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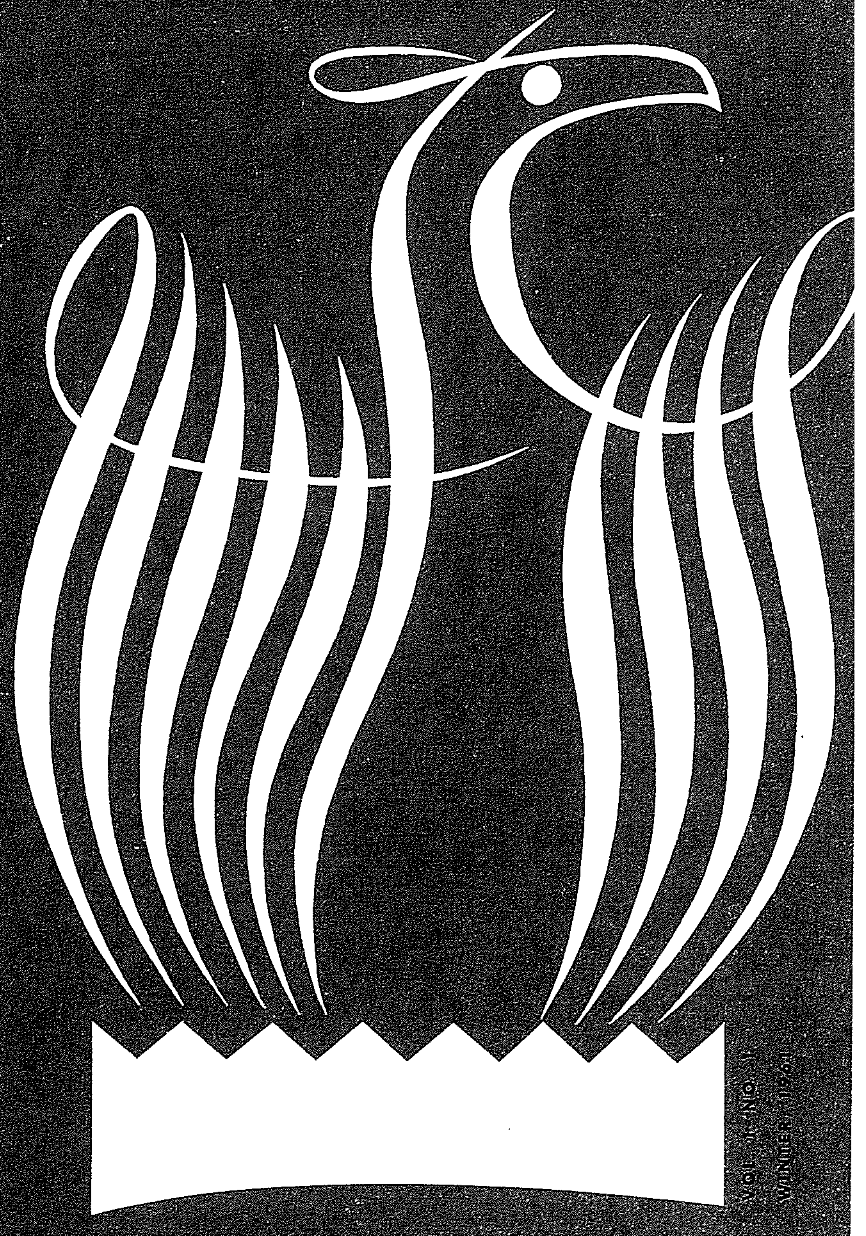

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PHOENIX

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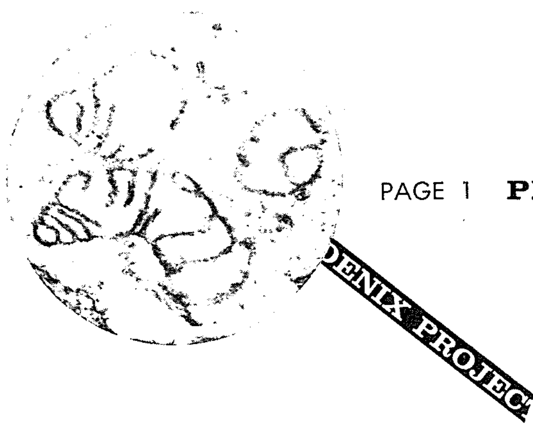
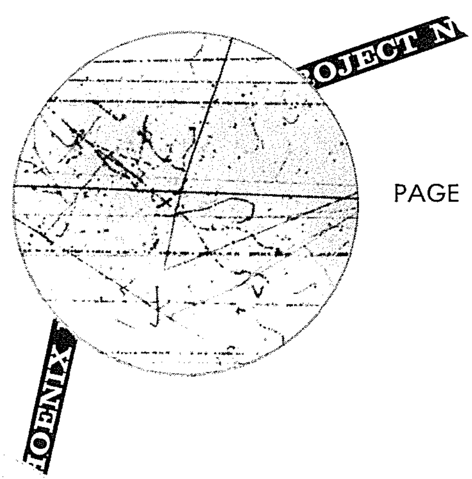
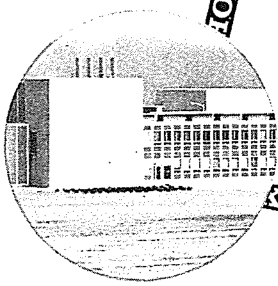
MICHIGAN MEMORIAL PHOENIX PROJECT







The Normal Ultrastructure of Lymph Nodes and Its Early Modification after X-Irradiation

PROFESSOR BURTON BAKER, Department of Anatomy: Project Supervisor
DR. SEONG HAN, Department of Anatomy: Principal Investigator

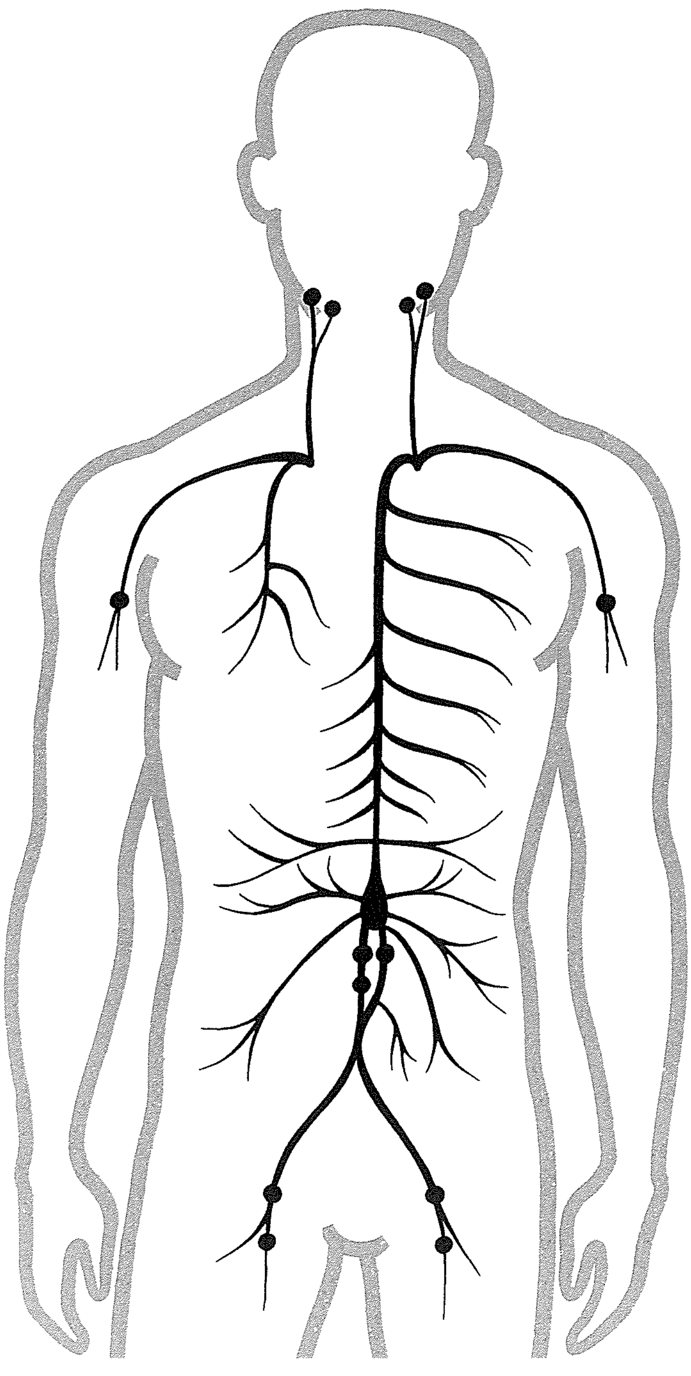
Despite the growing public and scientific interest in the effects of radiation on the human body, little is really known of the initial biological changes that take place after exposure to radiation. The gross changes that occur within cells after large doses and after long periods of time have been detailed in early investigations. We know, for example, that cells can be killed by radiation and that death is accompanied, perhaps even caused, by the disintegration of the nucleus of the cell. When cells are subjected to less than a lethal dose, we know that a variety of changes can occur, some reversible, some irreversible. These are suppression of motility, suppression of reproduction, and the creation of anomalies which may be transmitted to daughter cells.

What has not been known, however, are the biological events that occur in the nucleus and in the cytoplasm of cells immediately after exposure. As fine and precise as earlier studies have been, they have had to jump over the initial events in the chain that leads from radiation exposure to biological change. The primary purpose for going back to study the initial reactions of these minute parts of the human body is to add to our basic knowledge, but ultimately the information gained can aid in the diagnosis and treatment of disease and in the protection of life from the harmful effects of radiation.

Phoenix Project No. 145 is one such basic study. It seeks to discover the earliest structural changes that occur after irradiation in lymphoid cells, which are among the most radiosensitive cells in the body. Though rats were the source of the cells used in the study, the findings are generally applicable to humans because of the uniformity between lymphoid cells in animals. Since lymphoid cells comprise a mechanism essential to the maintenance of the body's general well-being, the results should be especially pertinent to the broader studies of radiation effects.

Within each of us the Amazonian family of lymphoid cells wages a constant struggle for our survival. Mother cells, called primitive reticulum cells because of their primary nature and their net-like shape, give rise to round daughter cells called lymphoblasts, which in turn give rise to second, third, and fourth generations of cells called lymphocytes.

FIG. 1
The main lymphatic channels in the body.



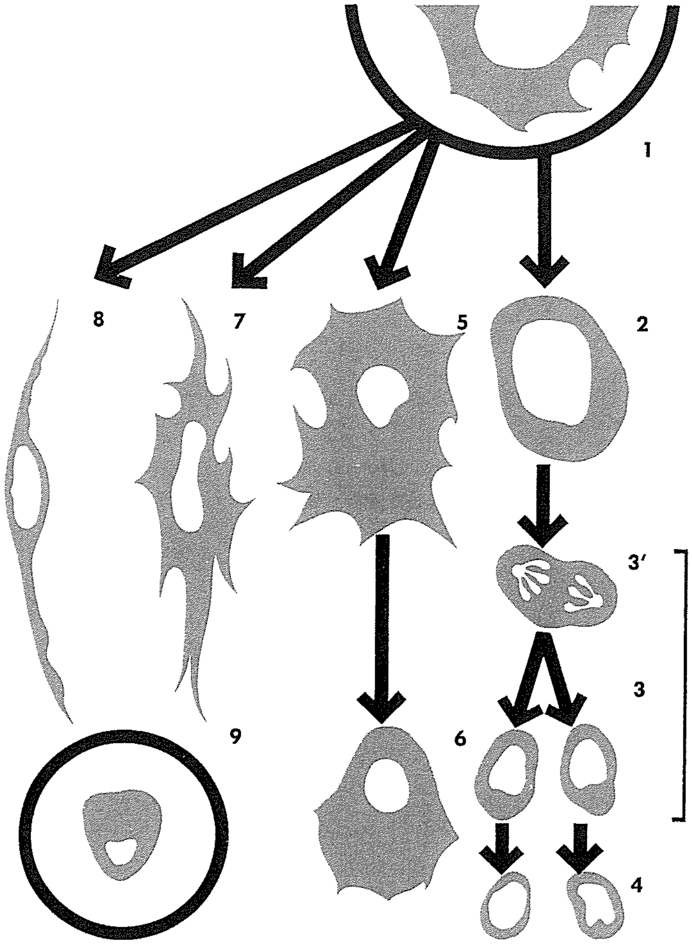
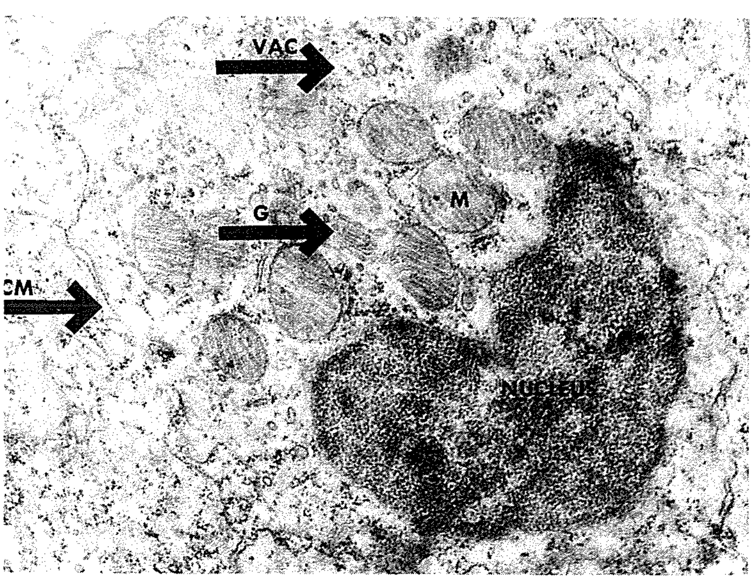


FIG. 2
THE FAMILY OF LYMPHOID CELLS
1. Reticular cell
2. Lymphoblast
3' Lymphocyte in mitosis
3. Maturing lymphocyte
4. Mature lymphocyte
5. Fixed phagocytic cell
6. Motile macrophage
7. Fibroblast
8. Endothelium-like cell
9. Plasma cell (origin uncertain)

FIG. 3
The unirradiated lymphocyte and its components: CM—outer cellular membrane; M—mitochondria; G—Golgi apparatus; VAC—vacuoles.



These lymphocytes, small in size, are produced in large numbers in the spleen, in the thymus, and in the lymph nodes that occur along the lymphatic channels that reach throughout the body (Figure 1). The lymphocytes are discharged into the blood stream where they compose 70 per cent of the white blood corpuscles. The exact lifespan of the lymphocytes is unknown—estimates range from eight hours to fourteen days or more—but during their short life, they are an important protection against general infection. When an infection starts, lymphocytes migrate to the infected area and attack bacteria in a manner that is still not thoroughly understood.

Without the family of lymphoid cells the human body would die, and in actuality many diseases are fatal not because they directly cause mortality but because they destroy lymphoid cells.

The small lymphocytes that fight infections are the end product in the life cycle of a large family of cells (Figure 2). The mother cell not only produces lymphoblasts that produce lymphocytes, but also produces fiber forming reticular cells and phagocytic reticular cells. The fiber forming cells perform as their name states. They produce fiber used for the framework of the particular organ in which they occur. The phagocytic cells perform a cleansing function, engulfing lymphocytes when they have died and digesting them in their turn.

All of this activity takes place within our body, in the minute world of cells that form living tissue. The lymphoid cells comprise a highly-regulated mechanism with a highly selective task in the scheme of life.

As early as 1903, it was demonstrated that radiation destroyed lymphocytes. Since that time, animal experimentation and human experience have shown that the lymph nodes are second to the thymus in being the most radio-sensitive organ in the body. After irradiation the number of lymphocytes in the blood decreases in direct relation to the size of the radiation dose. In case of a nuclear accident, the measurement of lymphocytes can be used as an indication of general radiation damage.

Earlier work on radiation effects on lymphocytes was limited by the efficiency of the tools available. Ordinary light microscopes, so named because they in solution. The granules are minute particles composed of ribonucleic acid, necessary for the cellular production of protein.

Because radiation is energy in motion it can affect these small complex cells and their constituent parts. Alpha, beta, and neutron particles along with gamma rays are all capable of penetrating the human body to different degrees. It makes no difference whether the radiation emanates from man-made sources such as x-ray machines or strontium-90, or from natural sources such as cosmic rays or ground minerals. When radiation moves past a cell, through a cell, or is absorbed by a cell, it can initiate a biological response. It does this mainly by ionizing the compounds of the cell.

To ionize is to change the electrical stability of atoms. Each of the numberless atoms in any cell is made up of its own positively charged nucleus and a surrounding orbit of negatively charged electrons. Together they make an electrically balanced atom. The energy of radiation, however, is greater than the energy which binds the electrons to their atom. Thus, when radiation strikes a cell it is capable of ejecting electrons and making atoms positively charged. By definition such an atom is a positive ion. An ejected electron goes on to attach itself to another atom and upset its balance of charges. This second atom becomes a negative ion. In addition the passage of radiation past an atom can simply excite the electrons and raise them to a state of higher energy without ejecting them.

These electrical changes, the creation of an ion pair and the excitation of electrons, are first steps which ultimately lead to biological changes in the cell.

Between the radiation and the biological consequences are chemical reactions and subsequent metabolic reactions. The chain runs from the penetration of radiation to electrical change to chemical event to metabolic event to an observable effect—the morphological change.

Phoenix Project No. 145, whose supervisor is Dr. Burton Baker of the Department of Anatomy in the Medical School and whose principal investigator is Dr. Seong Han, is concerned with describing the final aspect—the observable effect. A secondary goal is to relate these findings to known and theoretical chemical changes that occur earlier in the chain of events.

The first part of the project was a study of the ultrastructure of the unirradiated or normal lymph cells, a task that had not been accomplished by electron microscopists. This was necessary to ensure that natural structures and events would not be mistaken for those induced by radiation.

The cells chosen for study came from the mesenteric lymph nodes of young adult white rats. Fifty rats comprised the unirradiated group, forty, the irradiated group. The forty rats in the second group were given total body x-irradiation of 400 roentgens for 12 to 13 minutes at the Atomic Energy Commission laboratory on campus. Dissections were made five, ten, fifteen and twenty minutes after irradiation in order to have a chronological record of the changes that occurred.

In both groups the tissues dissected were approximately one cubic millimeter in size. They were immediately fixed, sectioned, and placed on grids suitable for use in an electron microscope (Figure 4). More than 2,000 photographs were taken of normal and irradiated cells.

The whole family of lymph cells was studied and each type, from the primitive reticular cell to the small lymphocyte, was analyzed separately. The emphasis, however, was placed on the small lymphocyte which is the most radiosensitive of an already radiosensitive family.

After irradiation two major changes are noticeable, one in the mitochondria, the other in the nucleus. In a normal cell (Figure 3) the mitochondria are round or ovoid and their cristae are regularly stacked. After irradiation (Figure 5) the mitochondria become irregular in shape. The cristae also lose their neat appearance. They no longer spread evenly across the width of the mitochondria. These changes are movements backwards in the life cycle of lymphoid cells. The condition of mitochondria in a lymphocyte after irradiation is very much like that in the primitive or mother cells. Because mitochondria are necessary for cell metabolism, it is possible that these post-irradiation changes are the beginnings of a deterioration that will hinder the metabolic processes of the lymphocyte and prevent it from adequately fulfilling its functions as an infection fighter within the human body.

The second change occurs in the nucleus, the controlling mechanism of the cell. The normal nucleus (Figure 6) is a very dense object clearly surrounded by an unbroken double-walled envelope. It has a deep indentation at the crown, where interaction between the nucleus and mitochondria appear to take place. It is known from earlier research with light microscopy that the death of lymphocytes after irradiation is accompanied by and probably caused by the disintegration of the nucleus. The nucleus, rather than remaining a separate entity, has broken down and its components spread throughout the cytoplasm. Under the electron microscope, photographs show what may well be the first step that leads to this complete disintegration of the nucleus and the death of the cell. Immediately after irradiation (Figure 7) the double walled envelope appears to be blistered or ruptured.

Both of these morphological changes—in the mitochondria and in the nucleus—need to be correlated to known and theoretical chemical changes within the cell. When this has been done, new facts in the chain of radiation effects on human beings will be known.

Phoenix Project No. 145 will be completed during the coming year. Its full findings should establish the first physical changes that occur within the lymphoid cells after irradiation. These are changes we should understand that we may prevent damage by radiation, that we may use radiation wisely to cure disease, and that we may add to our knowledge of life.

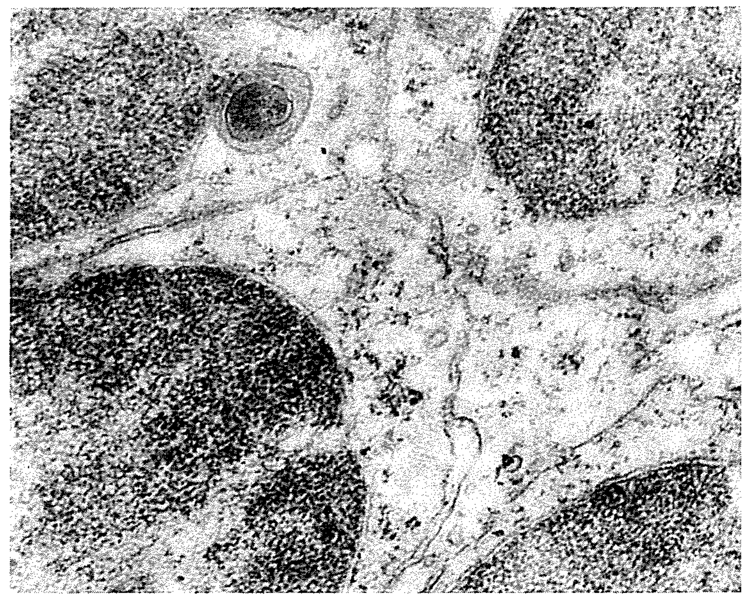


FIG. 6

The unirradiated nucleus: the double-walled envelope marks the boundary between the nucleus and the cytoplasm.

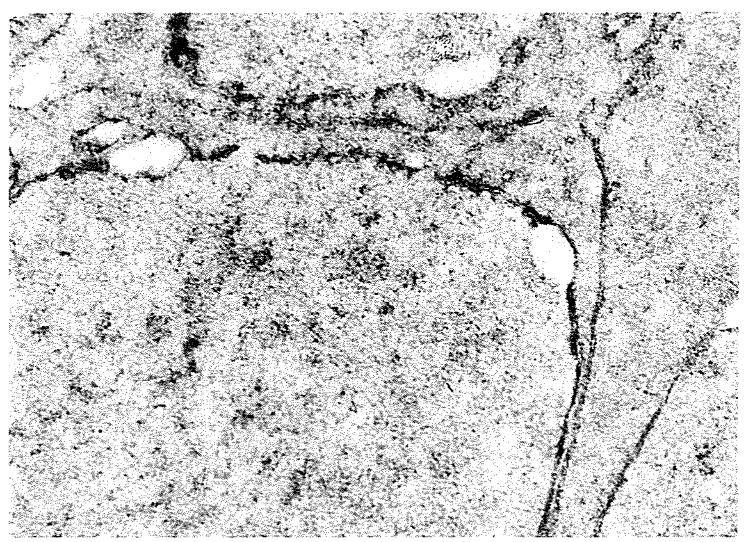


FIG. 7

The irradiated nucleus showing the blisters or ruptures that appear in the nuclear envelope.

A Contingent Injury Fund for Radiation Incidents

PROFESSOR SAMUEL ESTEP, Law School: Principal Investigator

As nuclear technology becomes an increasing part of our daily routine, the question arises as to how the law can provide compensation for radiation injuries which will not be manifest for many years. Early Phoenix-sponsored research on the legal problems of atomic energy has shown that the possible answers to the question require a complex blending of medical research, statistics, public health regulations, and legal procedure.

That the problem needs to be faced is demonstrated by the lapses in the excellent safety record in atomic activities. Incomplete figures published by the Atomic Energy Commission show that between 1945 and 1958, one hundred eighty-nine people were involved in radiation incidents. Of these, thirty-five were hospitalized and three died. Fifty-one others received a radiation exposure beyond the Maximum Permissible Dose recommended by the National Committee on Radiation Protection and Measurement.

There was no typical pattern to these radiation incidents. Those that occurred in 1958 ranged from a uranium-carrying truck that skidded on an icy road, to a defective X-ray machine that continued to operate after it was turned off, to a criticality accident that occurred in waste drums, to a tritium gas release caused by a faulty sealing ring. Perhaps the most bizarre radiation incident occurred in 1956 when a construction worker took home an unguarded cobalt-60 source that was being used to radiograph welds because, he claimed, he wanted the string to which the innocuous looking source was attached. The worker received an estimated whole body gamma dose of 22 to 26 rads, approximately five times the recommended MPD and an estimated dose to two small skin areas of about 3600 rads each.

It is reasonable to expect that each successive year will produce additional incidents. At present, over 6000 installations, ranging from source suppliers to isotope units, are licensed by the AEC to perform some activity that involves radiation. Added to these are the numerous medical and industrial X-ray installations that do not come under federal supervision but which are sources of radiation. The national pattern of nuclear activities is one of growth in a variety of areas embracing more and more people. Every added use increases the chances of radiation incidents due to human, mechanical and natural failures, with possible attendant overexposure.

The effects of overexposure to radiation cover a wide range of diseases and ailments: genetic damage, sterility, embryonic damage, cancers, leukemia, aplastic anemia, cataracts, epilation, skin damage, heightened susceptibility to disease and a shortening of the life span. These effects, however, do not necessarily appear immediately. The current latent period for leukemia is estimated to be at least thirteen years, for cancer thirty-five years and for genetic damage, twenty generations.

A further complication for man and for the law seeking to provide compensation for radiation injuries is that all these effects have causes other than radiation, as well as having unknown causes that group them in the category "occurring due to natural incidence." There is no direct line forward from a radiation exposure to a specific disease and there is no direct line backward from a disease to a specific radiation exposure.

What has happened to the person overexposed to radiation is that he has increased the probability that at some future time he will contract one or several of these diseases—but to what extent the risk is increased is unknown.

The evidence for probabilities is still inconclusive. The difficulty is evident in the long-standing debate between the linear theory and the threshold theory. The threshold theory claims that small doses of radiation produce no harm in humans, that there is a value of radiation that is the upper limit of safe exposure. The linear theory, in contrast, holds that the effects of radiation are directly proportional to the amount of dosage, no matter how small, that as soon as there is radiation, damage begins.

Neither theory has been proven or disproven. Radiological health standards that govern the dose to which a person should be exposed are based on the threshold theory but contain a safety factor of ten to offset the absence of exact knowledge.

How ephemeral the standards are can be seen in the definition of the Maximum Permissible Dose in the National Bureau of Standards *Handbook No. 59*, issued in 1946:—"The dose of radiation that, in the

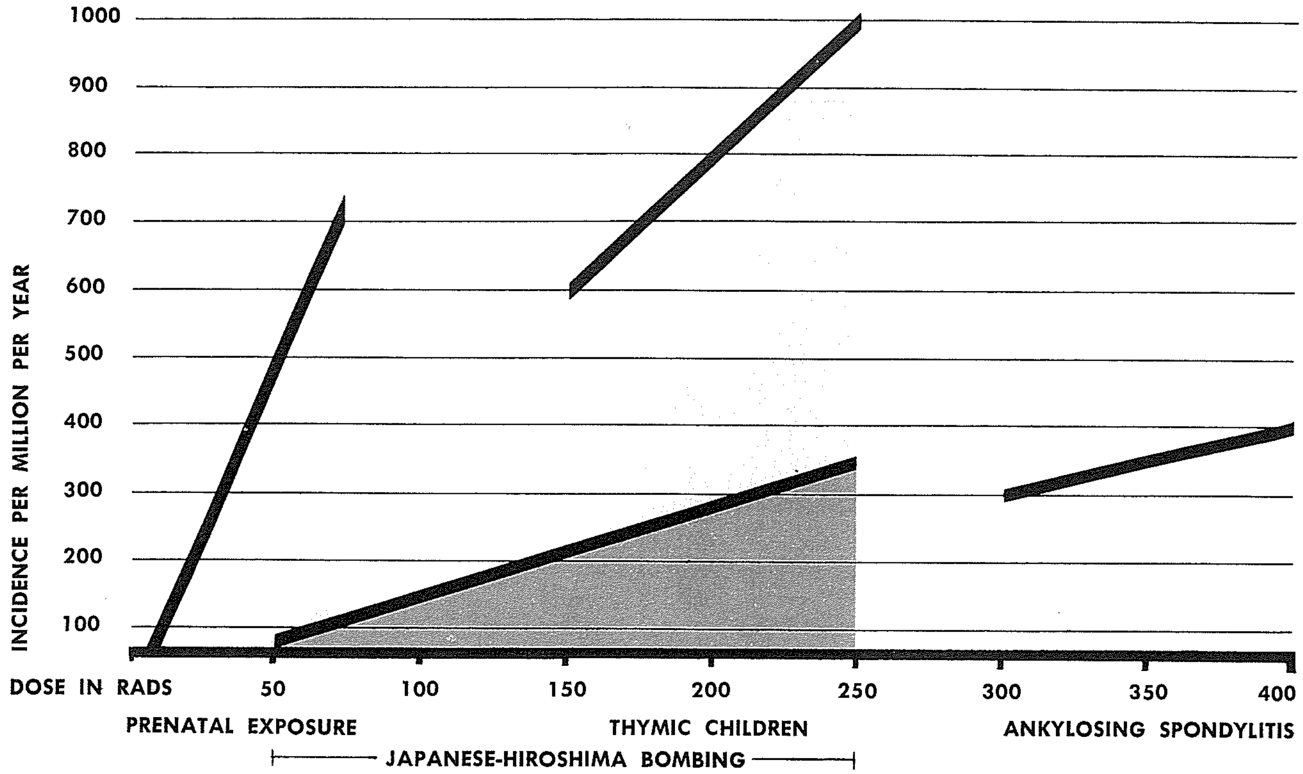


FIG. 1

The incidence of leukemia among four groups exposed to radiation is projected to populations of one million. The base line is the normal incidence of leukemia among an unirradiated population.

light of present knowledge, is not expected to cause appreciable body injury to a person at any time in his lifetime."

By 1959, in the revised handbook, now No. 69, the same basic definition of the MPD held. "In the light of present knowledge occupational exposure for the working life of an individual at the maximum permissible values recommended is not expected to entail appreciable risk to the individual or to present a hazard more severe than those commonly accepted in other industries."

While the definition had not basically changed between 1946 and 1959, the Maximum Permissible Dose had. In 1946 the MPD was 30 rems per year. In 1959 it was 15 rems per year. Prior to 1934, it had been 100 rems per year. For obvious reasons Dr. L. S. Taylor of the National Bureau of Standards has termed the establishment of permissible levels not a matter of science but rather of philosophy, morality, and sheer wisdom.

To make the health standards scientific, extensive research is being carried on in the life sciences. Data are being collected on the effects of radiation on different species of animals. In addition studies are being conducted on relatively small groups of people who have been overexposed to radiation—either through their work in the early days of radium and X-rays, through accidents, through nuclear bombings, or through radiotherapy.

Still the area to which the law must apply itself remains nebulous and will remain so for many years.

The easiest course for the law, and the one that usually has been followed, is to treat the immediate effects of each nuclear incident through existing workmen's compensation laws and to cause the plaintiff to bring suit under existing liability laws for any future effects. This course of action, far from smooth, can often result in little or no recovery.

Compensation laws vary from state to state and in many are still inadequate: radiation induced ailments are not always covered by law; often there are requirements for on-the-job manifestation of the injury, an impossibility for latent effects; statutes of limitation can prevent any recovery for latent diseases; limits on the amount of medical payments can make such awards meaningless; limits on the time over which compensation can be paid may leave a chronically injured person without support.

Furthermore, under both compensation and ordinary tort liability it is difficult to prove cause. The primary problem is one of proof of a direct causal relation between a specific irradiation and a specific disease, e.g., leukemia, in a given person. If cause can be proven our legal system requires an award for damages, no matter how difficult evaluation of the amount may be. Under existing tort laws the general theory used to determine liability for causing personal injury is one of "more probable than not." If a specific cause is more probably the cause of the injury than all other forces or possibilities then liability is imposed on him who put this force in motion if he was negligent or if absolute liability is applied. Reduced to percentages this would mean 50 per cent is the breaking point. If it is "more probable than not," full damages theoretically should be awarded, and if not more probable, then nothing should be awarded.

Since the onset of leukemia is delayed, an attempt to collect compensation at the time of exposure must show that it is "more probable than not" that the person will contract leukemia in the future, an impossible task in the light of present knowledge. Proof of such a claim depends on correlating data on natural incidence rates of leukemia with data on radiation induced incidence rates. Because the natural incidence of leukemia is low (approximately 69 per year per million population), existing legal rules will deny recovery to all plaintiffs claiming for possible future injuries. The point at which it is "more probable than not" that an exposed person will get leukemia can never be reached by projecting future probabilities. If a person's chances are doubled or even quadrupled by radiation exposure, they are still only a small fraction in a million.

Once leukemia has occurred, attempts to prove causal connection for a specific case are difficult because of the non-specific biological origins of leukemia. Any case, even that of a heavily irradiated person, could have arisen from some cause other than radiation. Again statistical correlations must be offered as evidence. The most exact data on the relationship between radiation and leukemia in humans has been drawn from four sources: survivors of atomic bombings, infants exposed to therapeutic radiation of the thymus gland, patients with ankylosing spondylitis treated by radiation, and children with a history of pre-natal exposure to radiation. In each group the incidence of leukemia is directly proportional to the amount of radiation exposure, but the relation of incidence to a specific dose varies from group to group. A typical conclusion based on these studies is that "the estimates that the incidence of leukemia is doubled at doses in the neighborhood of 50 to 100 rads do not seem unreasonable."

As vague as this conclusion is, should it be accepted as fact it would enable a person with leukemia to prove "more probable than not" causation by showing that he had received a doubling, or greater, dose of radiation. If the evidence pointed to exposure less than a doubling dose, e.g., 49 rads, the "more probable than not" principle would deny recovery, even though it is possible that the leukemia still could have been caused by the exposure.

A similar numbers problem imposes a hardship on the defendant. Even though leukemia has occurred and exposure to a doubling dose is proven, the leukemia could still be the result of "natural incidence." Since there is no way of knowing specific cause, the defendant could be paying for a case for which he is not responsible.

Bringing suit at some indefinite time in the future has other built-in hazards. Statutes of limitations more often than not will set a time limit that will prevent most cases from going to court. Should the statutes of limitation be rescinded for such cases, the proof of exposure through records and witnesses may no longer exist. The defendant may no longer be in business or if in business financially incapable of meeting a judgement against him. The defendant in turn also would have the undue financial burden of always being prepared for an unexpected claim.

A possible solution to these problems of compensating latent radiation effects is being investigated under Phoenix Project No. 174—the Establishment of a Contingent Injury Fund.

A simplified example will demonstrate the operation of a contingency fund. Assume that damages for leukemia are arbitrarily set at $20,000, and that a population of one thousand is exposed to a doubling dose by a nuclear accident. The Contingent Injury Fund would need enough money on hand to pay for all the leukemias that occur among the one thousand exposed people during the next twenty years, assuming this is the latent period of leukemia.

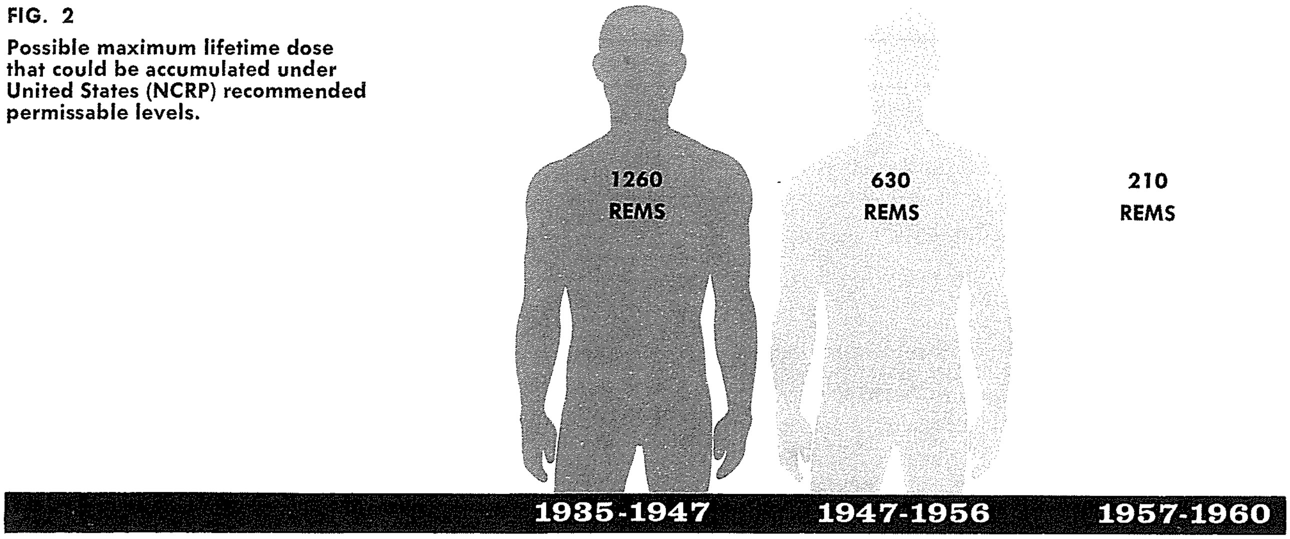
Roughly this would amount only to 3 cases. Current research sets the natural incidence of leukemia per year per thousand people at between .06 and .07 cases. Over twenty years, 1.4 cases would be caused naturally and an additional 1.4 cases would be caused by the doubling dose of radiation.

Under a contingency fund no recovery would be permitted until leukemia actually occurred, and suit for recovery would be brought not against the original defendant but against the Fund. The radiation exposure would already be a matter of record, having been proven at the time of the incident when the defendant was shown to be liable. If leukemia were proven, full recovery of $20,000 would be allowed. Hence, the Fund must expect to pay $60,000 to leukemia victims from this particular exposure. The gross initial cost would be $6 for each of the one thousand persons exposed to the doubling dose.

There are at least four ways of financing the Fund. The responsibility could rest solely with the negligent defendants who would thus become insurers against leukemia in all persons exposed to radiation

FIG. 2

Possible maximum lifetime dose that could be accumulated under United States (NCRP) recommended permissable levels.



for which they are responsible. The other methods make the defendant responsible for the possible number of radiation-induced cases but spread the cost of the possible natural incidence cases. The atomic energy industry as a whole could be taxed to take care of the natural incidence cases, the assumption being that this is a price industry pays for being active in the nuclear area. The cost could also be met by public funds, the risk being considered a burden of society in the development of new technologies. Or the plaintiffs could be required to make a contribution to the Fund that would cover the natural incidence cases, a type of self-insurance.

The statistical refinements of the Fund are complex. They should include a scaling up or down of payments depending on whether the exposure was more or less than a doubling dose. They should take into account life expectancy statistics that would cut the number of leukemias for which the Fund must be prepared to compensate simply because many of the people covered would die natural or accidental deaths before they could contract the disease. It should also take into account the possible rise in the incidence of leukemia over the next twenty years.

The major legal innovations of the Fund are its incorporation of statistical evidence and its flexibility that allows a partial decision at the time of the incident and leaves to the future the final decision on whether or not compensation is necessary.

Though there are many legal cases in which the use of statistics and scientific data has been permitted, the validity of such evidence has either not been argued or the question of validity has been ignored. The principal objection to statistics is that they violate the hearsay rule that permits a witness to testify only to that evidence of which he has direct, personal knowledge. A witness would be unable to testify from personal knowledge as to the accuracy of the statistics generally and the diagnosis of the individual cases specifically. An exception is the rare instance in which the witness has investigated all of the cases cited. Other objections are that statistics are liable to change, are not agreed on by all scientists, and can be used out of context.

The precedence for provisional decisions also exists but like the use of statistics, provisional decisions are not firmly part of our traditional court procedure. The workmen's compensation laws of New York State established in 1953 a "fund for reopened cases" that was meant to relieve the defendant of continued liability while at the same time providing for future compensation for injuries or diseases that arose, returned or worsened after the initial award of compensation. French civil law has a similar practice that allows a judge, at his own discretion, to render a provisional decree that allows reopening of a case for later discovered damages. Neither, however, are sufficient legal precedent to guarantee acceptance of the principle in United States courts in normal personal injury cases.

A further problem raised by the Fund is basic to the inclusion of new technologies into all social systems. Without special training, it is reasonable to expect that a jury, judge, or administrator will not have the expert knowledge necessary to pass judgment on the scientific evidence presented. This, together with the restricting nature of high costs of litigation in our courts could cause trial of any kind to be replaced by some broad medical insurance plan to which the Fund could be readily adapted.

First, however, it must be decided what radiation effects will be compensated. Some, like genetic damage or shortening of the life span, may prove impossible to handle legally. Then, a method of handling statistics must be devised so that current scientific information can be translated into legal conclusions.

NOTE: As this article went to press, the A.E.C. announced that the Maximum Permissible Dose would be five rems per year effective January 1, 1961.

New Methods of Detecting Ionizing Radiation by Its Effect on Phase Changes

PROFESSOR DONALD GLASER: Principal Investigator

(This work, supported by the Department of Physics, the Horace H. Rackham School of Graduate Studies and the Phoenix Project, was awarded the Nobel Prize in Physics for 1960.)

Over the past thirty years, elementary particles, the fundamental structural parts of the material world, have multiplied from the familiar electrons, protons, neutrons and photons to the strange Sigmas, Lambdas, K-mesons, Mu-mesons, Pi-mesons and Neutrinos. We live with these particles every day. They abound in the cosmic radiation that surrounds us and even penetrates us. We manufacture them in huge machines—in accelerators, in reactors, in cyclotrons and bevatrons. They emanate from radioactive materials in the air and in the ground. They are contained within stable matter. Yet, we have never directly observed them nor can we hope to do so. They are too minute.

Throughout the history of experimental nuclear physics, this minuteness has plagued scientists who sought to study the nature of the elementary particles. Their solution has been to study the particles indirectly, to observe not the particle but the effects it creates as it passes through some medium, effects that are on scales much larger than the particles.

Whatever method is chosen to observe the reaction of these particles, it takes advantage of one of their distinguishing properties—their ability to transfer energy to the matter through which they pass. They do this either by exciting the electrons that make up the atomic structure of matter or by ionization, changing the atomic structure by ejecting one of its electrons. The denser the medium through which the particle passes, the more frequently excitation and ionization occur. The more frequently they occur, the more easily the particle is detected.

The familiar Geiger counter measures the effect of elementary particles by recording the electrical current created when particles ionize a gas. The scintillation counter measures the light pulses emitted by the atoms of crystals when particles have passed through them and excited their electrons. Both these instruments are commonly used to detect the presence of radiation—even the presence of a single particle. The scintillation counter can also be used in limited ways to measure the energy of a particle. But when scientists wish to answer more quantitative questions, to measure not only the energy but also the electric charge of a particle, the particle's mass or the forces of interaction between one particle and another, they study reactions that provide a visual history of the particle over a significant length of time.

The two traditional devices that record such a visual history are the Wilson cloud chamber, invented in 1911, and photographic emulsions, first used for particle detection in the same year but not perfected for this purpose until after World War II.

The Wilson cloud chamber contains a supersaturated vapor. As an electrically charged particle flies through the chamber, droplets of liquid condense around the ions the particle creates along its trail. These droplets form linear tracks, called cloud tracks because their formation is similar in principle to that of natural clouds. Though such tracks exist only for a fraction of a second, they can be photographed, and the record of the particle, as represented by droplets, preserved for study.

When photographic emulsions are used, the ionization created by the particle affects the grains of the emulsion. Upon development, the path of the particle appears as closely spaced black specks.

Cloud chambers and photographic emulsions serve two purposes. They can be used as a medium in which particles can be detected and their behavior observed. They can also be used as a target to provide nuclear collisions in order that the tracks from particle interaction can be observed. Both cloud chambers and emulsions enable the scientists to study the nature of the particle path and the rate of energy loss of the particle as it moves through matter. In addition, the cloud chamber enables scientists to bring magnetic and electric fields to act on the particle path and thereby measure the reaction of the particle to known external forces.

Both the cloud chamber and photographic emulsions have built-in drawbacks. Due to the low density of the vapor in the cloud chamber, ionization and collisions are not as frequent as scientists would like them to be. Photographic emulsions, on the other hand, are dense enough to provide frequent ionization and frequent collisions, but their tracks are so

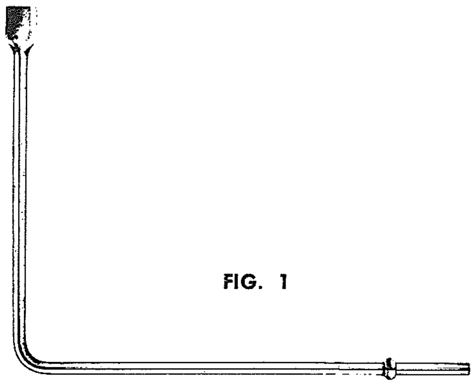


FIG. 1

FIG. 2

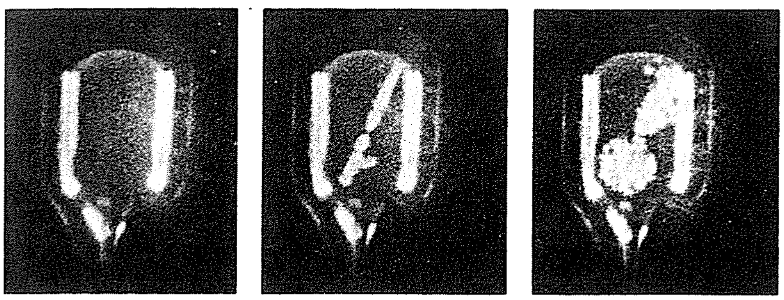
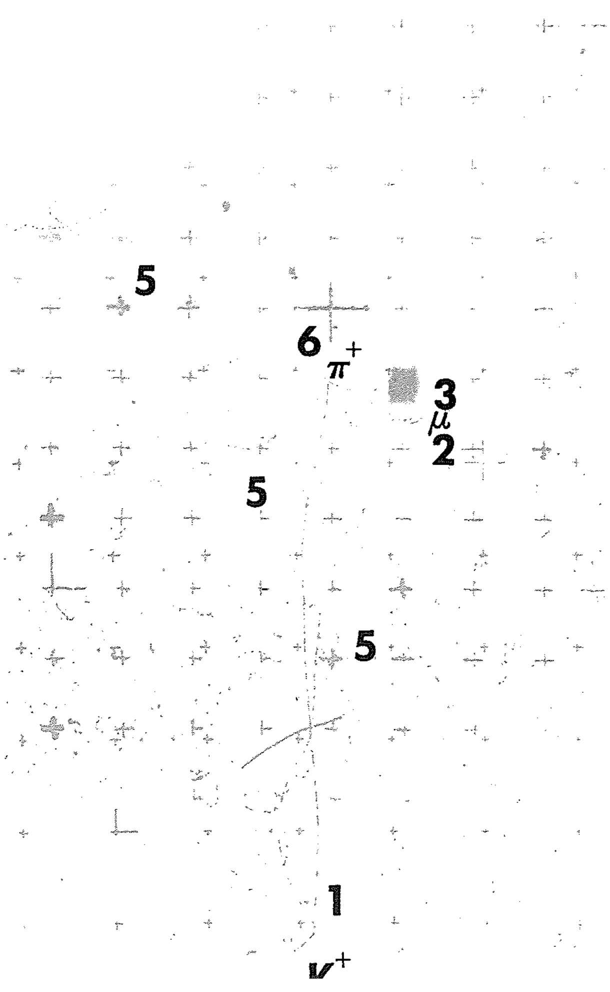


FIG. 3

A typical Bubble Chamber picture.

1. **A K+ enters the chamber and decays into a π^+ and two π°s. The π°s do not make tracks.**
2. **The π^+ stops in the xenon and decays into a μ -meson.**
3. **The μ -meson decays into an electron.**
4. **Each of the two π°s decays into two γ rays, which do not make tracks.**
5. **Three of the γ rays convert into e$\pm$pairs.**
6. **The fourth γ ray strikes an electron, causing it to recoil.**



microscopic in size that they are hard to study and particularly difficult to correlate with a single particle's history. Moreover, large stacks of emulsions must be used in order to get a three dimensional history of one event, a small segment of each event being reproduced on each emulsion plate. Hence a need existed for a new method of detecting the tracks of particles, a method that would be sensitive, that would provide easy three dimensional representations, and that would allow external fields of force to be applied to the particle.

In 1952, Donald Glaser, then an Instructor in Physics at the University, tried a new approach based on a familiar principle. "Physical chemists," Glaser has written in recounting his initial experiments, "have long known that in a clean, smooth-walled vessel a very pure liquid may be heated above its usual boiling point without boiling. When the superheated liquid does begin to boil, it erupts with considerable violence, sometimes smashing the vessel. In chemical processes subject to this hazard bits of broken glass or other "boiling stones" are often thrown in to provide triggering points for boiling and thus prevent superheating. I wondered whether a flying particle might, under suitable conditions, trigger the formation of the microscopic bubbles that start the boiling process. If so, it might make a visible track in a superheated liquid."

Glaser proved the correctness of his theory in two simple experiments. Two lengths of heavy walled pyrex tubing, 3 millimeters wide, were joined by a capillary tube and partially filled with liquid ether. The two ends were immersed in beakers of hot mineral oil, thus raising the pressure in the tubes and at the same time keeping the liquid from boiling. When one tube was removed from the mineral oil, it cooled and the pressure dropped, making the ether a super-heated liquid on the verge of boiling. The ether in the tubes remained in this unstable state for about a minute, after which eruptive boiling started. However, when a radiation source was brought near the super-heated ether, it boiled immediately. The particles emitted by the source acted as "boiling stones."

The next experiment localized the process in order to form a track of bubbles. A large bulb, a halfinch in diameter, was regulated by a hand operated pump. High-speed movies, taken at 3,000 frames per second (Figure 2), clearly showed that a track of bubbles was formed when a particle emitted by a radiation source darted through the superheated ether.

The currently accepted theory as to how the bubbles are formed is that the particle, as it passes into the superheated liquid, exciting and ionizing its atoms, produces heat. Each minute place that is excited or ionized becomes a pocket of heat in which the temperature has risen just enough to push the superheated liquid over its unstable state and into localized boiling. The result is a line of bubbles along the particle's path.

Since these early experiments in 1952, the technology of bubble chambers has become a standard part of high-energy particle research throughout the world. The first chamber large enough for experiments in nuclear physics was put in use with the Cosmotron at Brookhaven National Laboratory in 1955. It was only six by three by two inches and sat, with its pumping apparatus, on a table. Today, bubble chambers can be as large as the mobile two story giant chamber that is used in conjunction with the Bevatron at the University of California at Berkeley. A variety of liquids are now used in the chambers—liquid xenon, propane, liquid hydrogen and liquid nitrogen—depending on the types of collisions and the particles being studied. Xenon, because of its high density, is good for studying gamma rays; hydrogen for studying collisions with "free" protons. As with the cloud chamber, the events occurring within the bubble chamber are photographed (Figure 3) to record the particle's history.

The great advantage that the bubble chamber has over the previous devices for viewing particles is that it provides pictures of a large number of events that were rarely or never seen before. Bubble chamber pictures are exceptionally clear and also easily studied. These gains are a result of the chamber's large size and its adaptability to numerous liquids with different densities and different target nuclei.

Thirty years ago a photograph of a nuclear event was a rare and cherished object. Today, physicists have literally millions of such photographs to study and analyze. Though new methods of particle detection are still being sought, the bubble chamber has proven to be the best device yet invented to record particle events. The problem of interpreting the record, however, still remains. At present, electronic machines are being developed to scan the bubble chamber pictures and analyze significant events within the complex pattern of darting lines and spirals. Aided by such information, the physicist seeks to understand the laws of particle behavior and to discover if there are even more fundamental particles than those with which he now works. The answers may lead to an understanding of the nature of the material world; they will undoubtedly lead to more questions.

GLOSSARY

COBALT–60
a radio-active isotope produced by neutron bombardment of cobalt–59, a naturally occurring element.

FIBROBLAST
a connective tissue cell which forms fibres.

GAMMA
a wave-like form of radiation, similar to x-rays.

MACROPHAGE
a large round phagocytic cell.

RAD
a unit of measurement defined as the absorbed dose of radiation which is accompanied by the liberation of 100 ergs of energy per gram of absorbing material.

RADIO-SENSITIVE
prone to being injured or affected by radiation.

REM
abbreviation of *roentgen equivalent man;* the quantity of radiation which produces the same biological damage in man as that resulting from the absorption of 1 rep (a dose of 97 ergs of any nuclear radiation absorbed).

EDITORIAL COMMENT

In a series of lectures in 1959, C. P. Snow, the English physicist and novelist, divided the intellectual life of western society into two polar groups, one scientific, the other humanistic. Between what he termed "the two cultures," Snow saw a gulf of mutual incomprehension which language and education find difficult to span. In reality, as Snow indicates, there are more like two and twenty "cultures" or two hundred and twenty "cultures," each with a language and a core of adherents all its own.

Each of these "cultures" flourishes on a university campus, for the most part in isolation. There is mutual appreciation for what each is accomplishing, but it is based more on the general belief in education and research than on specific knowledge of the subject matter under study. Often this specific knowledge is hard to come by. The "cultures" have become so specialized, so complicated, that professional literature tends to read like a cross between hieroglyphics on an Egyptian tomb and Aramaic on a Dead Sea Scroll.

The Phoenix Project straddles this communication gulf with one foot firmly planted in Science and with several toes precariously balanced in the Humanities. The Phoenix Project has gained this position through its support of research throughout the University, from the Law School to the Medical School, from the Literary College to the School of Engineering. Because the Phoenix Project is dedicated to the peaceful uses of atomic energy, each project touches, if only tangentially, on nuclear energy. The individual research project, however, belongs not to one "superculture" of nuclear energy but rather to its own discipline, one of the hundred and twenty "cultures." The language in which the project is originally reported makes this apparent. It is always the language of the particular discipline, with here and there a scattered talisman—"neutrons," "U-235," "isotope," "radioactive."

These projects do not coincide with the public image that science is a man landing on the moon, that humanities is a play by Shakespeare and that all else is too complicated, too confusing, too dull, too usless. In reality research is not world-shaking though it may be. It is not revelationary though it may be. It is not practical though it may be. What research is, however, is accurate and cumulative. It seeks to build on all that has gone before and to discover what is unknown. It is more correct to think of the researcher, scientific or humanistic, in an image he probably resents: a man filling the cubby-holes on a wall with bits and pieces of knowledge, occasionally assisted in his labour by intuition and fortune.

The brief reports contained within these pages are about the bits and pieces. One is about research in the Law School, another is about research in the Medical School, and the third is about research in the College of Literature, Science, and the Arts. They are typical of the range of basic research that Phoenix support makes possible. All Phoenix projects are devised and pursued by staff members of the University. They exist only because the faculty who perform them see a purpose in seeking knowledge about or with nuclear energy in a specific, limited area.

Their ultimate justification comes in the information they discover and the developments to which they contribute. Recognition of the value of this work was emphasized this year with the awarding of a Nobel Prize in Physics to Donald Glaser for inventing the Bubble Chamber. Glaser's work was initially supported by a Phoenix grant that appears extremely modest when compared to the current world-wide expenditures on Bubble Chambers.

In writing these reports it has become obvious that they lie in a no-man's land. They are not detailed enough to tell the whole story of any project. They are not general enough to be fraught with excitement. If the rules of narrative were applied to the reports their conclusions would be termed anti-climactic. This, unfortunately for our sense of drama, is an overwhelming reality of research. Nobel prizes are few and far between.

The reports have been written with the cooperation of the research personnel involved. The vocabulary is that of a collegiate dictionary. Where undefined technical words are used, a glossary is provided. It is hoped that in a limited way these reports will serve to connect some of our "cultures,"—that by partially explaining the work in progress, understanding can be created and a desire to initiate new work can be stimulated.

A medieval woodcut of a Phoenix from *Hortus Sanitatus*, published in Strassburg, c. 1497. The book, popular in its day, was a compilation of folk medicine, natural, and "unnatural" history. (Enlarged two times)

—Courtesy Crummer Collection, Medical Library, The University of Michigan

PHOENIX

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