wider range of error, especially when attempts are made to make them quantitative. There are just too many unknown factors to be sure what will happen to a population after many generations of exposure to radiation.

Some of the facts that lead geneticists to believe nuclear bomb fall-out radiation and other high-energy radiation will produce unfavorable hereditary changes in man are:

- Such radiation is known to produce changes in the heredity of all experimental plants and animals on which the effects have been studied.
- The number of such changes is proportional to exposure—the greater the dose, the greater the number of changes in heredity.
- There is no theoretical or experimental basis for believing that there is a level of exposure below which hereditary changes will not occur.
- Exposure is cumulative in producing hereditary changes. Ten r units per month for 20 months will tend to have approximately the same genetic effect as 200 units received in a single short period, say one hour.
- For most types of genetic damage that result from low doses there is no recovery. The effect is permanent and is transmitted from generation to generation until removed by the slow process of natural selection.
- Probably 99 percent of the changes in heredity, whether spontaneous or induced by radiation, are deleterious. On the average, for two such changes, an individual in some later generation will die before reproducing.
- Most induced changes in heredity are recessive or largely so. This means they are not likely to be easily detected among the children or grandchildren of exposed individuals. It may be many generations before two like changes come together in the same individual and produce an easily detectable deleterious effect.
- In man many genetic deaths that occur in later generations as a result of like deleterious genes coming together will take place early in development and will be expressed as miscarriages. Some will result in stillbirths. Others will reduce the efficiency of individuals only slightly and in ways that will not be obvious. Probably only a few will produce visibly defective individuals. The proportion that will produce viable "monsters," following any dosage permitting survival, will probably be so very small as to be a statistically undetectable addition to those that occur now.
- In a population of constant size any increase in frequency of deleterious gene mutations will be counterbalanced by differential reproduction. This means that to maintain equilibrium in the population more individuals will die before reproducing or will reproduce at a lower level.

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•If a high proportion of deleterious mutations is expressed in the heterozygous state through reduced probability of reproduction (reduced life expectancy, reduced fertility, reduced social acceptability, etc.), most of the selection required to maintain equilibrium will occur among such individuals. This is simply because there will be so many more individuals of this kind for a given mutant gene than there will be of persons homozygous for the same mutant gene.

EFFECTS ON POPULATION

What will be the number of individuals affected? This will depend on many factors, among which amount of exposure per individual and number of individuals exposed will be of primary importance. The total genetic effect on a population will depend on what might be called population exposure. Thus a large exposure to a few individuals may have the same effect on the population as a whole, as does a smaller exposure to a much larger population. It is for this reason that permissable or tolerance exposures must take into account the number of individuals exposed. An exposure of 1000 individuals to 15 r units for one year constitutes 15,000 r units to the population to which they belong. But an exposure of only 0.1 r unit to the entire population of our nation is roughly 15,000,000 r units in terms of total genetic effect, and will have a thousand times as much genetic effect on population.

H. J. Muller of the University of Indiana has estimated that as a result of test-bomb radiation to date, there will be something like 80,000 hereditary changes among the descendants of the present population of the United States. Earl Green, a geneticist who was formerly in the Washington office of AEC, estimates that the number will be one-fifth to one-half as large. These estimates are subject to large errors but most geneticists agree that they are both plausible guesses. The number is almost certainly not zero. Whatever the number, they will be added to a very much larger number of changes that have occurred and will occur spontaneously, without any exposure to artificial radiation.

If the bomb-testing program continues at its present level, or even if it is accelerated considerably, it is unlikely that in 20 years individuals will have received an average of more than 2 r units of radiation over and above that from natural causes—cosmic rays, etc. This exposure continued for generations might raise the number of children born in the United States each year with new hereditary changes by a factor of about 10 percent, or by an absolute number of something like 8000 children. For the world as a whole the figure would be 25 times this. Again these figures are rough estimates only. They could easily be in error by a factor of 10 either way.

But, for the reasons explained above, most of this addition to our already large load of hereditary defects, whatever its magnitude, will be hidden both because most changes will have only slight effects in the heterozygous condition, and because many eventual deaths of homozygotes will occur before birth, and will be partly compensated for by additional pregnancies in the families in which they occur.

The danger to any one individual is negligibly small. It is perhaps comparable to the danger of acquiring lung cancer from smoking cigarettes—assuming purely for the sake of argument that such a danger does exist. But there are three important differences: (1) With cigarette smoking, each of us has a free choice; in radiation of certain kinds, fallout for example, no such individual choice is possible. (2) In the case of cigarettes the individual who elects to take the risk pays the penalty himself if he loses; with radiation his descendants suffer if a mistake is made. (3) After exposure to cigarettes, the species can recover in a single generation if a mistake is made; but after exposure to radiation it could take thousands of years for the species to recover from a mistake.

The conclusion seems clear that, from a genetic standpoint, the exposure of human beings to high-energy radiation should be kept as low as possible. It makes no difference whether the radiation comes from natural or man-made sources—or whether the latter originates in weapons of war or from peacetime use of radiation.

Will an increase in hereditary damage endanger the survival of our species? It all depends on its magnitude. With a 10 percent increase in number of genetic changes, the answer is almost surely, "No." We do not know how great an exposure it would take to constitute such a danger but my guess is that it would have to be several hundred times higher than the present background—and this for a very large fraction of the human population.

The question naturally rises as to what these considerations have to do with our program of building, testing, and using nuclear weapons of war. Geneticists have sometimes been accused of being alarmists—of saying or implying that all tests of nuclear weapons should be discontinued. Such charges are unfair and unjust in my opinion. Geneticists are moderately normal citizens, and as such, their individual opinions on social questions vary widely. But I do not know of a single geneticist who has publicly advocated termination of all nuclear weapons tests. I am sure that geneticists, like other sensible people, want to do everything possible to decrease the probability of war. Unfortunately they possess no magic formula for this.

There is, however, one way in which geneticists differ significantly from non-geneticists. They have special knowledge about the genetic hazards of radiation, and in my opinion, they would not be fulfilling their responsibilities as citizens if they did not do everything within their power to disseminate this knowledge as widely as possible.

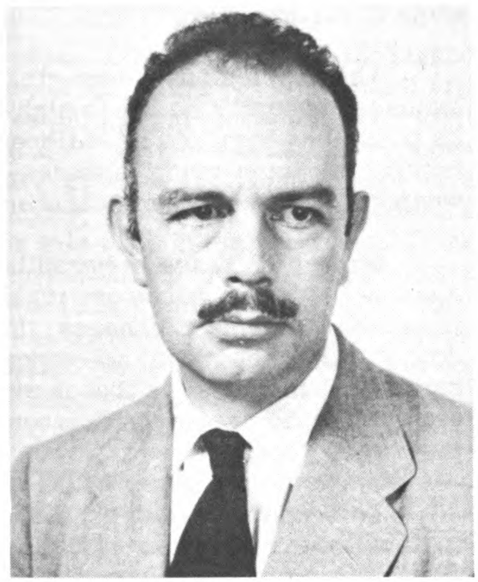
New Nomenclature

In a news conference recently, ADM Arleigh A. Burke informed those present that he had notified all naval personnel to cease calling ships "vessels."

"Ships," he said, "are for sailing in. Vessels are for an entirely different purpose."

The Growth of Nuclear Physics

Dr. F. N. D. Kurie
Technical Director
U. S. Navy Electronics Laboratory



The laboratory I represent is situated in the lower left-hand corner of the United States; it is Navy operated like the Radiological Defense Laboratory. We are doing many exciting things that are of substantial scientific interest at the U.S. Navy Electronics Laboratory, but only a few will be discussed here as so much of our work is classified. Nucleonics is a likely subject with many mutual interests, and while actually I haven't done any research in the field of nucleonics for several years, I persuaded myself just to talk about how nucleonics came into being, and, because it is easy to do, I thought I would wrap the story around myself.

When I first heard of this subject it was called radioactivity; I was an undergraduate at McGill University where Lord Rutherford had left less than ten years before. The memory of his great work in the University--establishing the nature of the alpha particle—was still very green in the minds of people there. I well remember a room set aside as a sort of Rutherford museum in which many of the pieces of equipment he built with his own hands were still preserved. With these he demonstrated an alpha particle as we know it today.

I began working in radioactivity, on the side, as an undergraduate because one of my favorite professors had just recently returned to McGill from working in Cambridge with Rutherford. This was Dr. Etienne Bieler, who died rather prematurely a few years later. He was really the pioneer who first demonstrated a potential wall, an electrostatic wall, around the nucleus. He was such an inspiring teacher that I found myself doing things I wasn't required to do along the lines of radioactivity.

There is a decided contrast in the way we had to work in those days as compared to the magnificent equipment we have today. The primary instrument was the gold-leaf electroscope. This was simply a little piece of the sort of gold leaf such as used in making signs on windows. You put a charge on an insulated piece of it, peeked through a sort of microscope, and counted the length of time it took for radioactive radiation to discharge the leaf. This was anything but a precision instrument, and yet a great amount of precise work was done with it.

Another instrument which was really the most vexing of all was the so-called scintillation counter. It was not the scintillation counter we know today; it was simply a little screen, with some zinc sulfide on it, that you put in the focal plane of a microscope. Then you sat in the dark twenty minutes to half an hour until your eyes got accustomed to see the little scintillations of light the alpha particles produced. We now do this sort of counting rapidly. In those days it was very tedious; one could spend literally weeks to get one point on a curve.

I had the pleasure of attending a meeting of the British Association for the Advancement of Science in Toronto in 1924 and actually met Rutherford. I didn't impress him in the least, because he was in a fume over a young upstart, by the name of Compton, who had introduced at that meeting an absurd theory about the scattering of X-rays. Rutherford just couldn't accept this; he was in such a to-do I don't think he saw anything that went on that evening. He was mainly preoccupied in blasting off at Compton.

In those days, in the early and middle twenties, this country was doing practically nothing in the field of radioactivity. If you wanted to look at the latest work, you read the "Proceedings of the Royal Society" or the "Zeitschrift für Physik," but never the "Physical Review." I had been so imbued with an interest in the field of radioactivity that I wanted to continue with it. So I took steps to find who in the United States was really prominent in the field. When I asked that question I always got one answer--Bertram Boltwood, Professor of Chemistry at Yale. So I bent every effort to get to Yale University, and was finally awarded an assistantship. I went there preparing to associate myself, if I could, as a physicist with Boltwood. But unfortunately, and for reasons I don't know, he committed suicide. This was a great tragedy, because Boltwood was in his prime at the time. However, I did go into the field because I found both Kovarik and McKeehan were almost equally well known as Americans in the field of radioactivity. I did a rather mediocre thesis on the ranges of alpha particles from Uranium I and II, which we now know as Uranium 238 and Uranium 234. At this time there was a great deal of speculation as to the source of the actinium series, and it was postulated that there might be a common ancestor to the actinium and the uranium series. This was given the name "actino-uranium." I looked for it and didn't find it. It was finally found just before the war and is now called Uranium 235.

The discovery was followed very shortly thereafter by an amazing series of break-throughs which converted the theory of radioactivity into something that one could understand. At this time we began using the term nuclear physics to define this branch of physics. I will discuss some of these discoveries without attempting to put them in any significant order.

One was the isolation of heavy hydrogen, whose nucleus came to be known as the deuteron. The existence of heavy hydrogen had been predicted by Professor Birge at the University of California on the basis of some spectroscopic observations. Once this heavy brother of ordinary hydrogen had been isolated, it became quickly evident, largely be experiments carried out by Professor Lawrence and his group in Berkeley, that this was a very potent tool to use in artificial disintegration. They were fortunate in that Dr. G. N. Lewis of the Chemistry Department had become interested in heavy hydrogen and was able to supply them with it in quantities that were in excess of those obtainable by anyone else in the world. Shortly thereafter, Lord Rutherford's Laboratory also began working with the heavy hydrogen nucleus, and—probably because they were somewhat more scholarly--they named the particle the "diplon." The Berkeley people called it "deuton." For a long time these two words meant the same thing, but were being spelled quite differently. And the story goes, and I am sure it is apocryphal, the English finally conceded to our word "deuton" when Ernest Rutherford said, "I'll buy that American word if you will put my initials in it." They put the initials in the center, "er," and it is now known as the "deuteron."

The second discovery was that of the positron by Carl Anderson at the California Institute of Technology. This was a very interesting discovery because the existence of such a particle had been predicted already by the English theorist, Dirac. With the discovery of the positron, we added a new particle and a new concept of the electron. It turned out the positron was not stable and was prone to engage in a happy occupation called "annihilation" which gave rise to two quanta of gamma rays. Here was probably one of the first examples in which we actually observed the transmutation of matter into energy.

A third discovery in this same wonderful year (1932) came after a series of rather frustrating experiments by the Curie-Joliots in which they seemed to have evidence that very-high-energy gamma radiation could undergo Compton-like collisions with protrons. But it turned out that the high-energy gamma radiation was actually particulate in nature, and James Chadwick of the Cavendish Laboratory demonstrated this. He named this new particle the "neutron" because, some seven years before, Lord Rutherford had in a lecture contemplated the possibility that one might find such massive uncharged particles as the neutron and named it at that time. It was not a new name; however, Walter Nornst had used it in his "Theoretical Chemistry" some twenty years before that. When Rutherford was talking about neutrons he was thinking of a close combination of a proton and electron, not of a single particle, and it was Chadwick who, in a series of really magnificently simple and direct experiments, not only demonstrated that this was a single particle, but that furthermore it had a mass close to that of a proton. Many of these experiments in those early days were done with apparatus that looked appallingly crude, yet there was one piece of equipment that went with this crude apparatus which is sometimes lacking in our own experiments, and that is a good head.

A fourth thing that happened about this same time was a series of three or four papers in "Zeitschrift für Physik" by Heisenberg, in which he took the daring step of proposing that the nucleus might not be composed of protons and electrons, which had become a sort of theoretical millstone around our necks, but might indeed be a combination of protons and neutrons as we now still continue to believe. This again was a shot in the arm, because the proton-neutron theory began to let us make computations about the nucleus which we could not do on the proton-electron theory.

Finally, the thing that I thought the Nobel committee was going to overlook forever, but finally it did not, was the Cockroft-Walton experiment in which it was demonstrated for the first time that transmutations can be undertaken by completely artificially accelerated particles. It was a matter of some thirteen years prior to this time that Lord Rutherford had demonstrated the first transmutation using alpha particles. It is amazing how these things happen, because almost simultaneously with the first crude accelerator developed by Cockroft and Walton, it turned out that half a dozen other people also had the same idea.

One of the farthest advanced was the one that Ernest Lawrence was working on at the University of California and in which he had demonstrated, even before the Cockroft-Walton experiment, that he had accelerated particles higher than the voltages he was applying by means of a repetition of accelerations. Dr. Lawrence invited his present Assistant Director, Dr. Cooksey, and myself to come out to Berkeley in the summer of 1932 and see if we couldn't repeat the Cockroft-Walton experiment. We came out with boxes of geiger counters which at that time were not very common. We didn't repeat the Cockroft-Walton experiment, but it was sufficiently well set up in the month we had, so that, after we left, Lawrence and his people did repeat it. The first time the experiment was repeated in this country came only three or four months after the paper was originally published in the "Proceedings of the Royal Society."

Another thing that happened about that same time was the theoretical analysis, by Oppenheimer and Phillips, of the way in which deuterons disintegrated atoms. These investigators proved that what a deuteron did essentially was to act as a freight car to bring a neutron up to a nucleus and drop it off. The reactions with deuterons were identical with those obtained with neutrons.

A little bit later we began to hear of the Italians as prominent leaders in the field of nuclear physics.

I think it might be well to say historically that when I arrived at the University of California Radiation Laboratory only five or six people were there. One was a retired Italian naval officer, Commander Lucci, who acted as general assistant to all of us. He was possibly the beginning of Italian prominence in the field of nucleonics.

I became interested in beta-ray energies at this time because they were not falling into line with the general understanding of the nucleus as other reactions were. About this time Fermi's theory of beta emission came out. It is remarkable that his theory, published in 1934, has been confirmed only in the last twenty years. There has been found essentially no flaw in it all and it started purely as theory.

In the early days of the Radiation Laboratory, we missed a few boats because of instrumentation. We had no geiger counters, for example. The ones Cooksey and I brought out were designed for a particular job, and when it was done, they were thrown away. An all-purpose geiger counter was not known in most laboratories with the result that even though we were simply crawling with artificial radioactivity, we were not the first to discover it.

We learned about radioactivity one morning when a cable came from the Curie-Joliots, telling us about their experiment. We verified it. This should have been a lesson, but several months later we got a cable from Fermi telling us that he had discovered that neutrons could make things radioactive. These great discoveries in the early 30's, which really set nuclear physics on the way, were followed by a period of relative stability in which we all found that an easy way to make a living was simply to bombard something new and find new radioactivity. A paper could always be written, and papers were the things that counted. So, literally, for years people would take things and bombard them; then they'd take the neighboring elements in the periodic table and try to figure out what the activities really were. Incidentally, this didn't take much in the way of apparatus. We generally used an electroscope, which is a comparatively simple device that doesn't get out of order very easily.

But everyone, I think, began realizing that we were being held back by our instrumentation. In the 30's a great many instruments were devised; to mention one, the linear amplifier was invented by Wynn Williams in England in 1932. Various people were improving scaling circuits. We always built our own in those days because none were commercially available. Thus, any advances were extremely important in making possible the modern technology of the nucleus. We figured, for example, about 1934, that we were actually getting less than 20 percent of the working time on the cyclotron used for experiments; the rest of the time we were trying to fix the blasted thing. Now, one that doesn't rack up pretty close to 100 percent is almost never heard of.

In the meantime, Fermi was doing a series of extremely interesting experiments with neutrons. One thing he tried was to see transuranic elements by bombarding uranium with neutrons. When he got into this, be began to find all manner of strange things which he didn't understand and which puzzled the rest of the scientific world for a good many years. If finally fell to the German group of Hahn and Strassmann—even though a very talented German chemist by the name of Miss Novak had suggested it earlier—actually to demonstrate fission of uranium.

About this time those of us who were not in the Manhattan District project began to find that nuclear physics was "going underground." I remember visiting the Radiation Laboratory in 1941, and I was naive enough to think that the people there were unfriendly.

This was the time also that the Berkeley group, principally McMillan, had found neptunium and plutonium, and were settling into the war program. I think the war program is pretty familiar to most of you. When the curtains were gradually lifted at the end of the war—rather dramatically by the Smythe Report and then more slowly after that--we found that we had all sorts of new things that we hadn't dreamed of before. We had the ability to separate isotopes. We had reactors in which radioisotopes could be made in quantities that were completely unheard of and even unimagined before. Probably the most important commodity was that we had an extremely wide-spread interest in nucleonics and in its applications.

We also found that the commercial market had begun putting up for sale such things as vacuum pumps and vacuum parts, all sorts of electronic circuits and dosimeters, and related items which in the past we had to build ourselves. Perhaps I should amend that statement by pointing out that the radiologists had developed a number of extremely good dosimeters useful to nuclear physicists.

Most important of all, however, at the end of the war came the theory of phase stability, which was introduced simultaneously by McMillan in the United States and by Veksler in Russia. Essentially, this led to the ability to construct accelerators of practically any energy we care to build or can afford to build.

Since World War II, a number of other developments have come along. These have been, for the most part, comparatively simple, e.g., the scintillation counter. I have described earlier the crude way in which the eye was used in the scintillation counter. The scintillation counter of Kallmann in postwar Germany, in which he applied a photomultiplier tube, has given us an extremely powerful research tool.

Secondly, C. F. Powell in Bristol introduced the photographic emulsion which is a sort of solid cloud chamber that enables one to see the tracks of extremely high-energy particles. The emulsions have been borne aloft by our Sky Hook balloons which go up over 100,000 feet. This development together with the several huge proton synchrotrons, and other high-energy machines, have opened up a rather exclusive club of scientists. These people are the ones who either have the scanners to use the Sky Hook balloons--looking at the emulsion plates requires a great deal of time at the microscope and it's been found most convenient to train girls to do this and use the physicists only to make measurements on things that have been found—or those who happen to have a captive high-energy proton synchrotron in their laboratories.

I feel that classical nucleonics, and by that I mean nucleonics that deals with energies less than those energies which will produce mesons, is about in the same place as optical spectroscopy was when Sommerfeld's book was written. I think there is still a lot of interesting and fascinating work to do in working out energy levels and fitting theory to them. So one might say that possibly we can almost see the end of classical nuclear physics where it becomes almost a branch of engineering. The engineering phase of practical nuclear power has already been accomplished in the submarine NAUTILUS.

The British are very confidently going ahead to count on nuclear power replacing their other sources of power. The physics of mesons, hyperons, V particles, etc., is really not for the average physicist because it requires things that he doesn't have at his command. Therefore, I would look to see more centers like the European Council for Nuclear Research in Paris, and I think that the average basic nuclear physicist will begin acting more like an astronomer who doesn't rely on the telescope he has in his backyard, but rather on spending time at some center that has a 100- or 200-inch telescope. I shouldn't be at all surprised to see our nuclear physicists going to places like Geneva, Berkeley, and Brookhaven to do their work, and after spending a year or so there, then going back home to work up their data.

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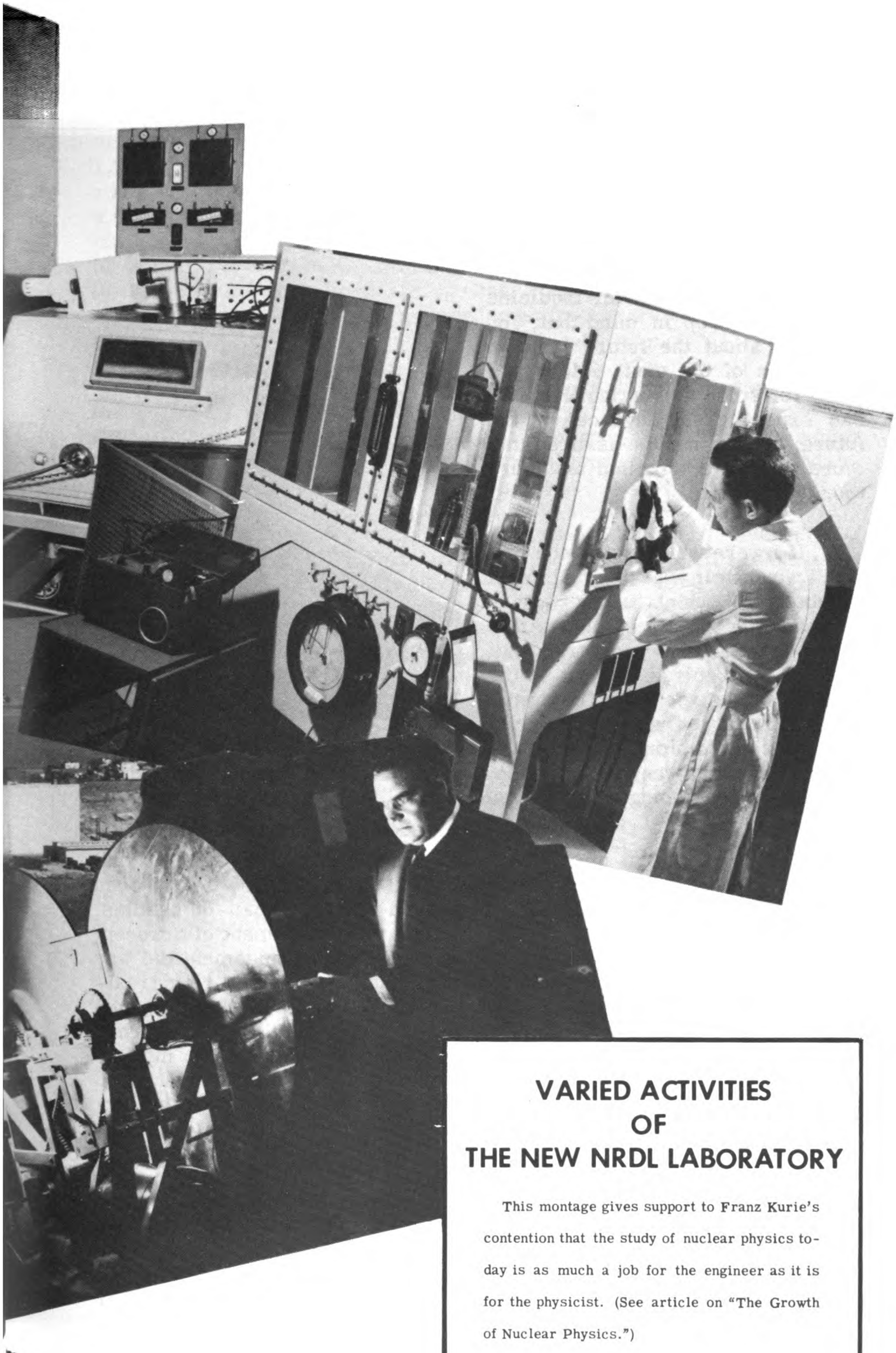
MAN LIVES IN A
RADIOACTIVE WORLD
1-COSMIC RADIATION FROM OUTER SPACE
Radioactivity in the world has been increased since the advent of the age of man-made radioactivity via nuclear reactor piles and nuclear detonations
2-INHALED RADIOACTIVE NATURAL GASES (RADON, THORON)
INTERNAL RADIOACTIVE POISONING
3-NATURAL RADIOISOTOPES IN FOOD (POTASSIUM-40)



VARIED ACTIVITIES OF THE NEW NRDL LABORATORY

This montage gives support to Franz Kurie's contention that the study of nuclear physics today is as much a job for the engineer as it is for the physicist. (See article on "The Growth of Nuclear Physics.")

What Do Radioactive Isotopes Promise for the Future Practice of Medicine?

Dr. Robert R. Newell
Professor of Biophysics
Director, Department of Radiobiology
Stanford University Hospital

In approaching the subject of what isotopes promise for medicine it is well to keep in mind that, you can't tell about the future from an evaluation of the past, unless you allow for some discontinuities. We can expect great advances in the future, but we can be assured that there will be discontinuities there too.

If I were writing science fiction I would tell you about Element Number 111 which is by way of being a philosopher's stone, and this has such wonderful properties that you will have only to show it to the patient, and he recovers from what ails him. And you have only to show it to a foreign diplomat and the whole world joins up in political amity. Until this breakthrough occurs, however, I shall talk about how things seem to be developing, gradually and logically.

Let us talk first about therapy. In clinical therapy we find that isotopes can be substituted for some of the things that we have been using already. Instead of radium needles you can use cobalt-60 needles. They're less expensive, are available in a large assortment of different sizes and strengths, and permit you to make the arrangement the way you would like to have it instead of being compelled to adapt your treatment plan to the radium needles that you happen to possess. A nice substitute for radon gold seeds is gold-198 wire in gold-197 tubes. They never leak and you can rely on their activity after you get them into the patient. Gold or cobalt can be put in hollow nylon thread and sewn through and around the tissue you wish to treat. This is an elegant method for interstitial irradiation.

Cobalt-60 or radium can be put in a catheter and held in the middle of the bladder for internal irradiation. One therapist at least has used bromine-82 solution in a rubber bag in the bladder and now another says to use cobalt-60 that way. I don't fancy having radioactive solutions around in something that a nurse can put a pin through. Colloidal radioactive gold has been put directly into the bladder (without any rubber bag) in order to treat widespread papillomatosis, and with good success in at least one patient. Otherwise some of the warts would have developed cancer, unless they had taken out the entire bladder and transplanted the ureters either to the outside or into the large intestine.

Cobalt-60 can substitute for an X-ray tube. There are a number of cobalt irradiators on the market. Cobalt-60 gives two gamma rays, 1.2 and 1.3 megavolts, which in quality is about half way between radium and a two-megavolt X-ray tube. The price is probably not higher than a two-megavolt X-ray outfit, and the beauty of it is, as the ice company used to say: "A lump of ice never gets out of order." When a belt breaks in the Van de Graaff machine you have to unbutton that high-pressure tank to get things fixed. Other long-lived isotopes can be used similarly, the latest promise being caesium-147 with half life about 30 years.

These are all things that we have been doing somewhat casually for a long time. But every little advance is hailed with joy by those who expect now to solve the cancer problem. There appears to be a regular cycle which goes like a sine wave. It rises through hope to enthusiasm. Then the reactions begin to appear and the bad late sequelae, so that we end up in the trough of disappointment only to have the next discovery come along and start the cycle all over again. I expect to see more of these disappointments before we adapt ourselves to what I think is the truth, namely that radiation per se is not the solution of the cancer problem. I do in fact expect to see isotopes solve the cancer problem. But they are going to solve it through fundamental studies in chemistry and physiology. When we really know what cancer is, then we shall be in a position to do something effective about it. I look for the cancer problem to be solved. I expect it to be solved with isotopes, but I don't expect it to be solved by the application of radiation to the patient.

Hahn and others are experimenting with interstitial injection of isotopes. Most hopeful is gold-198 into the prostate, hopeful for palliation, but I think not very hopeful for cure. It is also being tried by injection into the parametrium, in carcinoma of the uterine cervix. We can cure the local lesion with radium very successfully, but the patients often die because of metastasis to the pelvic lymph nodes. Colloidal gold will run out along the lymphatics to those same lymph nodes. There could be too many cases, however, where the cancer blocks the lymphatics so that the stuff will avoid the very places where you wish to have it go.

Colloidal gold-198 is also used successfully in peritoneal and pleural cavities. Cancer sometimes becomes seeded on these serous surfaces, then fluid collects and the patient has to be tapped every week or two, losing so much protein and so much salts that it is hard to keep him in life balance. Although no cure is to be expected in such a case, gold-198 can stop the fluid from collecting.

If a patient has an ovarian cyst which has cancer in it, and at operation this cyst is ruptured, the cancer is presumably seeded all around on the inside of the abdominal cavity. Gold-198 put in right away before these cancer seeds have a chance to grow, might save the patient from a fatal outcome. The beta rays from the gold penetrate only about a millimeter. But if cancer lies only on the surface, the beta rays can destroy it all. Radioactive chromic phosphate can be substituted for this. The precipitated chromic phosphate is sintered in a furnace, then ground in a ball mill to make a colloidal suspension. This is more difficult than the precipitation of colloidal gold, but it is easy to get, for the Abbott pharmaceutical people puts it up all standardized and sterilized. It has one advantage over gold-198, namely no gamma rays, so that the man putting it in isn't continually irradiated. However we have been able at Stanford to give 150 millicuries of colloidal gold into the abdominal cavity and measure only 8 or 10 milliroentgens of exposure to the operator.

Radioactive gold is being used experimentally in the lung, hoping that the lymphatics will carry it to the lymph nodes. I've already remarked a similar use in cancer of the uterus.

Neutron therapy has been done. Stone and Larkin worked with the fast neutron beam in Berkeley. They achieved some cures, but the reactions were severe. The war interrupted this clinical experiment, and Dr. Stone is not sufficiently convinced of its promise to take it up again.

Other investigators are experimenting with slow neutrons at Brookhaven. A brain tumor will take up many things faster than the rest of the brain does. Sodium borate rises to a concentration three or four times as high in the brain tumor as in the rest of the brain. If the patient is then set near a uranium pile where there are a lot of slow neutrons, those will enter into nuclear reactions with the boron resulting in a couple of alpha rays. So wherever the boron is, a secondary irradiation occurs. This is an interesting clinical experiment. We hope the doctors at Brookhaven will try it out to the limit.

The late Dr. Low-Beer pioneered in the use of phosphorus-32 on blotting paper for the treatment of superficial cancers of the skin. It is a useful technique because you can make your applicator exactly fit the region you want to irradiate. It should be used only for very superficial lesions, but in these it gives beautiful thin flexible scars.

Some clinical therapy is done with radioisotopes given systemically. Polycythemia is amenable to phosphorus-32. I think that it is the one disease of which you can say that radioisotopes are the treatment of choice. Still this is an uncommon disease and it is not much of a triumph to have an excellent treatment for a disease when the disease is so very infrequent.

In leukemia, phosphorus-32 is about as good as X-rays, maybe a little better. Dr. Osborne at Oregon showed practically parallel courses of the disease under phosphorus-32 and under X-ray treatment when both the treatments were carried on with the same good clinical judgment. As far as I know, no patient has been cured of leukemia by any treatment whatever. If we wish to irradiate the liver and spleen selectively (more than the bone marrow), we can use colloidal gold-198 intravenously. The colloidal particles are picked up by the Kupfer cells (reticulo-endothelial system).

Grave's disease, which is not cancer, is very successfully treated with iodine-131. I have held out for a long time, maintaining that surgery (thyroidectomy) is the treatment of choice. There are a number of thoughtful workers, however, who really believe that internal irradiation with iodine-131 is the treatment of choice. However, I would not do it in a young person because we don't yet know what is going to happen later in the radiation scar. We do think that radiation scars are prone to develop cancer. A very young person might live another 50 years, and with every year she lives would come an increasing possibility of developing cancer in the scar.

We can also use iodine-131 to obliterate or sharply reduce thyroid function in people who have incurable heart disease which still doesn't kill them, only cripples them. Such a person is unable to walk upstairs, sometimes unable to walk on the level. If you can reduce that person's metabolic rate, you may bring the demands of the body for the circulation of blood, meaning oxygen, down to a level where the heart can handle the load. Thus the person gets enough reserve so he can live comfortably, whereas before he could not find any satisfactory balance at all. This therapy should not be pushed too fast, lest too much stored thyroxine be released. There is evidence that this can increase the likelihood of coronary thrombosis a few weeks later.

Those carcinomas of the thyroid that take up radioactive iodine provide the one example of internal irradiation's going right where you want it and nowhere else. However, carcinoma of the thyroid only accounts for half of one percent of cancer deaths and only ten percent of those cases take up radioactive iodine. It follows that this is a pretty triumph when you have it, but woefully infrequent. There is some danger in the use of iodine because sometimes the destruction of the gland releases the store of thyroglobulin there. Injudiciously rapid attempts to irradiate the thyroid internally can thereby bring on a thyroid storm.

I have a newspaper clipping of a little girl photographed with the Governor of California to publicize Cancer Week. She had a thyroidectomy for cancer when she was five years old. Metastases in the abdomen were obliterated with repeated doses of iodine-131. She has been well three years.

Multiple myeloma is an infrequent disease and has no cure. Occasionally phosphorus-32 has been used for it but rarely with success. We are experimenting now to see if we can do any better with iodine-131. So far we've had just enough encouragement to make us continue its trial.

When cancer metastases take up iodine-131 (for instance) we want to locate and measure them. We are experimenting now with various kinds of what we call collimators to narrow down the area from which the scintillation counter will accept the radiation, and in so doing locate precisely where the tumor is and where the margins are. A machine is available (for $3500) which runs back and forth in front of the patient making a dot every ten or a hundred counts, which in turn gives a picture of the distribution of radiation. The beauty of this is that you can let the machine do the work while you do something else. Scanning by hand is very tedious, if you have to search all over the patient.

Dr. Tobias had developed a machine in which he runs ten crystals across the patient, each with its own narrow collimator, and its own electronic circuit to make the gamma-ray flash a neon light. A picture of the flashes taken with a Land-polaroid camera, finished in one minute, gives a picture of the spots of iodine-131 uptake. I am working with multichannel collimators which enable one to use a large crystal, yet make the scanning beam as narrow as one will. Dr. Bell at Oak Ridge is also working on multiple-channel collimators.

So much for therapy. Let us now talk about recent progress in use of isotopes in diagnosis.

Iron-59, given by vein, will tag the red cells. We can use this to detect bleeding into the intestine by measuring the radioactivity of the feces. Red cells are destroyed in the regular course of nature, of course, but the iron is recycled and doesn't get out. Uptake of iron-59 in the red cells as they are made in the bone marrow, affords a way to study an anemic patient's blood formation.

In aortography, a little iodine-131 in the opaque solution injected will give a signal when it goes under a geiger counter in the patient's groin, indicating the moment to make the X-ray picture.

Human serum albumin tagged with iodine-131 (RISA is the trade name) affords a convenient way of measuring the blood volume better, we think, than Evan's blue dye which doesn't stay in the blood plasma quite so well. This measures specifically the plasma volume. We can measure the red cell mass by tagging the red cells instead of the plasma. Phosphorus-32 has been used, but chromium-51 is better because it sticks to the red cells very well.

Isotopes that radiate gamma rays afford a way to study the dynamics of circulation. With the proper technique you can deduce the volume of blood which is flowing through the heart by measuring the rate at which a dose (of iodine-131) is diluted as it goes into the blood stream and through the heart. The standard method of doing this is to take blood samples every few seconds. The curve of rise and fall of specific activity provides the data for calculation of how much blood is going through the heart every minute and the size of the pulmonary pool. We are now trying to make quantitative Prinzmetal's "radiocardiograms." A dose of radioactive sodium (or iodine-131) is given by vein and the gamma rays are measured over the heart as the blood goes through it.

We also can measure the status of the peripheral vessels, particularly the peripheral arterioles. The circulation time can be measured very nicely with radioisotopes. We can measure the buildup of peripheral activity in the limb after intravenous injection of a radioactive isotope. In a case of diabetic gangrene, this could help you decide whether amputation is necessary. It has been shown that you can do about as well with a much smaller dose by putting the isotope into the limb (muscle) and measuring the rate at which it disappears.

Tobias and associates have made some studies of the arteriole situation in a general fashion by giving a dose of iodinated serum albumin and keeping track of the long-time rate at which it is diluted. There are several compartments apparently. First the dose gets diluted into the blood. Then it spreads out into the extra-cellular fluid. In the liver this apparently goes pretty fast depending on the status of the arterioles. A nice correlation has been demonstrated between age of patient and the rate of this secondary dilution, revealing what happens to our blood vessels as we get older.

Iodine-131 affords a way to measure the competence of local circulation as it develops in a pedicled graft. You put a tourniquet around the proximal end of the graft, then inject a little iodine-131. If the radioactivity gets out of the graft quickly, that means the distal end has already achieved its new blood supply and you can cut loose the proximal connection. Incidentally, we now know that such grafts get their new blood connections much faster than we had previously supposed, usually in ten days or two weeks.

There are a few more things we've learned by tagging red cells with iron-59 or chromium-51. We find that the amount of iron in the plasma is small and the rate of its turnover is amazingly rapid in polycythemia. We measure the rate of destruction of red cells and the location in hemolytic anemias (the spleen), and in other anemias. Normal red cells live from 100 to 120 days. In sickle-cell anemia they die off not at a given age, but rather young or old according to chance, and with very much shortened half-life. It was brought out in one of the lectures yesterday that there are half a dozen kinds of hemoglobin. By electrophoresis you can separate the hemoglobin from the other proteins, and the several varieties from each other, because they travel at different rates. By tagging them you can find out for example, which kinds affect the life of the red cell in which they are lodged. These are examples of the fundamental studies that isotopes make possible. Some of them might prove to be useful in clinical diagnosis.

Other functional tests have been getting attention, some of which are only promising ideas. For instance, we were trying to measure pancreatic function by seeing whether radioactive zinc would appear quickly in the duodenum. Nothing has come of that as yet. Another test, however, has proved practical. Radioactive iodinated serum albumin is given by mouth. If it is digested, the iodine is absorbed into the blood as iodide and collects in the thyroid where it is readily measured with a geiger counter. Then you know that the patient's pancreas is putting out trypsin into the intestine as it should. Radioiodinated albumin is also useful for measuring the anti-proteolytic activity of the blood plasma *in vitro*.

Newly available from Abbott Laboratories is radioactive iodinated Rose Bengal. This affords a very delicate test for liver function, twenty to a hundred times as sensitive as bromsulphthalein. The patient is given a few microcuries of this by vein and the rise of activity can be measured over the liver. It comes up very fast if function is normal. This also gives promise of a way to measure the rate of blood flow in the portal circulation.

Vitamin B-12 (so-called "extrinsic factor") is the only substance that I know of in the internal economy which contains cobalt. It is now available tagged with cobalt-60. If this is given by mouth it is normally absorbed, but not in the absence of "intrinsic factor," which is the defect characteristic of pernicious anemia. To make the test practical we give some non-radioactive vitamin B-12 by injection, to insure that the patient has an excess and will excrete it in his urine, where we can detect the radioactivity of any of the tagged vitamin that we gave him by mouth. Absence of radioactivity in the urine, of course, means no absorption which in turn means the patient has the defect in "intrinsic factor." These are only examples.

There is no saying how many fundamental tests we might use radioactive tracers for. We can trace the site of action of antibiotics by tagging them with sulfur-35 or carbon-14, and find out about their breakdown and excretion. The same thing for chemo-therapeutic agents used against cancer, and, in fact, all kinds of pharmaceuticals. Some pharmaceuticals can be labelled as they are synthesized. Some have to be labelled biologically. It is no secret that at Argonne they have a greenhouse in which they are growing medicinal herbs in an atmosphere containing radioactive carbon dioxide. This has to be done, of course, in a closed system, both because the radiocarbon is expensive and because you don't want to let radiocarbon dioxide loose on the countryside for people to breathe.

The clinically useful and clinically promising things have, so far, been discussed. But there seems to be no limit to the number of possible investigations which would yield an increase in knowledge in regard to biochemistry and biological changes in the body. The things we don't know are legion and the proportion of those in which one could profitably make use of a radioactive isotopic tracer is large. And so I would say that the promise for the future is not just in clinical application, but is overwhelmingly in basic research. And in basic research, I really think that for the future the sky is the limit. Now let's predict how high the sky might be by seeing what has happened in the past.

The Fifth Annual Report of the AEC has 333 pages listing the investigators who are doing open research, not secret, using radioactive isotopes. In 88 months AEC has made 17,000 shipments of iodine-131; 11,000 of phosphorus-32; 1500 of gold-198; almost 800 of cobalt-60. There are at present in force 162 open research contracts with the AEC alone and there are a lot of investigations, of course, in which the AEC is not supporting the research. For the AEC-supported research alone there are 162 contracts that concern medicine, 23 that concern biophysics, and 200 that concern other aspects of biology. The medical users in California at present are 108, in the United States 800. Of those, 17 are new in California last year, 1954, and 190 are new in the United States. The future promises to be busy indeed.

When apples are ripe, the trifling event suffices to decide which of them shall first drop off its stick; so a small accident will often determine the scientific man who shall first make and publish a new discovery.

---Sir Francis Galton

Radiation Hazards

Dr. Luis W. Alvarez
Associate Director
University of California Radiation Laboratory

In view of the interest of the Navy Radiological Defense Laboratory in radiation hazards, it seems appropriate to discuss the history of the subject. Many people associate this field in their minds with guinea pigs and geiger counters. To my way of thinking, health physics or radiation protection did not start, actually or historically, with such things. The starting point was men.

The early pioneers of X-rays and radioactivity--those who died from radiation burns--are men toward whom I feel a great personal debt. If it had not been for these men, it is quite probable that many of us long associated with radiation would not be here today.

In the course of my discussion I am going to write about men who got into trouble--when no one was able to tell them in advance that they were doing something dangerous. They were the ones who had to find out for themselves. The best way to start is to review briefly the history and discovery of X-rays and of radioactivity.

X-rays were discovered on the 8th of November in 1895. And the discovery of radioactivity came just five months later. This was a golden age in physics. There was another one in 1931 and '32.

Since the radiations from X-rays and from radioactive materials are very similar, we can group the two fields together and talk about the radiation problems as though they were the same. Now, the invention of the X-ray tube was not like the invention of the cyclotron and many other modern devices. After the invention of the cyclotron, and building of the first practical one, it was a number of years before another cyclotron was built anywhere else in the world.

The spectacular thing about the discovery of X-rays was that within a week after X-rays were discovered, they were used all over the world for medical purposes. You might ask, "How did so many people build X-ray tubes so fast?" Everyone in the world of physics had a "Crookes tube" in his laboratory cabinet, but just didn't happen to know that it gave off X-rays. This was Wilhelm Roentgen's greatest contribution.

He showed that a photographic plate close by such a tube would absorb the X-rays from the tube and be blackened.

Now Roentgen was not the first to discover this, because there are two recorded cases in the literature where similar observations were made. In one case, the man sent the photographic plates back to the manufacturer; they were foggy, no good. Another man wrote an article saying it was bad to store photographic plates near one of the tubes when it was running, because the plates would fog. Neither of these two men is credited with the discovery of X-rays; that is reserved for Roentgen. He described the properties of X-rays in great detail, and he pointed out how they could be used immediately in medical practice. Their first use was for diagnosis of fractures, because the early X-ray tubes were not powerful enough to permit penetration of very thick parts of the body. Fortunately, during this time, the people who had X-ray exposures, received them one at a time. A man would have his leg X-rayed or his hand X-rayed, and that would be all.

The first real trouble with X-rays came shortly after Edison invented the first practical fluoroscopic screen. He sent it to an International Exposition in Philadelphia, where it was demonstrated to thousands of people as they passed by in a long line. Edison's assistant stood with his hand over the X-ray tube for a couple of days, to let the visitors see his bones.

Those of you who know about X-rays can appreciate what came after this. The man suffered a great deal, his arm had to be amputated, and he died not long after that. This was the first really serious X-ray accident and it gave people a good scare.

Physicists were also using X-ray tubes about this time, but fortunately they didn't have much trouble. The main reason for this was they were too poor and couldn't afford the most powerful X-ray tubes; they were protected by their poverty. The doctors were the ones who bore the brunt of the X-rays; a very large number of them lost their lives in the early days.

I can remember when I first came to the Radiation Laboratory at Berkeley in 1936. One of the best things about the early days was that we had on the control desk of the cyclotron a book called "American Martyrs to Science through the X-Ray." We all used to read this while we were operating the cyclotron. It was a very healthy thing for us to be reading, since we were pioneers in a new field of radiation, and needless to say, we were anxious to avoid becoming martyrs.

I might point out in passing that the X-ray health-hazard situation is not yet really under control. I should say that as far as diagnostic X-ray equipment and therapeutic X-ray equipment is concerned, the situation is very good indeed. The men who use these machines are fully aware of their lethal qualities; they respect the machines, and they work with them in a very safe manner.

On the other hand, there are other uses of X-rays. For example, the X-ray machines which were installed in shoe stores after the war were really very dangerous. I am happy to report that they seem to be on their way out.

Another field where more care could be used is in dental X-ray practice. I don't think many dentists have been seriously hurt with dental X-ray machines, but it is easy to see changes in the blood picture of a patient after a full mouth X-ray. The X-ray companies are aware of this, and there is an educational campaign now on in the dental profession to assure better safety conditions.

In the field of radioactivity, the pioneering was somewhat hazardous, but because of the lower radiation intensities, it was not so serious as in the X-ray field. The first recorded case of radiation burn from radium involves Pierre Curie. He was, of course, the husband and teacher of Madame Curie, and, shortly after they found radium, he was in the habit of carrying a milligram of radium around in his vest pocket. I am sure that all the discoverers of new elements have been in the habit of carrying a little piece of their material around to show to their friends. So it was not at all surprising that Pierre Curie had in his vest pocket a milligram of radium. He found after a week or so that he had a very severe pain right below the sample. Later on it developed into a burn. But he recovered, and was killed shortly afterwards in an automobile accident. While we are on the subject of the Curies, I remember that when I was a boy, I read about Madame Curie, "who died of radiation burns and was a martyr to radium." She died at the age of 86, I believe. So she is very much like the "martyrs to King Tut's tomb," who "die of the curse" at the age of 96.

I see that I have mentioned the names of two scientists here—Roentgen and Curie. They are honored in the field of health physics; both have units named after them. The unit of X-ray or radiation dose is the Roentgen, or R; the activities of radioactive samples are measured in curies.

Rutherford's two great books on radioactivity have something to say about radiation hazards. In the 1904 edition, I found one page out of a total of three hundred devoted to the subject. This page told how you might get a little irritation in your fingers if you held a radium needle for too long. In the 1932 edition, which was supposed to tell practically everything that was known about radioactivity at that time, Lord Rutherford devotes three pages to the subject. One of the pages is the same as in the 1904 book, and there is also a little bit added about the effect of gamma rays on the eye ball. Those of us who are in radiation physics or health protection would immediately think of radiation cataracts in this connection. We are all sensitive about getting <u>any</u> radiation in our eyes. We all have friends whose lenses have had to be removed because they developed radiation cataracts.

But Lord Rutherford was worried about quite another thing. He said that if you want to see the scintillations that are produced when alpha particles hit a fluorescent screen, you will have trouble if your radioactive source is a strong emitter of gamma rays. He cautions you not to look straight at the sample with your microscope, because then your head will be in the direct beam of gamma rays from the source and your eyeballs will be flooded with fluorescent light, so you can't see the scintillations. He says to be sure to put a right angle prism in your microscope system so you can look at things from the side, and put a piece of lead between your eyes and the source. Then you can see the scintillation better. That is rather amusing to those of us who wouldn't be caught dead with any extraneous light in our eyes from any source of radiation. Nowadays, instead of one page, or three pages, we have in our books on radioactivity, a whole chapter on health physics. Or if you want a complete book on the subject, there are many to choose from. Health physics is now an important science in its own right.

Another kind of radiation hazard could not have been predicted on the basis of X-ray exposures. This has to do with the internal exposure caused by the ingestion of radioactive materials which give off the very short range alpha particles. These can't get through the skin, but if they get into the body, then can bombard the sensitive organs directly. We had to learn about this through a tragic series of accidents with which I am sure you are all familiar--the famous radium-dial painters in New Jersey. To paint the dials, the girls would first point the little brushes on their tongues. They absorbed tremendous amounts of radiation internally, and I think they have all died. Similar problems are very important these days, when we deal with intense alpha-ray emitters in our laboratories. A great deal of the health protection program these days is devoted to this problem instead of to the more obvious one of protecting from the penetrating rays, which can be taken care of with lead or concrete.

Rapid progress was made during the second big period of discovery in physics. Discussion thus far has centered on developments in 1895 and 1896 when electrons, X-rays, and radioactivity were discovered. In 1931 and '32 another breakthrough came when the positron, the neutron, heavy hydrogen, and artificial radioactivity were discovered in quick succession. Now it is interesting that most of the people who came into the field of artificial radioactivity were not the old radioactive workers. A whole new crop of people came in, and they were for the most part not fully alerted to the radiation problem.

At the Radiation Laboratory in Berkeley, Professor Lawrence had invented the cyclotron. This machine was the strongest source of artificially radioactive materials anywhere in the world. It generated more neutrons than any other machine, not by ten or a hundred or a thousand percent, but by many orders of magnitudes. I am pleased that we all got through that period so well. We managed it without any radiation problems for two reasons: In the first place, Professor Lawrence was very interested in medical problems--he had originally wanted to become a doctor. Secondly, he invited his brother, Dr. John Lawrence, to come to Berkeley in 1935 to look into the properties of the new radiations which were coming from the cyclotron.

When John Lawrence arrived, one of the first experiments he did is remembered by everyone who was there at the time. He said, "Let's see what effects these neutron rays have on a mouse." Nobody had ever irradiated a mouse with neutrons before; no one else had had enough neutrons to bother a mouse, so no one had tried the experiment. So Dr. Lawrence had one of the men in the machine shop build a little brass cylinder about four inches long and about an inch and one half in diameter, to hold the mouse in position in front of the neutron source. It occurred to him that the mouse might not have enough air. So he had the machinist solder in a little copper tube, and he ran a hose over to the air supply. The mouse was put in the cyclotron and irradiated for fifteen minutes. Then everyone crowded around to see what had happened to the mouse. It was deader than a door-nail--stone cold. You can imagine the effect this had on a group of men who had been working around an unshielded cyclotron for the past year or two. I might say that it was one of the greatest things that happened in the Radiation Laboratory, because it gave everyone a real emotional jolt. Eventually it turned out, on histological examination, that the mouse had suffocated; somebody had forgotten to turn on the air supply. But the mouse had not suffocated in vain; the effect of the initial jolt was long-lived.

I would like to go on record as saying that the efforts of Dr. John Lawrence are tremendously appreciated by all those who worked in the Laboratory at that time. If it were not for him I would now be wearing thick glasses to compensate for the loss of my natural lenses, which would have been removed because of radiation-induced cataracts. I have John Lawrence to thank for the fact that I am alive, and that my only optical worry is whether I should buy bifocals now or wait until next year.

I should point out that although no one at the Radiation Laboratory has had any difficulty with radiation so far, a record we are very proud of, all of us oldtimers still have our eyes examined every few years. Other laboratories with cyclotrons have not been so fortunate; they did not have a John Lawrence to help them. Now, it wasn't just this first mouse experiment that did it. It was the fact that we had a doctor working with us, a doctor who was there in the Laboratory every day, a man we liked, a man who was interested in medical problems. They were before our eyes all the time and, I should add, before our noses! One corner of the Laboratory had a lot of mice and rats and rabbits in it, and if you are not a medical man, you don't quite appreciate the odor that these creatures produce. So we were continuously aware that we were dealing with something that might possibly have effects on us as living beings.

Other laboratories have had radiation trouble. I know of about a dozen men, most of them my friends, who have had radiation cataracts in various degrees. Other people have had too much radiation. I can tell you a couple of experiences; of the things people used to do. I must confess we did things then that no one would think of doing any more. We got more radiation than would be allowed nowadays. Fortunately, it apparently hasn't affected us, although we won't know for some while. At least we think that the cataract test is the most sensitive indicator for radiation, so we take some comfort from that. After the animal experiments had been going on, we derived a fair amount of comfort from the fact that these tests indicated that we were not getting too much radiation. The X-ray pioneers didn't have this advantage; no one put mice in an X-ray beam before the men were exposed themselves. But fortunately this could be done in the case of neutrons and artificial radioactivity. Dr. Lawrence made a long series of tests, and proved that neutrons were approximately five times as lethal as X-rays when both gave identical readings on a standard dosage meter.

About this time we got our first radiation protection instrument at the Radiation Laboratory. It was a pocket electroscope made especially for us by Dr. Lauritsen of Cal Tech, who had invented the device. When we realize that nowadays our Laboratory has several hundred of these electroscopes, geiger counters, and film badges for radiation monitoring, it hardly seems worthwhile to speak of a single instrument of that kind. But all of us remember the good uses to which it was put. Shortly after this, the cyclotron intensity went up and we found we would have to put some shielding around the machine. Dr. Franz Kurie, who is known to most of you, designed the first water tanks to surround the cyclotron, and supervised their installation.

At one cyclotron laboratory, a famous physicist would often demonstrate the beam to a visitor by letting it produce fluorescence in his fingernail. I don't think anyone would do that these days. One of our graduate students accidentally got his hand in the alpha particle beam of the 60-inch cyclotron. It was in the beam for only a fraction of a second. It felt intensely hot to him, but there wasn't enough energy in the beam to raise his skin temperature appreciably; his sensation had to be from the direct excitation of the nerves. He had a red patch on his hand that healed in a few months, and he has had no trouble since. That is the only accident I can think of which happened at Berkeley, and it was not at all serious.

I can remember one incident that amused me at the time. I went home to Rochester, Minnesota, for Christmas, after working at the Radiation Laboratory for a couple of years. I visited the Mayo Clinic for a medical checkup, and one of my examinations was in the X-ray Diagnostic Section. I walked into a dark room and stood in front of an X-ray tube. The man who examined me spent most of his working day sitting in front of an X-ray tube; this was his speciality. I had lived next door to him as a boy, so he asked what I was doing. I said, "I'm working with Ernest Lawrence and the cyclotron out in Berkeley." He said, "Oh, that's terribly dangerous. I wouldn't work there for anything." I had already concluded that the last thing you could get me to do would be to sit in front of an X-ray tube for eight hours a day, fifty weeks of the year, as this man was doing. I particularly noticed that he would put his hands up underneath the screen and poke me in the stomach, and I could see the shadows of his hands. I was as horrified by his occupation as he was by mine, but we decided "Each man to his own poison."

A short time later, the Manhattan District project started and a whole series of new problems came in. At the Radiation Laboratory, one curie of radioactivity was considered a fabulous amount. I can remember two occasions on which we made a curie of radio-sodium for Professor Lawrence to demonstrate to a group of doctors. That required a full day's effort keeping the cyclotron running at full blast. Then along came the chain reacting piles at Hanford, making millions of curies of activity. The hazard problems increased by many million fold in a few years.

The protection of the workers became a very important problem and two new professions arose at this time: health physics and health chemistry. There had been no such things before the Manhattan District--the physicists and chemists had to watch out for themselves. One of the first things was to establish the safe daily dose, the amount of radiation that a person could take every day with no ill effects of any kind. This dose was set at 10 milliroentgens per hour, and it was based largely on the experience of people who had dealt with radium emanation in hospitals. It was very hard to judge how much exposure people working with X-ray tubes had received, but you could find men who came into a hospital every morning and pumped off the radon gas from a particular radium source. They could show you where they stood every day, and by measuring the amounts of radiation at those places, you could compute their yearly doses. I believe that was the way the safe daily dose was set. In fact it was set by taking dose rates for men who were in good health, and dividing by two and dividing by two again. The safety factor of four was to guard against unknown "long time" effects.

I would like to say a little bit about doses and dosage rates because there has been a lot of confusion about this. The difficulty is that what hurts you in the radiation field is a dose—so much radiation going through you--but the thing you generally read on a meter is the dose rate. You get hurt by a certain number of roentgens. But the meter reads roentgens per hour, and most people unfortunately use the abbreviation "mR" for both the dose and the rate. This is also true in the traffic business, where they confuse miles and miles per hour--"speed limit 45 miles." Everybody knows this means miles per hour. In the case of traffic, it is the rate which hurts you, not the distance you go. I wish someone would invent a new unit to replace the "mR per hour" which is usually abbreviated to "mR," and so is confused with the dosage unit or true mR.

In radiation hazards, it is the other way around. You are hurt by the total doses, but not by the rate; yet the rate is what is read on the instrument. This has caused a lot of trouble and lot of unhappiness between physicists on one hand, and health physicists on the other.

The Bikini test was the first large scale effort where untrained men had to be protected from radiation. Because of a shortage of time, the training of some of the radiation protection workers consisted of little more than being handed a geiger counter and being told to "look at the meter and when it gets up to the red line, get out fast!" Of course you all know that this isn't what you should do; if the meter reads very high you can stay for a reasonable period of time and then you can get out; if it reads higher, you can stay for a shorter period of time. The tolerance rate is one a person can take all his life. It is much safer to take 10 times that rate for an hour a week than to take the tolerance rate all week. The total dose is much less that way, even though the rate is temporarily higher. No one is to blame for the confusion at Bikini—there just wasn't enough time to do an adequate training job.

The health physicists and health chemists we work with these days have very good training and are good colleagues and associates rather than just people who tell you to stop doing what you want to do. The situation is very much like that of the anesthetist in medicine. For a long time, a person who administered anesthetics was a sort of technician so far as the doctor was concerned; he sat at the patient's head and gave him a little more ether when he started to wake up. That is what some of the early radiation protection people were. Nowadays, an anesthetist is an M.D. and may have a postgraduate degree; he is treated with as much respect as the doctors who do the operation. He is a real specialist. Health physicists and health chemists have similarly increased their scientific prestige. They are becoming real scientific workers, and not just people who just read meters. This is a very healthy sign, because people can get into trouble by not properly understanding the instruments they are using.

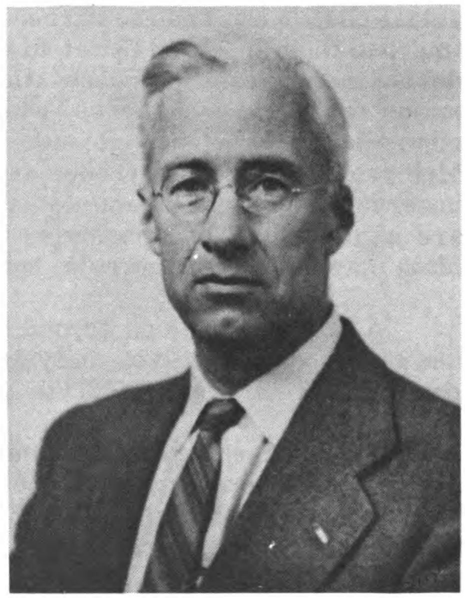
We have at the Radiation Laboratory a linear accelerator whose beam is so intense that it can kill a mouse in an exposure which lasts for about four hundred millionths of a second. Several years ago, a health physicist friend of mine suggested finding out the intensity of radiation in the linear accelerator area by using a geiger counter. I was immediately horrified, and he couldn't understand why I should be. He was trained around a pile, where intensity is constant in time—where a geiger counter is as good as anything else for radiation monitoring. The thing he had forgotten was that the geiger counter has the property that once it has registered a count, it is dead for a few hundred microseconds and so can't count again. Our accelerator beam comes on fifteen times per second. If a geiger counter were brought into the beam area, in fact if it were placed right in the beam itself, it would still count only fifteen times per second, although it will kill a mouse in a very short period of time. So my friend would have felt that everything was safe, since the counter was only going fifteen times a second, or about a thousand counts a minute. "It's perfectly safe here, so walk right in, boys!" This is the best single example I know to illustrate how thoroughly our health physics and health chemistry colleagues should understand the smallest details of their techniques. Fortunately it happened several years ago; the situation is now in excellent shape.

In closing, I would like to make a prediction about the future of NRDL. Although it exists primarily to cope with the problem of the decontamination of ships and other objects, that mission is much too narrow. The Laboratory therefore carries on fundamental work in physics, chemistry, and biology, even though it is physically situated on the grounds of a great shipyard--a most unusual place for a laboratory doing work in "pure science." Unusual, we may say, but not without historic precedent. In the late 18th century, Count Rumford was in charge of an arsenal making cannon for the Bavarian King. He made extensive studies of the heat liberated in the boring of cannon, and showed that heat was a form of energy, and not a mysterious fluid, as was believed at the time. His experiments are among the most important ever done in pure physics, and Count Rumford is remembered today, not for the performance of the cannon he built, but rather for his achievements in pure science.

I have the feeling that the same fate awaits this Laboratory. I believe that no matter how excellent are the decontamination procedures, nor how ingenious are the defensive techniques worked out by this Laboratory, such techniques will never be given an adequate test. In other words, I don't believe we will have a nuclear World War III. Instead, I believe that a century or two from now, this Laboratory will be remembered for its great works in pure science, which were accomplished while the Laboratory staff kept in readiness for a nuclear war which never came.

How Scientists Work and Think*

Joel H. Hildebrand
Professor Emeritus
Department of Chemistry and Chemical Engineering
University of California
President, American Chemical Society



The ways by which scientists have learned, through a gradual evolution, to form sound judgments are exerting great influence on human affairs. This influence would become far wider and more beneficial, however, if these scientific methods could play a greater role in the education of everybody, including scientists themselves.

Let us consider a few examples. When Lenin stated that, "Politics is a structure erected upon an economic foundation," he was using a pure analogy, having no value whatever as proof. Plato's assumption that heavenly bodies move in circles because "the circle is the most perfect geometrical figure" may have been pretty good for Plato, but we have learned in the meantime that the stars are not governed by man's notions of perfection. A scientist knows that "the law of averages" does not influence the weather to strive to follow a dry year with a wet one. He distinguishes between events which are predictable, like the death rate, and those that are not, like the death of an individual. He should know that it is not scientific to expect that the stock market will either fall or continue to rise simple because it has been rising, and, similarly, that the prediction of a "historicist" that "some sort or other of totalitarianism is inevitable" is a quite unwarranted extrapolation.

No mathematician now defines an axiom as "a self-evident truth," and no intelligent scientist accepts a conclusion based upon the assertion, "it stands to reason . . ." He knows that the value of a battery additive is not determined by the testimony of satisfied users (the method of lawyers) and that getting well after taking an alleged remedy is not proof that the medicine caused the cure. He knows that foaming is not the proper measure of detergency; that advertising claims of "better," "faster," "bigger," are meaningless. He is aware of the danger of over-simplifying, and likely to be skeptical regarding such simple models as "the economic man," "the average citizen," "the typical Englishmen,"

*The article presented here is a severe abridgment; the original is to be given as part of a University lecture series and therefore cannot be presented in full at this time. Ed.

and of the simple solutions offered by politicians for complex national problems.

Our people would profit by a much larger infusion of scientific thinking into their personal and collective life.

Science is not a lot of book-learning; it is an active enterprise. It is what scientists do and how they do it. They do not wave magic wands, neither do they proceed by a series of rigid logical steps to sure conclusions. Instead, they keep their eyes open for discrepancies between actual phenomena and the current explanations for them, and they try to improve them in order better to understand, control, and predict. They devise instruments for observation and measurement. They use imagination to set up hypotheses, which they test by carefully designed and controlled experiments. Results found to occur so uniformly as to have high probability of recurrence are formulated as "laws," although it is understood that, unlike statute laws, they do not control. These laws are explained, where possible, by theories and models. Mathematics often plays an important role, but its limitations must be kept in mind.

A science develops beyond the initial stages of observing, naming, and classifying, by aid of unifying ideas or concepts, such as energy, entropy, quantum theory, and organic evolution.

The rich rewards of these methods in terms of economic prosperity and the health and well-being of the people are fairly well appreciated; what is not realized are their profound effects upon the ways in which we form judgments in general. Science is the great antidote to superstition, prejudice, wishful and emotional thinking. Its findings have, therefore, great influence upon social and ethical evaluations. It refutes, for example, the myth of racial superiority, responsible for so much of the world's injustice and cruelty. In the words of the philosopher, William R. Dennes, "Of all the servants of morality, science is the greatest; for it is the one serious way we have to discover what means are likeliest to lead to the realization of the ends we cherish."

Our Expanding Universe

Once again scientists have brought to a climax some experimental work in astronomy which adds a bit more to our understanding of the expanding universe. Results have been announced on the measurement of recessional velocity of a "radio star" in the constellation Cygnus. A giant 50-foot radio telescope was used in the study conducted by Drs. A. E. Lilley and E. F. McClain of the Naval Research Laboratory.

By use of radio waves "tuned" to hydrogen atoms in the radio star, the two scientists were able to measure the velocity of the radio star, finding a velocity of 10,560 miles per second for the object. The term "radio star" is used by scientists to describe a celestial source of emanation of radio waves which may or may not be visible to the optical telescope. It is generally a concentration of gas.

The significance of the experiment is that it was performed with radio waves, and, that the recessional velocity agrees with the velocity of the radio star measured by optical waves with the giant 200-inch Palomar telescope.

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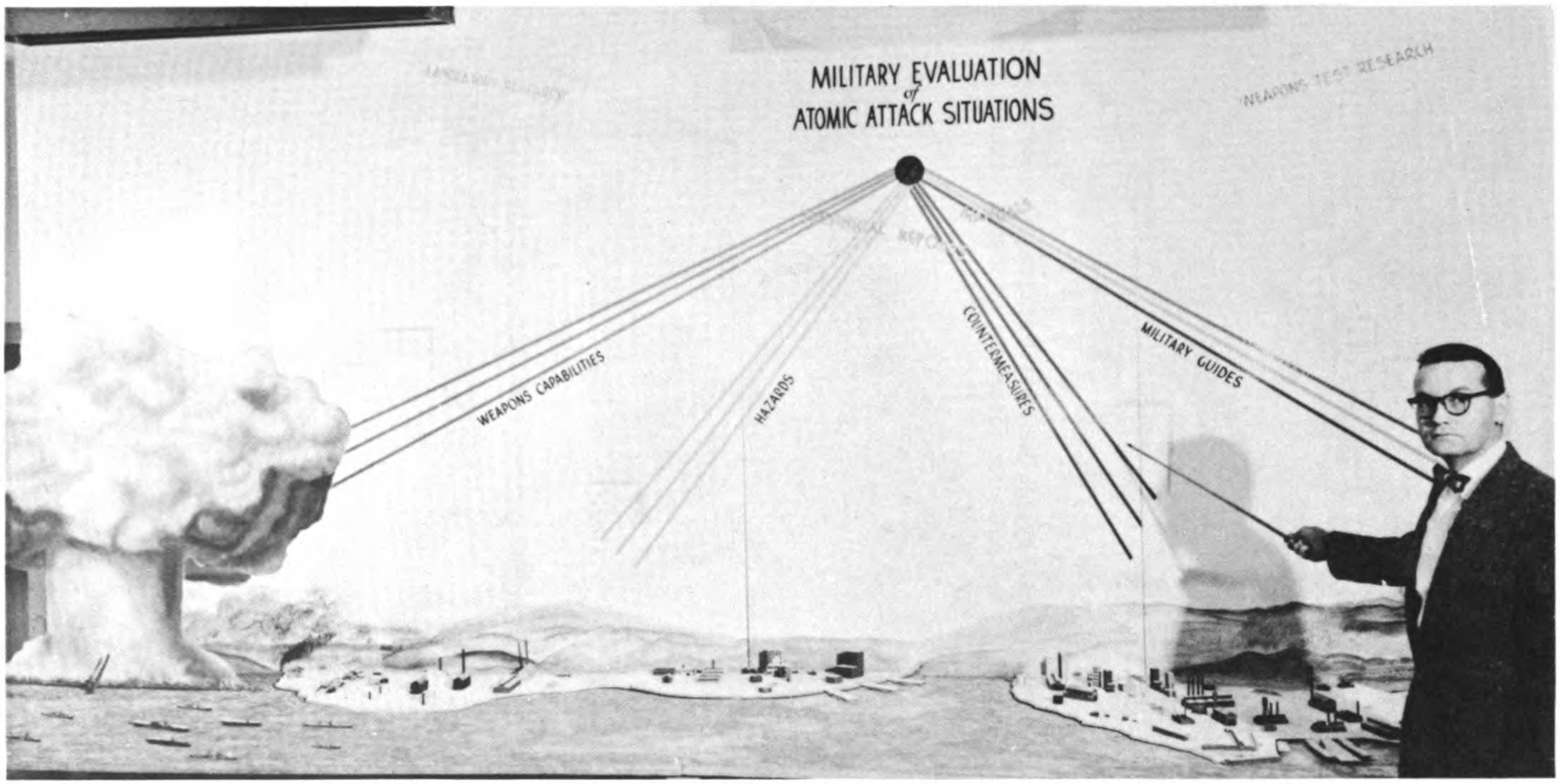
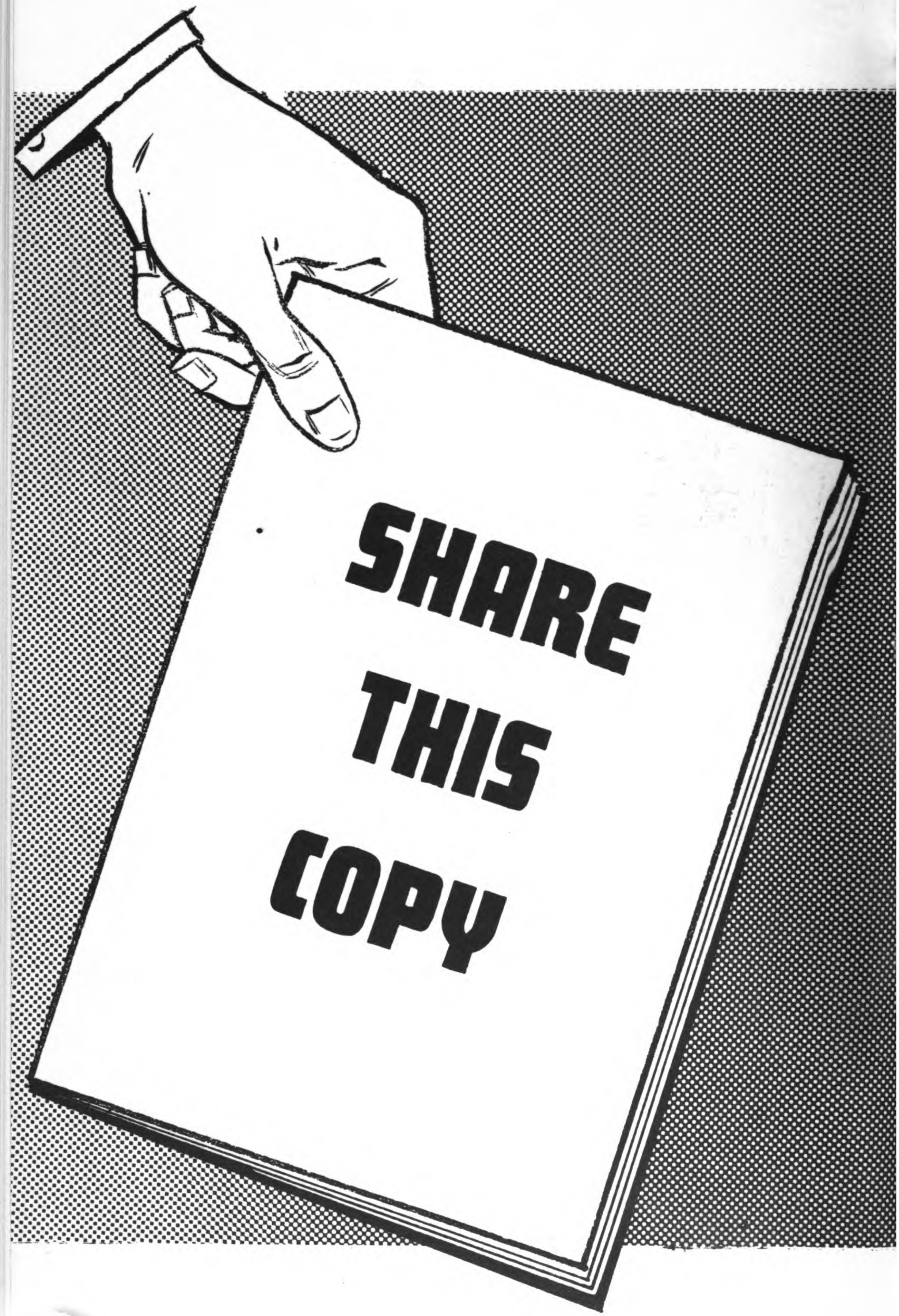


USNRDL military evaluation display on an atomic attack involving both land and sea targets.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