THE NATURAL RADIATION ENVIRONMENT

by Jacob Kastner

The Understanding the Atom Series

Nuclear energy is playing a vital role in the life of every man, woman, and child in the United States today. In the years ahead it will affect increasingly all the peoples of the earth. It is essential that all Americans gain an understanding of this vital force if they are to discharge thoughtfully their responsibilities as citizens and if they are to realize fully the myriad benefits that nuclear energy offers them.

The United States Atomic Energy Commission provides this booklet to help you achieve such understanding.

Edward J. Brunenkant

Edward J. Brunenkant, Director
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Figure 1 *Scientists measuring cosmic rays on Lake Michigan. (See the chapter "Experiments are Fun" that begins on page 30.)*

THE NATURAL RADIATION ENVIRONMENT

By JACOB KASTNER

WE'RE ALL IN THE SAME BOAT

"He's so thick-skinned he doesn't know when he's being insulted." This cliche has applied to living things since their existence on this earth. Plants and animals have always been exposed to radiation that could (and did) damage the living cells by stripping electrons from the cells' atoms (i.e., converting them to ions). However, the damage has generally been so small that most species do not show any injury, and it is only within the last hundred years that man has been aware of this natural radiation.

This little book was written to give you an idea of the kind and amount of this radiation, where it comes from, how we can measure it, and why we think about it, especially since it has been ignored for years.

There's More to the Sun Than Meets the Eye—External Radiation Exposure

The girl in the picture is getting more than she bargained for in the form of external radiation exposure. Besides the *photons** from which she hopes to develop a tan (an effect within the skin), she is being bombarded by even more penetrating radiation, both terrestrial and extraterrestrial in origin. She can't feel it because the intensity is relatively low and most of the energy is distributed inside her body where there are few sensors. Furthermore there are few lasting effects since the body is pretty good at repairing such minor damage, which might be compared with a tiny sunburn.

Figure 2 *Girl getting a tan.*

Most of the terrestrial background radiation consists of gamma rays or X rays, which result mainly from the *radioactive* decay of unstable potassium,† thorium, uranium, and other radioactive elements in the soil. These elements are widely distributed; minerals containing them are found nearly everywhere (see Table I). The X rays are generated, in

*A photon is often called a *quantum* (or little package) of radiations. It behaves more like a cloud of energy than a ball of matter. *X rays* or *gamma rays* are high-energy short-wavelength electromagnetic radiation (photons). Only when such photons are emitted by a nucleus are they called gamma rays. More generally, X rays may result when an excited orbital electron loses its energy or when a charged particle suffers an abrupt change in velocity.

†Natural potassium, like many other elements, is an elemental family, composed of several members, or isotopes, which have different weights. In this case the fat isotope, ^{40}K, is the unstable one and occasionally leaves the family after giving up a piece of itself (a beta particle) to become part of another family, the calcium family.

general, as a result of electrons ejected from the atom's nucleus when it spontaneously disintegrates. X rays such as these led Henri Becquerel to the discovery of natural radioactivity in 1896. He had been investigating a certain salt of uranium that, as he had shown some years earlier, glowed brilliantly under the action of ultraviolet light. A bit of this salt, after exposure to light, was wrapped in black paper and placed near a "sandwich" consisting of a sheet of silver and a photographic plate. Becquerel found, by accident, that the photographic plate was affected, or fogged, regardless of whether the salt had been exposed to light. He concluded that uranium produced penetrating radiation similar to that discovered by Wilhelm Roentgen a year before. Roentgen had generated X rays* artificially by directing electrons into a metallic target. Following Becquerel's discovery it was soon determined that the atoms of such heavy metals as uranium or thorium are constantly, though very slowly, breaking down and giving off *alpha rays*† and *beta rays*‡ as well as X rays in the process.

That part of our external exposure that is extraterrestrial in origin can be traced to the steady rain of charged particles, or *cosmic rays,* moving

Table I
RADIOACTIVE ELEMENTS IN THE LITHOSPHERE

Isotope	Abundance	Half-life (years)	Radiation
Radium-226	2×10^{-12} g/g*	1622	alpha, gamma
Uranium-238	4×10^{-6} g/g	4.5×10^{9}	alpha
Thorium-232	12×10^{-6} g/g	1.4×10^{10}	alpha, gamma
Potassium-40	3×10^{-4} g/g	1.3×10^{9}	beta, gamma
Vanadium-50	0.2 ppm†	5×10^{14}	gamma
Rubidium-87	75 ppm	4.7×10^{10}	beta
Indium-115	0.1 ppm	6×10^{14}	beta
Lanthanum-138	0.01 ppm	1.1×10^{11}	beta, gamma
Samarium-147	1 ppm	1.2×10^{11}	alpha
Lutetium-176	0.01 ppm	2.1×10^{10}	beta, gamma

*Gram per gram of soil.
†Parts per million.

*X rays that are machine generated are properly called "Roentgen rays".

†Alpha rays are streams of alpha particles, which are positively charged and consist of 2 neutrons and 2 protons (really a helium nucleus). It is the least penetrating of the three common forms of radiation (alpha, beta, and gamma). It is so weak that it can be stopped by a sheet of paper, and it is dangerous only when inhaled or ingested.

‡Beta rays are streams of beta particles, which are identical with electrons when negative, and when positive are called *positrons*..

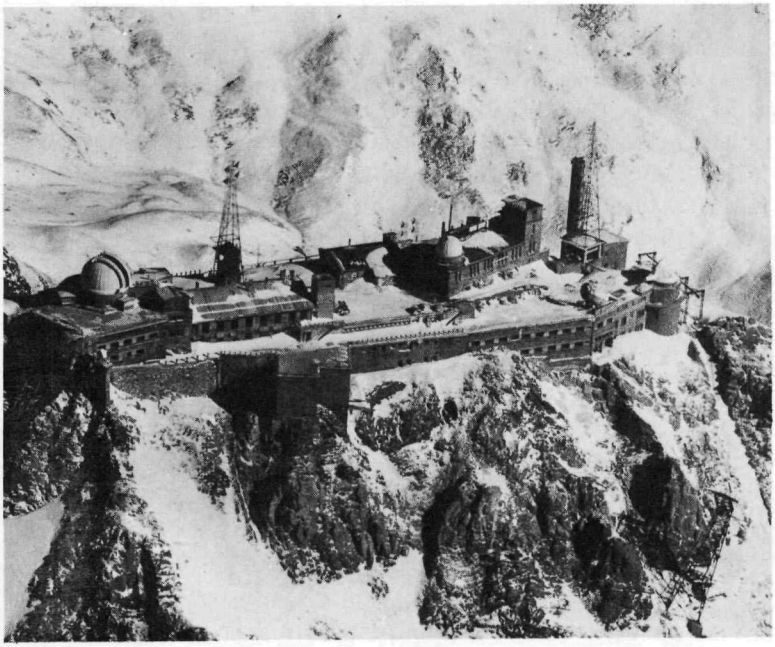
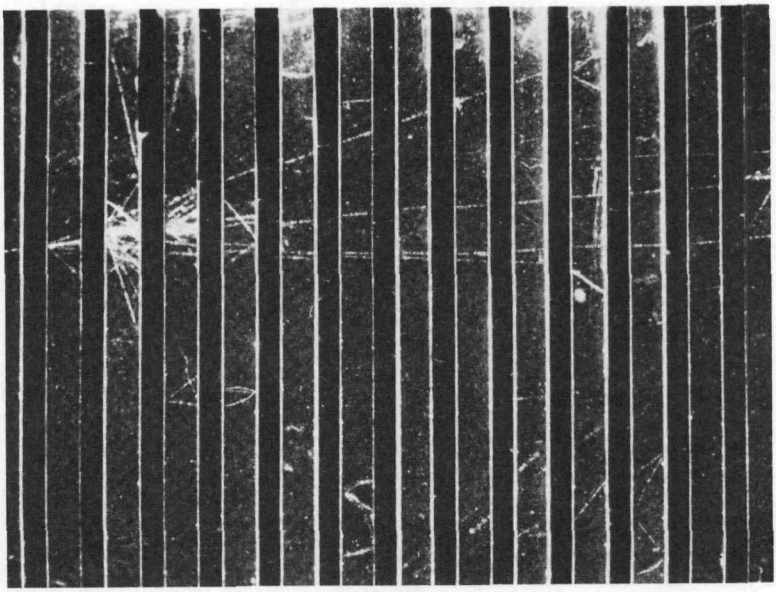


Figure 3 *Cosmic-ray research is often conducted at high altitudes such as at the Pic du Midi Observatory in the High Pyrenees. Below is a cloud chamber photograph of a nuclear disintegration resulting from a cosmic-ray collision.*



at nearly the speed of light and falling upon our planet at all times and from all directions. These particles are just the nuclei of ordinary atoms stripped of their electrons—for the most part the nuclei of hydrogen (protons).

As pointed out by Dr. Bruno Rossi in his excellent book,* the property of cosmic rays that sets them apart from all other kinds of radiation and accounts for the extraordinary role they have played in the development of modern physics is the very large individual energies of their particles. Before their discovery, the highest energy particles known were those emitted in the spontaneous decay of radioactive atoms.

Sometime later, largely in an effort to duplicate the effects of cosmic rays under controlled laboratory conditions, physicists began developing accelerators capable of yielding particles of higher and higher energies. Recently, man-made machines, having achieved energies about 10,000 times greater than natural radioactivity, have overtaken the "average" cosmic-ray energy. The projected National Accelerator Laboratory in Illinois will develop hydrogen nuclei with more than 100,000 times the energy of natural radioactivity.

Now why are physicists interested in such high-energy particles? Because they have the potential of smashing atomic nuclei into bits and the hope is that man, by studying the details of the crash, may understand the forces that hold the nucleus together. In fact, before man-made machines were developed, scientists were looking at the debris resulting from the collision of cosmic rays with oxygen and nitrogen nuclei in our atmosphere (see Figure 3). This flying debris accounts for most of the radiation exposure of our sunbathing young lady. A large part of this radiation consists of photons (or electromagnetic radiation) covering a fairly large spectrum of energies. Another part consists of subatomic particles, called *mesons,* whose mass is intermediate between the electron and the proton. Another small but important component is a flux or wash of high-energy *neutrons.*†

The neutrons are eventually slowed down to the point where their energy is about the same as that of the molecules of our atmosphere, which is the same as saying that they end up at the same temperature. At this slow speed they are easily captured by nitrogen atoms to form

---

**Cosmic Rays,* Bruno Rossi, McGraw-Hill Book Company, Inc., New York, 1964.

†Neutrons are uncharged elementary particles with mass slightly greater than that of a proton. The isolated neutron is unstable and decays with a half-life of about 13 minutes into an electron and a proton. Neutrons sustain the fission chain reaction in a nuclear reactor. Half-life is the time in which half the atoms in a radioactive substance disintegrate to another nuclear form.

radioactive carbon (^{14}C) or super-heavy radioactive hydrogen called tritium (^{3}H). Refer to Table II for a list of radioisotopes produced by cosmic rays. The disintegration of these isotopes contributes little to the external exposure because their radiation is not penetrating. However, in gaseous form these materials can be ingested or inhaled and, like alcohol or tobacco, can be dangerous if taken in large quantities. This brings us to the unavoidable problem of the intake of radioactivity from food and drink.

Table II
SOME RADIOISOTOPES PRODUCED BY COSMIC RAYS

Isotope	Half-life	Concentration (dis/min/cu.m)*
Tritium-3	12.3 yrs.	10^{1}
Beryllium-7	53 days	1
Beryllium-10	2.7×10^{6} yrs.	10^{-7}
Carbon-14	5760 yrs.	4
Sodium-22	2.6 yrs.	10^{-4}
Silicon-32	700 yrs.	2×10^{-6}
Phosphorus-32	14.3 days	2×10^{-2}
Phosphorus-33	25 days	1.5×10^{-2}
Sulfur-35	87 days	1.5×10^{-2}
Chlorine-36	3×10^{5} yrs.	3×10^{-8}

*Disintegrations per minute per cubic meter of air in the lower troposphere.

Brazil Nuts and Cereals—Internal Radiation Exposure

Whenever scientists bring up the question of internal exposure due to natural radioactivity in food they immediately think of Brazil. Not only because of the very high gamma-ray activity of the soil, which exists in certain areas of Brazil as well as India, but also because of the Brazil nut with its extraordinarily high radioactivity—some 14,000 times that of common fruits. Of course the Brazil nut is exceptional and by no means characteristic of nuts in general. Cereals are also relatively high—perhaps as much as 500–600 times that of fruits, which have the lowest concentrations of natural radioactivity. Table III points out pretty clearly that it pays to keep away from rich foods for more than *one* reason.

Actually the table discusses only the alpha activity of foods and this tells nothing about the radioactive potassium contribution. All muscle-

Table III
RELATIVE ALPHA ACTIVITY OF FOODS*

Food Stuff	Relative Activity
Brazil nuts	1400
Cereals	60
Teas	40
Liver and kidney	15
Flours	14
Peanuts and peanut butter	12
Chocolates	8
Biscuits	2
Milks (evaporated)	1–2
Fish	1–2
Cheeses and eggs	0.9
Vegetables	0.7
Meats	0.5
Fruits	0.1

*From *Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy,* September 1–13, 1958, Geneva, Switzerland, United Nations Publication, Volume 23, Experience in Radiological Protection, page 153, W. V. Mayneord.

Figure 4 *Tourists sunning themselves on the black sands of Guarapari in Espirito Santo, Brazil. The external radiation level on these beaches runs as high as 5 millirads per hours. (A rad is the basic unit of absorbed dose of ionizing radiation.) In the picture some of the bathers have rubbed the sand on their bodies.*

building foods contain potassium and we must eat to live. Recent surveys indicate that for most populations the radioactive potassium in our muscles provides 10–20 times the internal exposure of any of the other incorporated radioactive materials, such as radium or carbon-14.

Clear, Cool Water

With the exception of some of my friends who claim it rusts pipes, most people believe that there is virtue in clear, cool water. Well, there is when it isn't well water. In the midwest there is a study in progress that began with the discovery, 20 years ago, of the high natural radioactivity in the drinking water of several municipal water supplies. In 1955 the radioactivity was found to result from radium, which had been leached out of the soil along with the other more common salts, such as calcium, magnesium, etc.

The deep wells of Joliet, Illinois, for example, have 300 times more radium than Chicago's lake water. Eventually analyses were carried out all over the country.

The water from Maine's wells has 3000 times the radium concentration as the Potomac River, which serves our capital. Of course, Maine's radioactivity is mild indeed when compared with that of some springs in Kansas, Colorado, or Jachymov, Czechoslovakia, where the concentration is 10,000 times greater.

Amazingly enough it has been less than 50 years since such quantities of radium in water were considered a great asset. Cures for all sorts of ills were ascribed to radium or thorium. Figure 5 illustrates an advertisement that appeared as recently as World War I and is unequivocal in its support of radium as a medication. Fortunately it only took a generation for most of the medical profession to become aware that radium chemically resembles natural calcium so much that it tends to pile up in our bones and do serious damage. There are still places in the world that tout the advantages of bathing in radioactive mineral springs. Just last year, I ordered mineral water in Milan and noticed that the label on the bottle boasted about the radioactive contents and the merits of such radioactivity in curing a host of gruesome diseases.

Figure 5 *Old advertisement for radium preparations.*

"STANDARD"

RADIUM PREPARATIONS

"Standard" Radium Solution for Drinking

—

Each bottle contains two micrograms radium element in 60 cc. aqua dist.

—

Maximum-equilibrium constant of radium emanation, 5400 mache units.

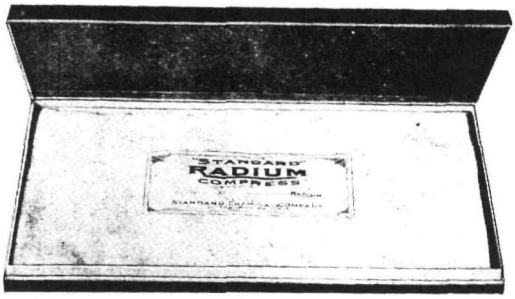
PERMANENT

"Standard" Radium Solution for Intravenous Use.

—

In Ampulles of 2 cc. N. P. S. S. containing 5, 10, 25, 50, or 100 micrograms radium element.

PERMANENT



"Standard" Radium Compress

—

A means of applying radium locally for the relief of pain.

—

A flexible pad of standardized, guaranteed radium element content.

PERMANENT RADIO-ACTIVITY

INDICATIONS

Subacute and Chronic Joint and Muscular Conditions.
High Blood Pressure. Nephritis.
The Simple and Pernicious Anemias.

"The value of radium is unquestionably established in chronic and subacute arthritis of all kinds (luetic and tuberculous excepted) acute, subacute and chronic joint and muscular rheumatism (so called) in gout, sciatica, neuralgia, polyneuritis, lumbago and the lancinating pain of tabes."—Rowntree and Baetjer, Journal A. M. A. Oct. 18, 1913.

For Descriptive and Clinical Literature Address

New York
C. Everett Field, M. D.,
50 E. 41st St.

Boston
Samuel Delano, M. D.,
39 Newbury St.

RADIUM CHEMICAL COMPANY
PITTSBURGH

Chicago
C. W. Hanford, M. D.,
749 1st Nat'l Bank Bldg.

San Francisco
Fred I. Lackenbach
Biologic Depot
908 Butler Bldg

WHO CARES AND WHY?

A quick answer to the question, "who cares?", is that scientists want to know and therefore care, safety engineers need to care, and politicians certainly ought to care about the radiation to which man is exposed. However, before expanding on the motivation of these groups, let me explain briefly that it is important to know the quality and quantity of the radiation to which man is exposed because of the damage that radiation can do to biological matter. Dr. Isaac Asimov has written a booklet in this series entitled "Genetic Effects of Radiation". To explain the potential harm associated with radiation let me call heavily in the following sections upon Dr. Asimov's descriptions of somatic and genetic effects.*

What Harm Can It Do?

In general, radiation damages the complex molecules within a cell, interfering with its chemical machinery to the point, in extreme cases, of killing it. The delicate structure of the genes and chromosomes is particularly vulnerable to the impact of radiation, and broken chromosomes are the main cause of actual cell death. A cell that is not killed outright may be so damaged as to be unable to undergo replication (*mitosis*).

If a cell is of a type that normally doesn't undergo division, the destruction of the mitosis machinery isn't fatal to the whole organism. The fruit fly *Drosophila,* which, as an adult, has very few cell divisions going on among its ordinary body cells, can survive radiation doses a hundred times the fatal dose to man.

In humans, however, there are many tissues whose cells must undergo division throughout life. Hair and fingernails grow as a result of cell division at their roots. The outer layers of skin are steadily lost through abrasion and are replaced through constant cell division in the deeper layers. The same is true of the linings of the mouth, throat, stomach, and intestines. Also, bloodcells are continually breaking up and must be replaced.

How Much Is Too Much?

If radiation kills the mechanism of division in only some of these cells, it is possible that those that remain reasonably intact can divide and eventually replace or do the work of those that can no longer

*Genetic effects of radiation are those that can be transferred from parent to offspring. Somatic effects of radiation affect only the exposed individual.

divide. In that case the symptoms of radiation sickness are relatively mild and eventually disappear.

Where radiation is insufficient to render a cell incapable of division, it may still induce mutations, and it is in this way that radiation may bring on skin cancer, leukemia, and other diseases. It is this type of somatic or bodily cell damage that may arise from natural radiation background although the probability, like the background's intensity, is extremely low.

Mutations can be generated in the sex cells too, of course, and when that happens succeeding generations are affected and not merely the exposed individual. Actually, where sex cells are concerned, the relatively mild effect of mutations is more serious than the drastic one of nondivision. A fertilized ovum that can't divide eventually dies and does no harm; one that can divide but is altered, may give rise to a defective individual.

Experiments in the early 1930s by geneticist Hermann J. Müller and others showed that the number of mutations was directly proportional to the quantity of radiation absorbed. It is generally believed that this proportionality is valid at very low radiation doses; however there is no *threshold** for the genetic effect of radiation.

*A threshold is a radiation dose below which there is no effect. A threshold dose is the minimum radiation dose that produces a detectable biological effect.

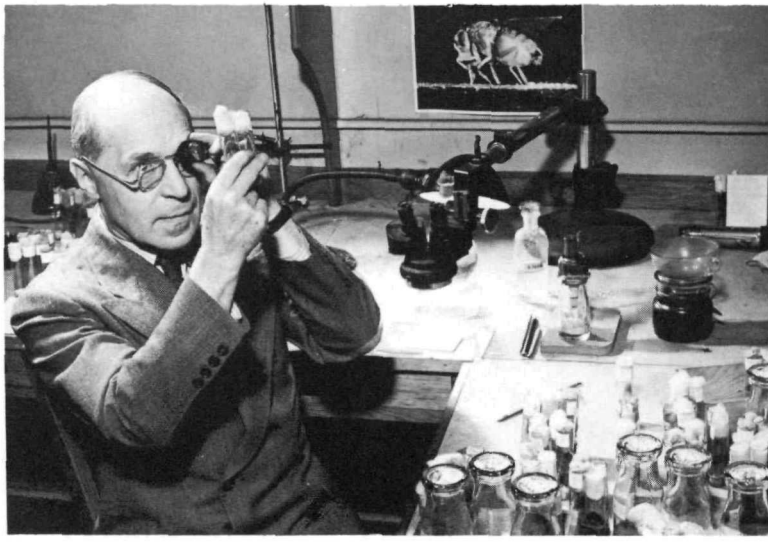


Figure 6 *Geneticist Hermann J. Müller studying* Drosophila *in his laboratory. In 1946 he won a Nobel Prize for showing that radiation can cause mutations.*

This is quite different from the somatic effect. A small radiation dose may affect growing tissue and prevent a small proportion of the cells of those tissues from dividing. The remaining, unaffected cells take up the slack, however, and if the proportion of affected cells is small enough, symptoms never become visible.

In the genetic effect, however, there is no undamaged cell that can take over the work of the affected sex cell once fertilization has taken place. Suppose only one sex cell out of a million is damaged, then it will take part, on the average, in one out of every million fertilizations. And when it is used, it will not matter that there are 999,999 perfectly good sex cells that might have been used—it was the damaged cell that *was* used. That is why there is no threshold in the genetic effect of radiation and why there is no "safe" amount of radiation insofar as genetic effects are concerned. However small the quantity of radiation absorbed, mankind must be prepared to pay the price in a corresponding increase of the genetic load.*

Background radiation accounts for much less than 1% of the spontaneous mutations that take place naturally. The others arise out of chemical effects, random heat (molecular vibration) effects, and so on. If the background radiation is doubled or tripled, only a small portion of the mutation rate that radiation causes will be doubled or tripled. Thus we can have a large factor of increase in the background radiation and yet only increase the total number of mutations by 1 or 2%.†

Quality Is More Important Than Quantity

So far we have discussed the relation of the quantity or intensity of the radiation to the somatic or genetic damage effect. What about the *quality* or *kind* of radiation? It seems fairly obvious that alpha rays, which barely penetrate the skin, can have no genetic effect when kept outside the body. Of course, if these were somehow ingested and deposited within the gonadic tissues‡ they could cause severe damage. Conversely, these same alphas could result in considerable local damage to skin tissue by depositing all their energy in a very thin layer. Thus certain organs and areas of our body are more susceptible than others to radiations of various kinds. Any discussion of potential damage by radiation must deal with its composition as well as with its intensity. In radiobiology, particles can be compared on the basis of their average

*This is the burden of undesirable genes that each species possesses.

†For a more complete discussion, see *The Genetic Effects of Radiation,* a companion booklet in this series.

‡The reproductive tissues.

Linear Energy Transfer (LET). This is just the average amount of energy lost per unit of distance traveled.*

In the light of the relatively small somatic or genetic effect resulting from our natural radiation environment let us now explore the motivation of those key groups that were mentioned earlier.

Scientists want to know both for the sake of knowing and for the applications that the knowledge can provide. Two hundred scientists from all over the world attended the first International Symposium on the Natural Radiation Environment held in 1963 at Rice University in Houston, Texas. A wide variety of sciences were represented, from physics and chemistry to botany and zoology, from meteorology and mining to ecology and medicine.

The organizers of the symposium pointed out that although the effect of ionizing radiation on man "is often a strong motivation for many of the studies described", much of the information relating to the natural radiation environment was derived from investigations that were completely unconcerned with human environmental questions. For example, Dr. Henry Faul, in "Nuclear Clocks", another booklet in this series, points out that it would be difficult to find a reason why anyone would really have to know the answers to such questions as "How old is a rock?", "How old is man?", and "How old is the earth?". Yet they have been asked over and over again since the dawn of human society.

The only reliable method of measuring such very long intervals of time is based on the discovery by Pierre and Marie Curie in 1898 that some atoms are radioactive, i.e., they change spontaneously into other atoms at regular and constant rates. We call the original radioactive atoms *parent* atoms, and the atoms they disintegrate into *daughter* atoms. When we measure the population ratio of parent atoms to daughter atoms and perhaps even great-grandparents to great-grand-daughters for very long-lived elements like uranium† we can get a pretty good estimate of say, the age of the earth which is 4.5 billion years.

Radioactive beryllium-10 with a half-life of 2.7 million years is produced by cosmic rays and has been detected in marine deposits. As recently as June 1967, the Scripps Institution of Oceanography reported an analysis of the ^{10}Be activity in a ferromanganese nodule obtained by dredging from a depth of 4000 meters at 20°N., 160°W. From this activity they were able to deduce that the nodule accumulated (i.e., formed from dissolved chemicals in the seawater) at a rate of 1.8 ± 0.5 mm per million years!

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*For a more complete discussion, see *Your Body and Radiation*, another booklet of this series.

†Most of its atoms live for billions of years.

If we want to determine the age of man, we look for a natural radioactive material that decays at a much faster rate. When we find a piece of wood in some ancient structure, we can measure the amount of carbon in it, determine how much of it is ^{14}C (half of whose atoms decay every 6000 years), and then calculate back to the time when the radioactivity from the ^{14}C was the same as we now find in living wood, where it is continually being replenished from the atmosphere.*

Natural radioactivity has also been very useful as a "tracer" in studying a great variety of geologic, meteorologic, oceanographic, and soil science problems. In December 1967, there was an elegant report by scientists at the Lamont Geological Observatory that described how natural radioactivity can be used to develop quantitative information about our oceans. Let me use their own introduction and abstract to explain what they did and what they found out.

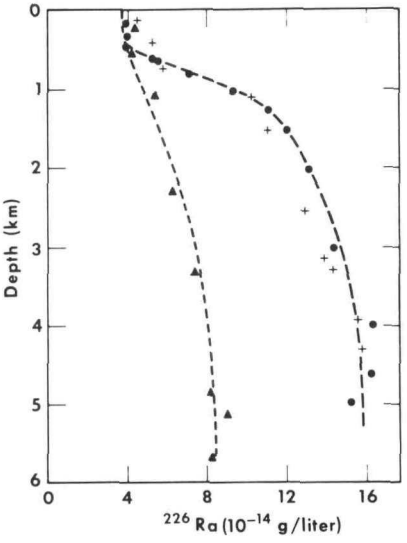
Shipboard analysis of the concentration of radon gas in samples of seawater offers three important types of information: (1) the distribution of radium-226 in the world ocean, (2) the exchange rates of gases across the air–sea interface, and (3) the rates of vertical mixing near the surface and near the bottom of the ocean. Briefly, radon-222 (half-life, 3.85 days) is produced in seawater by the decay of its parent, radium-226 (half-life, 1600 years). Well away from the air–sea and sediment–sea interfaces, the rate of radioactive decay of radon is equal to that of its parent radium.

Thus a measurement of the radon content of such a water sample is a measurement of its radium content. As the radon content of the atmosphere is negligible, compared to that in surface seawater, radon continually escapes from the sea. By analyzing the vertical distribution of radon deficiency in the surface ocean it is possible to determine the rates of both vertical mixing and gas exchange. Water in the pores of deep-sea sediments contains $10^4 - 10^5$ (10,000–100,000) times more radon than the overlying seawater. Hence, radon diffuses from the sediment into the sea. The vertical distribution of excess radon in near-bottom water provides an index of the rate of vertical mixing.

The radium-226 content of surface water in both the Atlantic and Pacific Oceans is uniformly close to about 4×10^{-14} gram per liter. The deep Pacific has a concentration of radium-226 that is four times higher, and the deep Atlantic has a concentration twice as high as that of the surface. These distribution profiles can be explained by the same particle-settling rate for radium-226 from surface to depth for the two oceans and by a threefold longer residence time of water in the deep

*A full account of such time measurements using natural radioactivity is given in *Nuclear Clocks*, another booklet in this series.

Pacific than in the deep Atlantic. Figure 7 shows the kind of information obtained in this experiment.



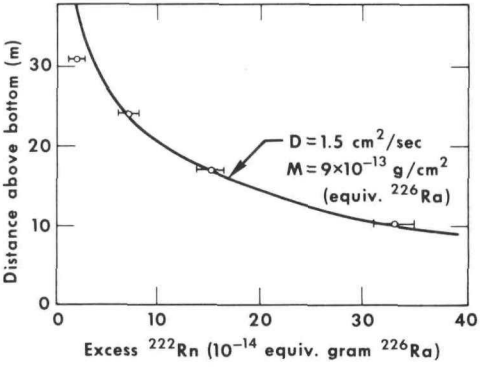


Figure 7 *Vertical distribution of radium-226 in the oceans: ▲ northwestern Atlantic Ocean; • northwestern Pacific Ocean; + east equatorial Pacific Ocean. On the right is excess ^{222}Rn shown as a function of distance above the sea bottom in the south Atlantic; 22°47′S, 32°37′W.*

Biological scientists and medical practitioners alike have used incorporated natural radioisotopes to help them learn about humans and animals in a nondestructive way. As mentioned before, muscle contains a lot of potassium where fat tissue has none. The radioactive potassium isotope ^{40}K emits gamma rays that are so penetrating they can pass through a 250-pound athlete or even a cow. An important medical application is the correlation of muscle-fat ratios in humans with pathological problems. Highly sensitive detectors in rooms with thick iron walls (to cut out the earth's gamma rays) are now available in most of the major biological institutions and hospitals of the world. The meat industry has even carried out some preliminary experiments to establish the feasibility of purchasing cattle on the basis of muscle-fat ratios determined in this way. Maybe we'll see such iron rooms set up in every stockyard!

Scientists will seize upon any source of information to further their knowledge. Thus even man's bad habits are used in this way. It recently has been shown that cigarette smoke contains a naturally occurring radioactive element, polonium-210. Studies have demonstrated that more of this radioelement is found in the lung and other soft tissues of cigarette smokers than those of nonsmokers.

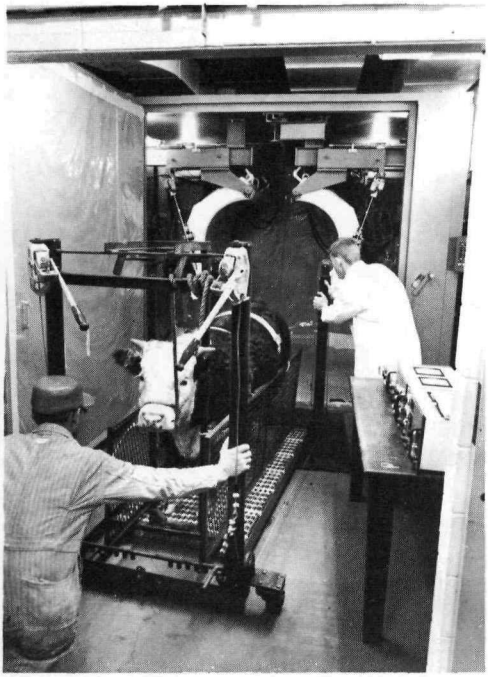
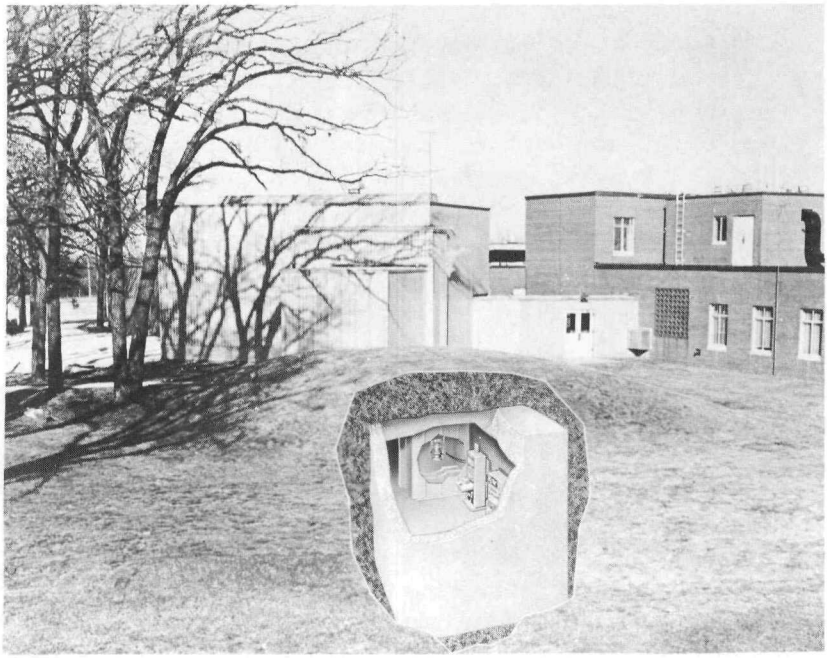


Figure 8 *A University of Illinois project to breed meat animals with a high lean-to-fat ratio has been aided by whole body counters. The tendency to deposit fat seems to be inherited, and breeding stock with low fat content can be selected, using muscle-seeking potassium-40 to show the proportion of muscle in each potential parent. Below is a cutaway of an iron room containing a whole body counter at Argonne National Laboratory.*



Another naturally occurring radioactive isotope, lead-210, which undergoes radioactive decay to become polonium-210, also is present in cigarette smoke. In addition, lead-210 was found in lung tissue and in the bones of cigarette smokers in twice the concentrations normally found in the non-smoking population.

Lead-210 in the smoke is the primary source of the increased concentrations of both these radioelements in body tissues. These higher concentrations, in turn, may increase by 8–30% the internal radiation dose to the bones of cigarette smokers over that received by mankind as a whole. The contribution of this increased dose is worthy of consideration in attempts to evaluate the effects of low-level radiation doses on mankind.

Still another technique arises from the tiny amounts of radium remaining in the bones of humans who have been exposed to radium poisoning. Examples of such people are the men and women in the U. S. and Switzerland who used to paint watch dials with radium paint. The bones of these victims are an important source of information on bone growth and metabolism as well as on the effect of radium on human bone. The time taken to build up bone cells and to resorb them is an important clue to the mechanism of bone growth. It is possible to estimate this turnover time of human bone by measuring the fraction of a bone section still labeled with radium even as much as 40 years after it was acquired (see Figure 10).

Figure 9 *A group of radium-dial painters at work in a watch factory in 1922. Almost all these employees have been identified and the living ones participated in a study at Argonne National Laboratory to determine the extent of radium accumulation in their bodies.*

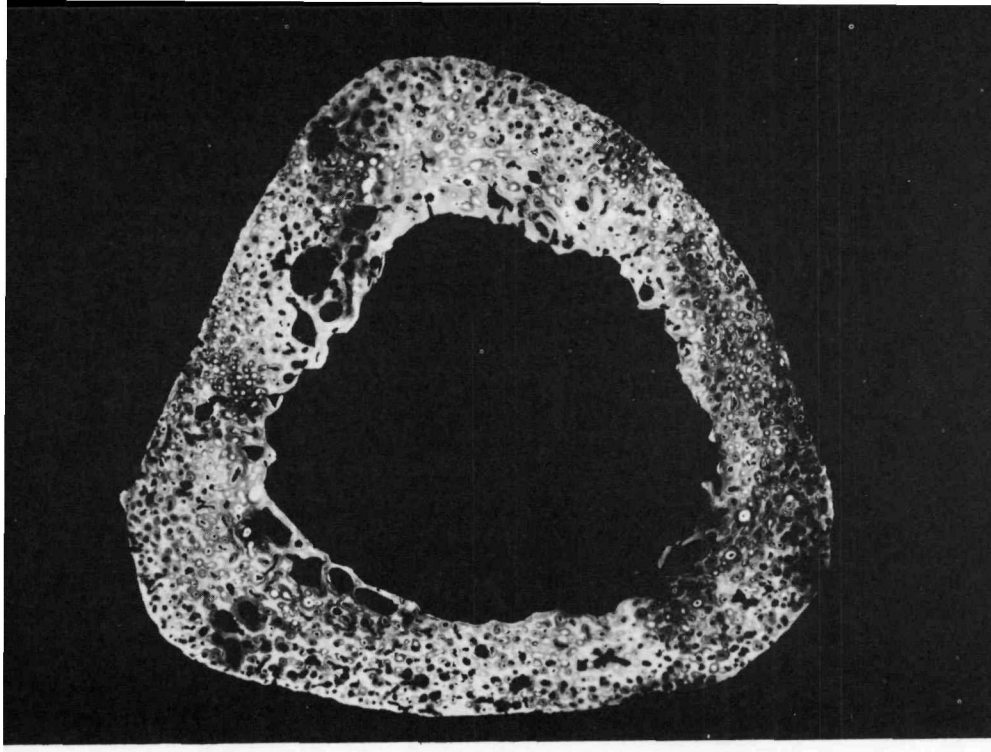


Figure 10 *A section of bone from the body of a former radium watch-dial painter, who, in order to maintain a fine brush tip, was in the habit of touching the tip with his tongue. The photograph on the left shows darkened areas of damaged bone. On the right*

Safety engineers need to know the kinds and quantities of natural radiation to which man is exposed. To quote Professor Merril Eisenbud, Administrator, Environmental Protection Administration, The City of New York: "With the advent of man's utilization of nuclear energy, studies of the natural levels of radioactivity have become necessary to understand fully the environmental influences of the radioactivity produced by the atomic energy industry. Only by having knowledge of the amounts of natural radioactivity and the manner in which it varies can intelligent interpretations of monitoring data be ensured, whether in the vicinity of a reactor site, the oceans, the atmosphere, or in the tissues of man."*

Before a reactor-powered electricity generating facility is constructed on a site, public relations people usually call in radiation safety officers (called health physicists in the United States) to make measurements of the natural background. This then provides a threshold or base against which to monitor future plant operations. Thus, if the effluent cooling

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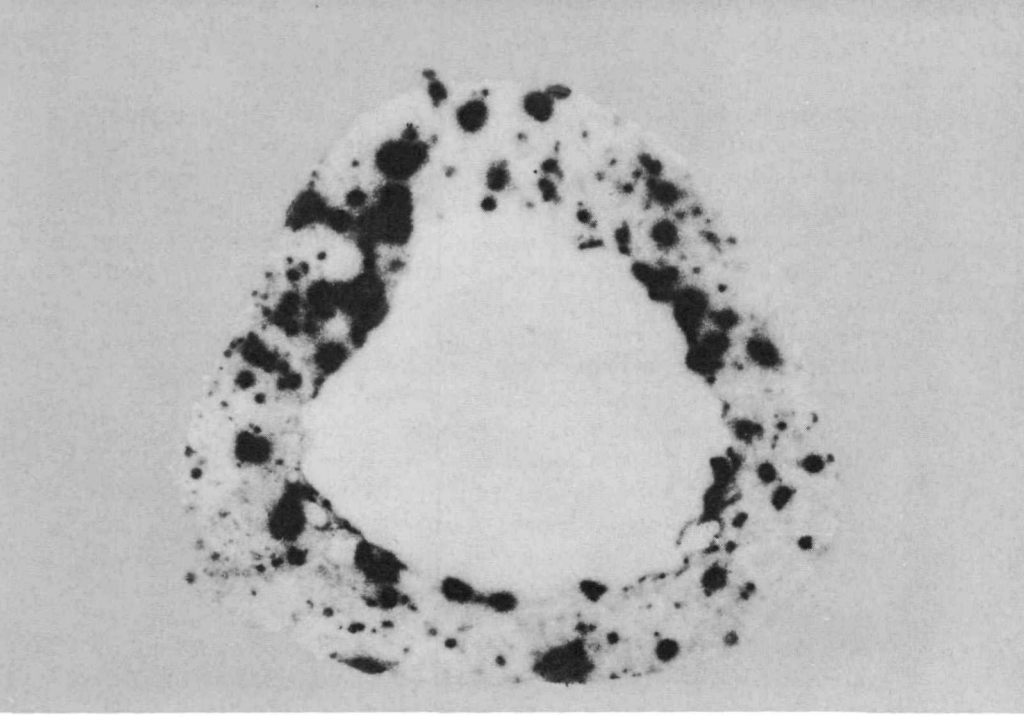
**Environmental Radioactivity*, Merril Eisenbud, McGraw-Hill Book Company, Inc., New York, 1963, p. 135.



is an autoradiograph, in which the bone "took its own picture" by being held against film, showing areas exposed by the radium alpha particles. Note that the areas of high alpha activity correspond to the areas of maximum damage in the photograph (left).

water exhibits more beta-ray activity than was present in the intake from the local stream, measures should be taken to improve the purification technique. Of course, the local public health people might insist that the water coming out of the plant be cleaner than when it went in. This, for example, is the situation in a German Westphalian Nuclear Research Establishment near the Rhine. The Rhine is so filthy that fish have trouble living in it. A white whale recently lost its way from the North Sea and was sighted upstream in the Rhine River. Even though it was an air breather, the poor thing was in terrible straits staying alive by keeping its blowhole free of the muck from the river.

Nevertheless, the effluent from Westphalian reactors is amazingly free of contaminants. Such stringent and excessive restrictions on the part of the public authorities are based on the political facts of life; namely, a psychological fear of radioactivity that derives from the drastic bombing damage suffered by the Rhine cities, despite the fact that the bombing was non-nuclear.

Another factor that is of great concern to reactor safety people is the possibility of discharging radioactivity into the air. The general method used in sampling the atmosphere is to draw air through a filter at a

known rate for a known interval. The filter radioactivity is then measured and the activity per unit volume determined. The joker in this simple technique is that there are days when the air is heavy with the daughters of radium: radon, radium A, B, and C. The concentration of these natural and short-lived radioisotopes can be as much as 500 times the maximum permissible concentration for exposure of the general population to long-lived plutonium-239, which may have escaped from the reactor. It behooves the radiation protection officer to be aware of natural contaminants, their properties, and potential quantities so that the proper detective work will be carried out on the monitoring data.

On the other hand, radon's presence in the air can serve to present the meteorologist with a built-in tracer for determining atmospheric conditions within a few hundred feet of the ground. After all, the best method of estimating the exposure to people from airborne radioactivity is through a knowledge of basic meteorological data. For example, the existence of cool and warm layers was determined by a straightforward but ingenious and well-planned experiment involving the natural radioactive tracer, radon gas. Copper piping was led up to different levels of a 130-foot Ranger tower and air sucked in at each level. The radon in the samples of air was measured precisely even though the quantities were minute. From the different concentrations at the various levels and at separate times of day and night it was possible to make definitive conclusions about the stratification of the air as a function of temperature, season, and so on.

That **politicians ought to know** some truths about whatever they decide to talk about goes against a popular misconception. The facts are, however, that most successful professional and part-time participants in political affairs are shrewd, intelligent people who take care to be accurately informed. Thus it was no accident that when the father of "carbon dating", Dr. Willard F. Libby, was an AEC commissioner, he encouraged the AEC to sponsor a great deal of effort by the nation's scientists to learn quantitatively the composition of our natural radiation environment. I have often said that my own function is to provide precise numbers for the politicians to fight with. This was particularly true in the period before the Nuclear Test Ban Treaty.

It was as recent as 1956 that a great debate occurred on the dangers of radioactive bomb fallout between the scientists and part-time politicians, Dr. Linus Pauling and Dr. Ralph Lapp on the one hand, and Dr. Edward Teller and Dr. Willard Libby on the other. This culminated in the pre-campaign debate by Governor Stevenson and President Eisenhower on the cessation of H-bomb testing. The politicians of the day couldn't afford to stay uninformed. Studies were initiated by the

Joint Committee on Atomic Energy on the "Nature of Radioactive Fallout and Its Effects on Man".* Hearings, which were open to the public, were held in May 1957 by a Special Subcommittee on Radiation under the chairmanship of Representative Chet Holifield of California. In all, some 50 expert witnesses from the major scientific areas involved either appeared personally or submitted statements. The records constitute over 2000 pages of fine print. Permeating these many thousands of words and ideas is the concept that whatever man does to himself in the way of radiation exposure must always be considered in the framework of nature's insults.

For example, Dr. A. R. Gopal-Ayengar, head of the Biology Division of the Indian Cancer Research Center at Bombay, submitted a statement on the "Possible Areas with Sufficiently Different Background-Radiation Levels to Permit Detection of Differences in Mutation Rates of Genes". He pointed out that in certain parts of Southwest India (Travancore-Cochin State) the coastline is characterized by patches of radioactive sand with the highest thorium content in the world—as much as 33%. Thus conditions are particularly favorable for studies of radiation-induced mutations. The gamma-ray backgrounds are often such that the native population receives more exposure than our U. S. governmental agencies will allow a worker whose job necessitates handling radioactivity.

Similar conditions exist in the State of Minas Gerais near Rio de Janeiro in Brazil. In 1964 a genetic cell study of the population of the village of Guarapari (population 6000) was started by the Institute of Biophysics, University of Brazil, and the Institute of Environmental Medicine, New York University. Radiation dosimeters were given to selected individuals. The dose rate these individuals received in moving through the variable gamma-ray field over a long period of time was thus accumulated. To induce these people to wear the packets continuously, they were disguised as religious medallions and distributed by the principal scientists, Jesuit Fathers Thomas L. Cullen and the late Francisco X. Roser. The average gamma-ray dose rate for the exposed population has been established as about six times the world average with some exposures as high as 30 times this amount.

The use of natural radioactivity as a baseline for hazard analysis was clearly demonstrated at the hearings in the statements concerning the amount of radioactive cesium-137, from bomb fallout, present in man and his food. These statements were always made in terms of how

*See Suggested References on page 44.

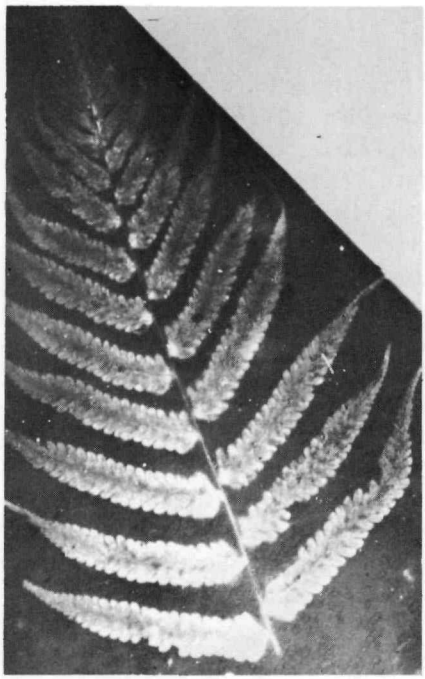


Figure 11 *Above Father Thomas L. Cullen, S. J., and Dr. Merril Eisenbud examine a termite hill on the Morro do Ferro, a radioactive mountain in the State of Minas Gerais, Brazil. Rodents living in burrows such as can be seen at the base of the hill receive very high lung doses because of the radioactivity of the burrow atmosphere. On the left is an autoradiograph of a fern collected at a point on the mountain where the external radiation dose is about 3 millirads per hour. The natural radioactivity is due mainly to radium-228.*

much potassium-40 is already present, generally referred to as the $^{137}Cs/^{40}K$ ratio.

The politicians also learned that there may be disadvantages in having a brick and concrete or granite home. Dr. William Spiers of Leeds, England, one of the world's foremost experts on natural radiation, pointed out that the intensity of gamma rays from radium in the brick may provide as much as three times the exposure one might expect in a wooden house.

HOW CAN YOU TELL?

This question is particularly valid for the presence of the natural environmental radiation because it's so elusive. This is the same question you would ask a fine primitive hunter if he told you that a leopard had just passed down the trail and that the leopard had injured its right front paw. The leopard's path, like radiation, can only be detected by its spoor. Spoor (or spur) derives from the Saxon word for track. German scientists still refer in this way to the tracks developed in photographic film after the passage of nuclear radiation. When the numbers of rays are as small as is generally the case in nature, the trail becomes very difficult. One must either wait a long time and build up evidence or set a very sensitive trap that will be triggered to give an alarm. In the following section we will outline some of the techniques that can and have been used to count and test the strength of the elusive radiations with which we are continually insulted. We will also describe some ingenious experiments.

Radiation Doesn't Tickle* But Fortunately Is Quite Photogenic

Very shortly after Becquerel's discovery of radioactivity using a chunk of uranium and a photographic plate, Roentgen used the gelatin emulsion to photograph X rays and thereby make "radiograms". (Incidentally, in correct scientific language a photograph is the camera and the resultant picture is a photogram. Compare with telegraph and telegram, spectrograph and spectrogram.)

The history of radiation detectors has followed the history of physics. From the first discovery, studies of radiation effects on matter continued to be carried out. Exclusively solid matter, crystalline particularly, was studied in the early laboratories. It was soon learned that the passage of radiation through certain chemicals, like zinc sulfide (ZnS), would give rise to flashes of light that could be seen with the naked eye. Lord Ernest Rutherford† and his students spent hours in a darkroom looking into a small eyepiece coated with ZnS, which he

*At least not at these levels. In his booklet *Your Body and Radiation*, Dr. Norman Frigerio points out that some people can detect an intense source by a tingling of the skin.

†Lord Rutherford received the Nobel Prize in Chemistry in 1908 for formulating the theories of radioactive disintegration of elements, the nature of alpha particles, and the atom's nucleus.

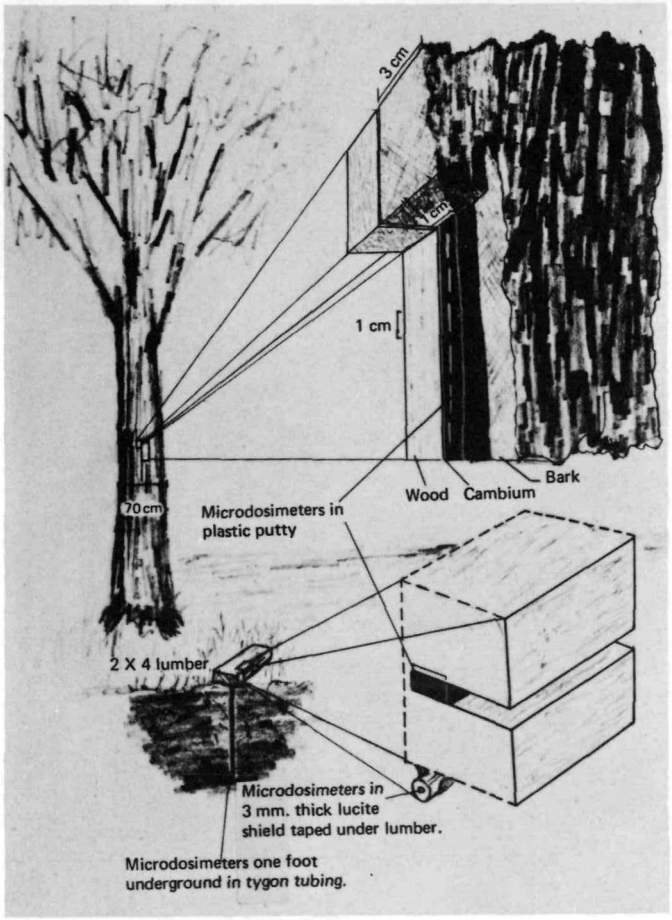
called a spinthariscope. They observed and counted the individual flashes of light or scintillations resulting from the impact of alpha rays. Today we are able to amplify these light flashes electronically and record both their number and intensity. In this way we can measure the rate of exposure fairly easily, whereas the emulsion can only sum or integrate the radiation over a period of time.

Other solids, crystals, and glasses are able to store radiation energy. When interrogated, by heating or ultraviolet irradiation, these solids give off visible light that is proportional to the stored radiation energy. Of course, many different kinds of exposure can give rise to the same total light. One therefore needs auxiliary evidence before being sure it was, to use our analogy, a leopard and not a tiger that passed down the trail.

An application that is most suitable for such solid, luminescent dosimeters is the evaluation of the natural radiation environment as related to plant growth; this is essentially a study in ecology. The advantage of such solids is their relative resistance to weathering, small temperature changes, humidity, etc. Such a study was carried out recently wherein a number of dosimeters were imbedded in the bark of oak trees (Figures 12 and 13) and every 2 weeks, a couple would be read to establish whether the background rate had changed. Figure 14 clearly demonstrates the marked break in rate during the onset of foliation in the spring. To distinguish between the general gamma-ray environment and beta-ray emission from radioactivity in the tree sap, thick aluminum capsules were later employed to filter out the beta rays.

As laboratory techniques became more sophisticated and physicists learned how to create vacuums, they began to study gases. Some of these experiments were the basis for the discovery of X rays. The *ionization* (or the splitting into charged fragments) produced in a gas is one of the most common and sensitive indicators of the passage of radiation.

A typical device for the detection of radiation is shown diagrammatically in Figure 15. Radiation, in the form of charged particles, strikes the ionizable gas in the little chamber (formed by the outer shield) and causes ions to be formed. If the voltage is high enough the ions will be attracted to the shield or to the collecting electrode, depending on their charge, before they can recombine. A little current (or *pulse*) will flow for each radiation particle that interacts in this way, and these pulses will be measured (or counted) on the meter. If the voltage is increased, more ionization occurs when the initial ions collide on the way to the electrodes. This is called gas amplification, and the pulses are much larger although still proportional to the ionization energy delivered by



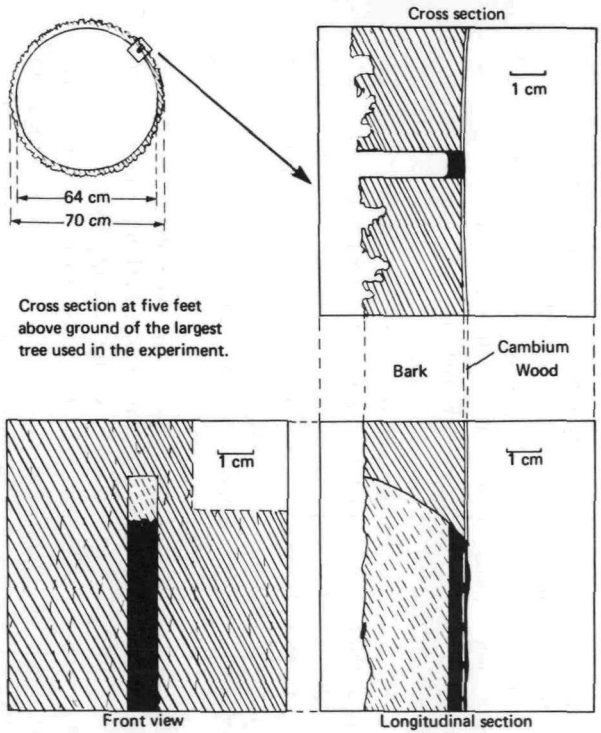


Figure 12 *On the left is a diagram illustrating the positioning of the microdosimeters in oak trees. Above is a cross section (left) of one of the trees and three views of the slit containing the microdosimeters.*

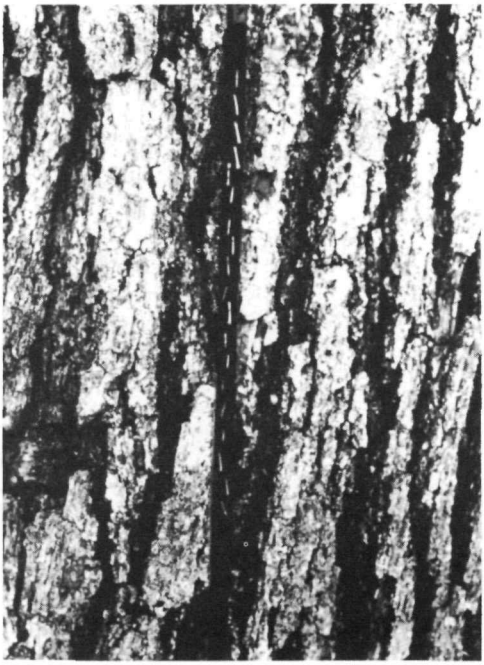


Figure 13 *Lithium fluoride dosimeters imbedded in the bark of an oak tree.*

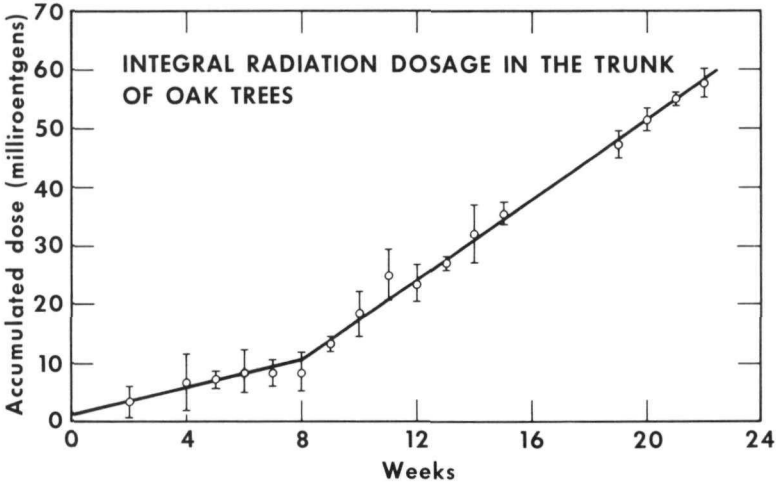


Figure 14 *Accumulated gamma exposure dose as a function of time.*

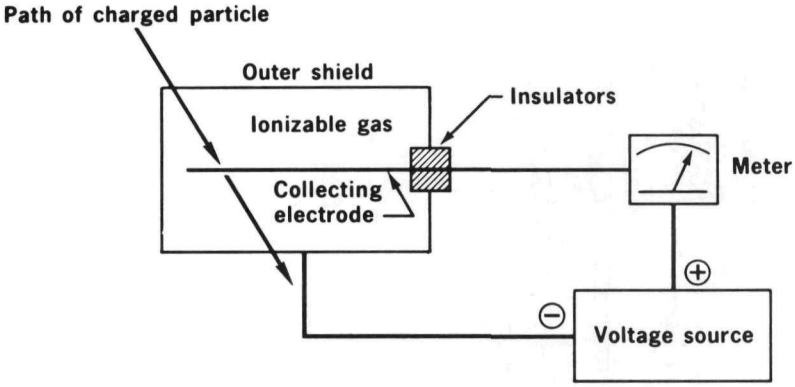


Figure 15 *A typical gas ionization chamber.*

the radiation particle. This detector is called a *proportional counter* and easily measures small ionizations.

If the voltage is increased even further, the pulses become very large and alike in size. The detector is now the familiar Geiger-Müller counter, which, although very sensitive indeed, tells us little about the kind (or energy) of radiation that has been encountered.

A liquid detector that grew out of the contemplation of a glass of beer led to a Nobel Prize in physics in 1960. Donald A. Glaser, an American physicist, pointed out in 1952 that bubbles will form along the track of a charged particle that has passed through a superheated liquid. The liquid, generally hydrogen, is under compression at a temperature just below its boiling point. If the compression is relaxed, boiling starts and bubbles grow on ion clusters present in the liquid. The high density of the liquid makes it far superior to the old-fashioned cloud chambers that exhibited jet-like vapor trails for lethargic particles, but were inefficient when it came to tracking the kangaroo-like trail of super-energetic radiation. Figure 16 is a photograph of tracks in a bubble chamber, which tell the story of a major collision.

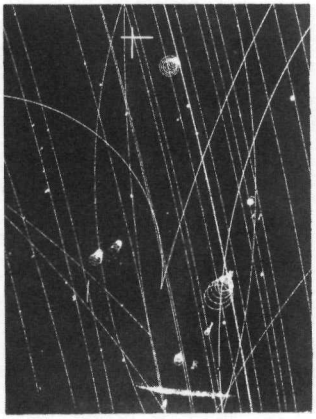


Figure 16 *Photograph of tracks in a bubble chamber.*

Contrast the size of the tiny solid detectors in Figure 17 with Argonne's

12-foot bubble chamber in Figure 18. The world's largest, the chamber will contain 25,000 liters of liquid hydrogen and weigh 3500 tons.

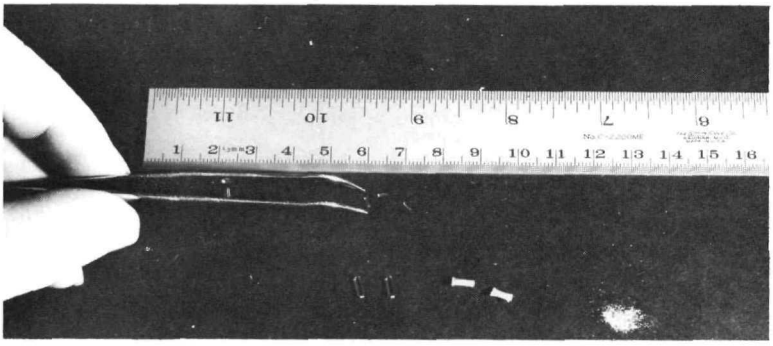


Figure 17 *Solid state detectors.*

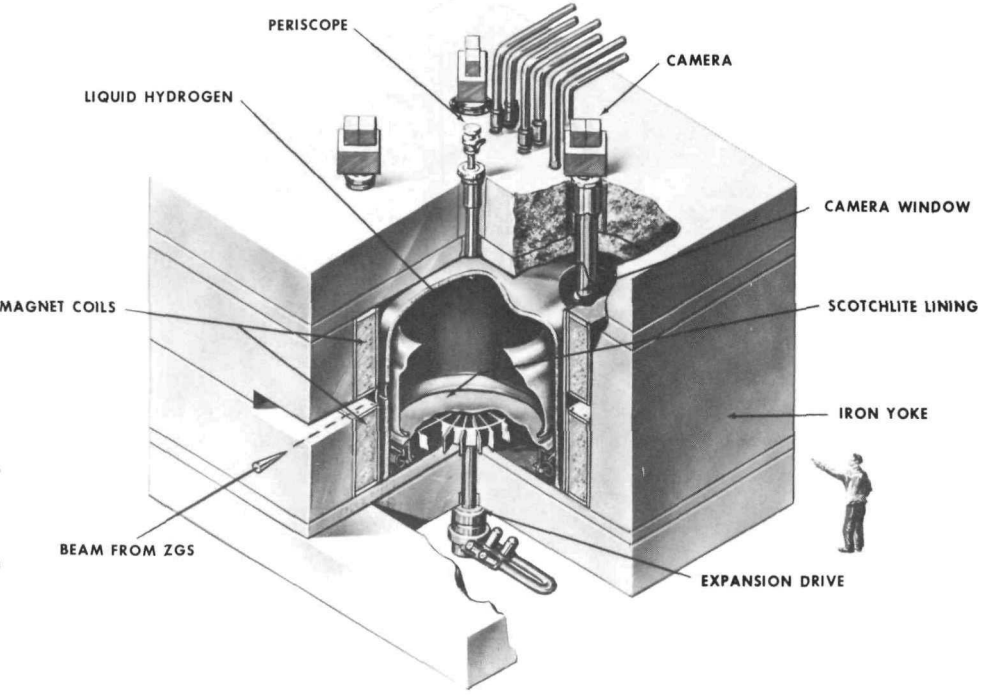


Figure 18 *Twelve-foot bubble chamber under construction at Argonne National Laboratory. The chamber will be the world's largest and should give scientists a much more complete view of nuclear particle reactions than any other detecting facility.*

Experiments Are Fun

The nosy experiments that we scientists carry out to spy on nature are fun. This is because the results not only satisfy our curiosity, but the experiments themselves often give us an excuse to get outdoors and sneak up on nature in her home territory. Let me tell you about some of the experiments we have carried out and some we are doing right now.

When I tried to requisition a small aluminum boat with an outboard motor, I was asked whether I also needed a fishing pole and what kind of beer I preferred. But why *did* we want to go boating on the lake? The answer was simply to get away from land and its high content of gamma-emitting materials. For several decades, efforts have been made to separate the natural gamma-ray background exposure into terrestrial and non-terrestrial components. Thirty feet of water is sufficient to shield all the gamma radiation from the earth. Thus, if sensitive measurements are made a mile or two from shore over fairly deep water, one ought to obtain a value for the gamma-ray contribution from extraterrestrial sources.

When Dr. Spiers visited us earlier and learned that we were using an extremely sensitive ionization chamber to measure terrestrial gamma-ray background (and therefore, willy-nilly, a non-terrestrial contribution), he urged me to go "fishing". Needless to say, I didn't need too much persuasion.

The system* is very portable as you can see in Figure 19 where measurements are being carried out with the aid of a "shave-pak"† plugged into a car's cigarette lighter. The men of the U. S. Coast Guard stationed at Lake Michigan were very cooperative. There were several complicating factors in what would otherwise be fairly straightforward measurements. We had to use a small aluminum boat (see Figure 1) because the gamma rays from the potassium and radium in the materials of a large painted wooden or steel ship would overshadow what we were trying to measure. Even the radium in the instrument dials on the bridge of the Coast Guard cutter gave more current than we were looking for. The cutter took us and our little boat out on Lake Michigan so far that the air would shield us from the gamma-emitting soil. Thus if we were separated by 10 meters of water from the nearest earth (beneath us), we needed to have at least 10,000 meters of air between us and the shore, water being about 1000 times as dense as air.

*Designed and constructed by Dr. F. Shonka, St. Procopius College, Lisle, Illinois.

†This is a small vibrating power supply that converts the cigarette lighter DC into AC for use with an electric shaver.

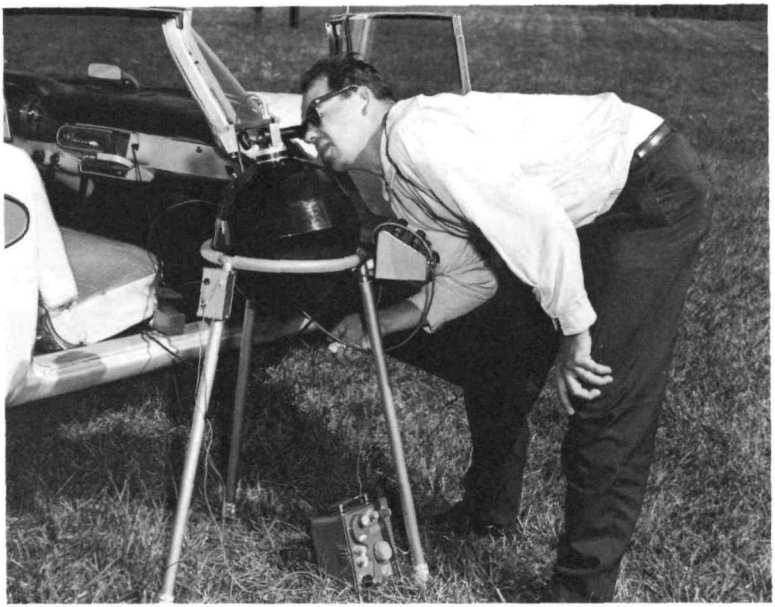


Figure 19 *Extremely sensitive environmental radiation measuring system.*

But what about radon gas carried by the prevailing wind from shore to us? To account for this contamination (radon daughters emit gamma rays when they decay), we carried on board ship several large collapsed balloons. The balloons were each enclosed in a large glass bottle, about 50 cm in diameter, and attached by a simple valve system to the narrow neck of the bottle. When one of us blew up a balloon, he acted as a pump to collect a substantial sample of air at the time and place of our measurements. These samples were later measured for radon content. The air was passed over finely divided and very cold charcoal or carbon that trapped the radon gas, and the alpha particles from the decaying radon could then be counted.

We were also concerned about the purity of Lake Michigan water; after all, soluble salts from surface runoff and human wastes do end up in the lake. We collected 10-gallon samples of lake water for analysis. Nowadays the analysis of gamma rays from weak radioactive sources is so sensitive that we were able to detect the presence of debris from the Chinese bomb tests! The main contamination in our water proved to be a slight trace of potassium-40 together with an even smaller trace of bomb-produced cesium-137.

After correcting our lake measurements for the small contributions from the contaminated air and water, we were able to tell the world the

value of the cosmic-ray component at 41°N. (53°N. geomagnetic) and 540 feet above sea level. For comparison with previously derived values, everyone corrects their figures to sea level and the equator. Values calculated in this way will be smaller because there is more atmosphere at sea level to thin out the primary cosmic rays. Furthermore, fewer cosmic rays enter the earth at the equator because of the earth's magnetic field, which tends to guide charged particles to either pole.

The cosmic-ray contribution at Chicago is about a quarter of the total radiation exposure on land. We generally quote the value as about 4 microroentgens* per hour (μr/h).

Having measured the gamma-ray and charged particle components of the cosmic rays, what about the other major product of cosmic-ray interactions in our atmosphere, namely, neutrons? It was known that there were much fewer of these than of gamma rays or charged particles. However, each neutron is as heavy as a hydrogen atom and, if energetic, can knock out of place the hydrogen atoms that make up most of our cells. It became a challenge to try to measure the exact number and energy distribution of these neutrons, which hit every square centimeter of area about once in 2 minutes.

We decided to use a hydrogenous liquid scintillator to sense and record the impact of as many neutrons as possible. When an energetic charged particle traverses a liquid such as benzene it leaves a track of ionized molecules, like a jet's vapor trail or the bubble chamber's "spoor". When these molecules recapture their electrons, light is emitted. The pulse of light accompanying each track can be recorded electronically. The light pulse's size and duration is a clue to the charged particle's energy and mass. If the uncharged neutron passes through the liquid without collision, there is no ionization and no light, thus no record. But, if the neutron hits a hydrogen atom, the latter will recoil with some energy and bingo! a light flash will be registered. There are myriads of hydrogen atoms in a liquid as dense as benzene—thus the probability of a neutron's collision is significant. Even so, we needed a quart of liquid to be hopeful of registering sufficient recoils to provide an accurate rate. This rate, near sea level, proved to be so low, that we recorded recoils for more than 2 months before being satisfied with our data.

At first, we carried out our measurements in the laboratory, but we discovered that people in a building 200 yards away were generating

*A roentgen is a unit of radiation that is the amount of gamma-rays required to produce 2 billion pairs of ions in 1 cubic centimeter of dry air under standard conditions (0° Centigrade and 1 atmosphere of pressure). 1 μr/h = 2000 ion prs. per cc.

neutrons periodically with an accelerator. A few minutes a day of this extra contribution was more than enough to match a week's background!

With the cooperation of the City of Chicago Water Department we located our apparatus at one of Chicago's water intake cribs offshore in Lake Michigan (Figure 20). The crib proved to be an ideal location for measurements because it is far enough from shore to be free of terrestrial and artificial radiation. You can see what the detector looks like in Figure 21.

Figure 20 *This water intake crib on Lake Michigan was the scene of experiments on neutron reflection from a water surface. This was part of a study of natural neutron dose rates due to cosmic rays.*

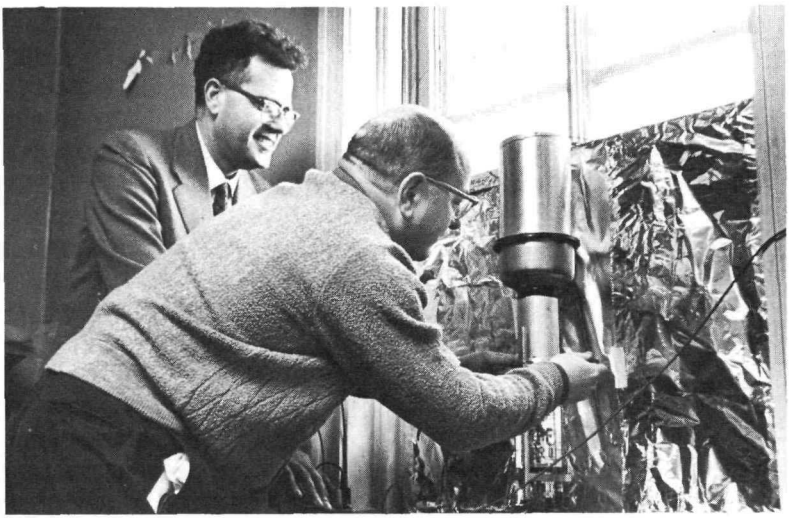


Figure 21 *At the water intake crib, scientists adjust scintillation counting equipment for recording neutron bombardment. Bending over the apparatus is the author and looking over his shoulder is Dr. Yehuda Feige, a visiting scientist from the Israel Atomic Energy Commission.*

Figure 22 *A scientist removes a can containing cosmic-ray detecting materials from a bridge on the water intake crib.*

Another type of detector was used to measure very slow, thermal, or room temperature neutrons. We made up half-pint cans containing special photographic emulsions that were loaded with the isotope lithium-6 (^{6}Li). This isotope has the property of capturing a thermal neutron and splitting into two new atoms, tritium and helium. The split or explosion shows up in the film as a small star or blotch, and these can be counted. In Figure 22 one of us is removing a can that has been on the bridge at the crib for 6 months. Thanks to the U. S. Coast Guard, we could also put some cans on navigation buoys 7 miles out in the lake.

At this stage of the experiment we are relatively satisfied with our measurements of neutron flux or total intensity. But to be sure of distribution we'll need another few years.

FROM MINE TO MOON

Of one thing we are sure—radiation of various types and quantities is everywhere. It is only a question of the proper technique to determine what kind and how much.

Recently, laws have been passed that force fairly stringent controls on exposure. There is now a flurry of activity to build instruments to measure both the external and internal exposure hazards. The principal radiation exposure in uranium mines is caused by the presence of radon gas and its solid, particulate radioactive daughters. The particulates are likely to be inhaled by the miner and a portion of the particles may be retained in the respiratory tree. The alpha particles emitted from these daughters are capable of producing tissue damage. Instruments specially designed to estimate the concentration of radon daughters in mine air are under development and test. Progress to date is such that we can expect significant improvement in the foreseeable future.

Not all mines exhibit a high level of radioactivity. In fact, quite the contrary. Mines of common table salt are often very free of radioactive impurities and deep enough to shield out most of the extraterrestrial radiation. Such mines in Ohio and Texas have been used by researchers to do experiments that require a radiation-free environment. I know a graduate physics student who means it when he says "back to the salt mines".

A delicate experiment to determine the stability of the proton is being carried out 2 miles below the earth's surface in a gold mine in South Africa. So far, it has been established that if the proton is unstable at all, its average lifetime is at least 10^{25} years!

From a scientific standpoint a source of background that cannot be ignored in these deep mines is a flux of neutrons arising from alpha-ray bombardment of the nuclei of common elements. The tissue dose from these neutrons is not of enough biological significance to cause concern. In fact the small yield would normally be inconspicuous if it weren't for the fact that the general background, especially extraterrestrial, is so low.

As man rises out of the mines and leaves the earth's surface he suffers fewer insults from terrestrial radiation but receives more impacts from extraterrestrial sources. This winter, we were fortunate to be able to fly our liquid scintillator on a DC6 at 20,000 feet above Miami. The U. S. Department of Commerce's Environmental Science Services Administration (ESSA) has Weather Bureau planes that have been used for a decade to spot and follow hurricanes. We were able, in 6 hours of flying at this altitude, to get as much data as in 2 weeks on the ground.

The question arises: What will be the exposure to the crew and passengers of the proposed supersonic transport that is slated to fly at 70,000–80,000 feet? It doesn't look too bad for an hour's flight under normal conditions. However, during a solar flare (Figure 23) the sun spits out an intense burst of protons. Furthermore, the earth's magnetic field is distorted so that more of these charged particles can arrive at the earth without deflection. Under such conditions there is a good possibility that the pilot will have to take evasive action and drop to 40,000 feet. Otherwise he will subject his passengers to as much in 1 hour as we now receive on the ground in a month!

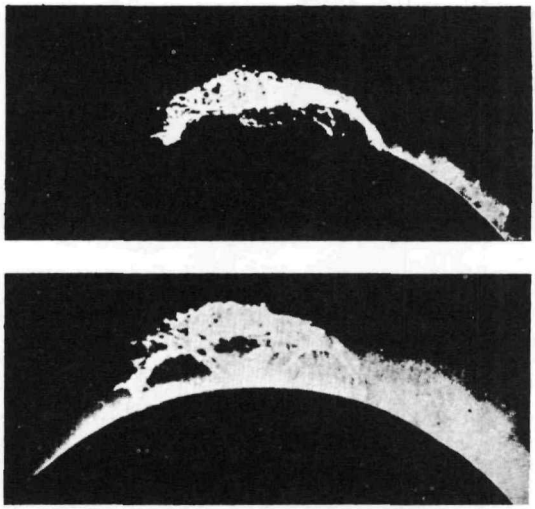


Figure 23 *These photographs were taken during the total solar eclipse on May 29, 1919.*

As man keeps going up out of our atmosphere and into space, our astronauts will no longer experience terrestrially produced exposure. More and more of the radiation will be clean unadulterated cosmic rays, including some flurries of radiation originating on the sun. Some of the electrons and protons are trapped in the earth's magnetic field and constitute belts of radiation surrounding the earth. Professor James A. Van Allen discovered these belts in 1958 when he sent up some Geiger counters by rocket as part of the Explorer 1 satellite. Later it was determined that these belts begin about 500 miles above the earth's equator and extend out about 40,000 miles (Figure 24).*

*For more information, see *Space Radiation*, a companion booklet in this series.

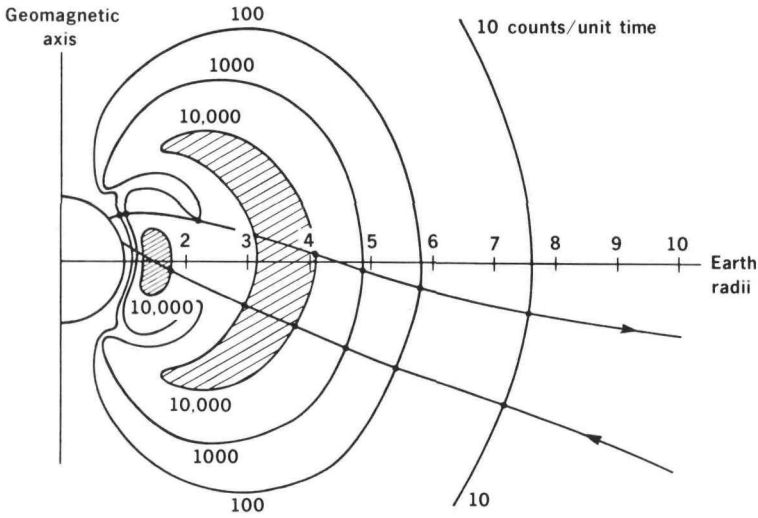


Figure 24 *Van Allen's famous map of the radiation belts derived from the GM tubes carried by Explorer 4 and Pioneer 3. The belts are indicated by the slanting lines. The contours indicate regions of equal counting rates.*

In space, of course, there is no blanket of atmosphere to shield man from direct bombardment. We will have to provide him with his own radiation shield. The uncertainties concerning the intensity and kind of radiation exposure will need to be eliminated before we can provide the proper protection for a man remaining in space. Much of the incident radiation energy is dissipated in shielding material by ionization, i.e., the shield's electrons carry away the energy harmlessly. Good spacecraft radiation shields must therefore have a lot of electrons per unit weight. The best element for this purpose is hydrogen, which has almost twice as many electrons per kilogram as do all the other elements. Thus, weight for weight, it's a better shield. Furthermore, unlike all other elements, hydrogen nuclei do not contain neutrons and thus will not add to the medium-energy neutron flux under high-energy proton impact. Since hydrogen will remain a liquid in the cold of outer space (and is also a rocket fuel component), perhaps we shall see our spaceships with double walls containing liquid hydrogen like inside out thermos bottles.

Now, what happens when we arrive at the moon? Radiation conditions here ought to be similar to those experienced by our supersonic transport planes near the top of our atmosphere. Cosmic rays will come barrelling in from space (with no atmosphere to shield the astronaut), smash into the moon's soil and generate neutrons near

the surface, which will come boiling back out to pester the poor humans who have the gall to settle on the surface. There is one important difference, however, between the top of our atmosphere and the moon's topsoil. There is no nitrogen to gobble up thermal neutrons (and generate ^{14}C). Thus the flux or intensity of thermal neutrons could very well be orders of magnitude higher than on earth. As thermal or very slow neutrons are easily captured by stable elements, making them radioactive, this environment may prove a real hazard to spacemen, who wish to stay on the moon for any length of time. Their clothes may need to be lined with lithium or boron. These elements are very opaque to slow neutrons. At this writing we have not yet had a final interpretation of the information resulting from the Apollo-11 or -12 moon landings.

An additional but less important contribution to man's radiation environment on the moon is the lunar radioactivity. Like the terrestrial, it comes about mainly from basalt and granite regions containing

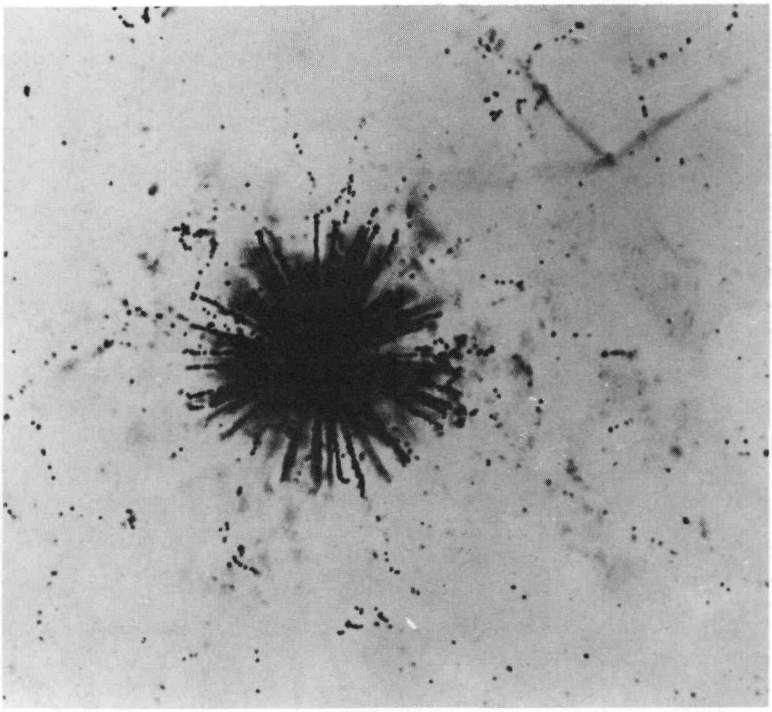
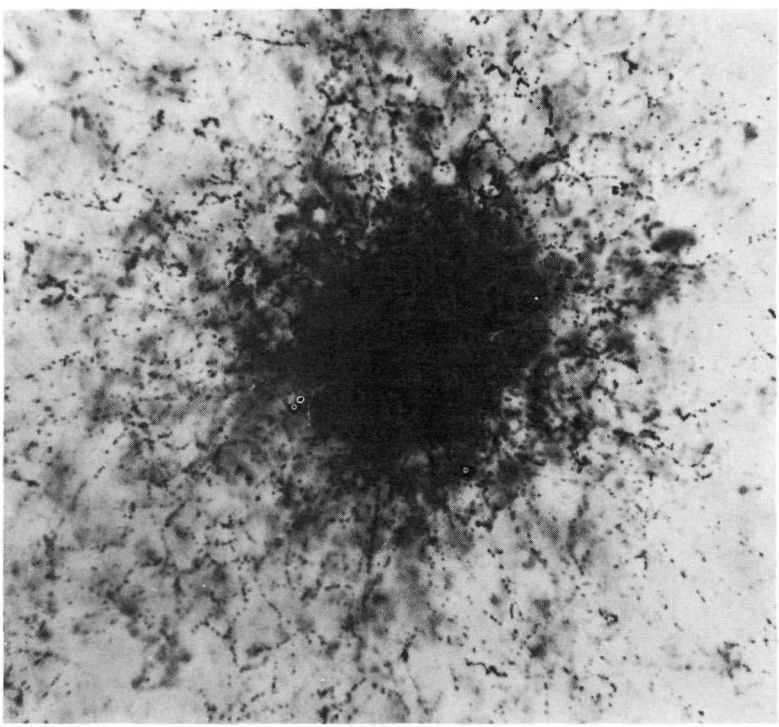


Figure 25 *Natural radioactivity (left) in the atmosphere is shown by this nuclear-emulsion photograph of alpha-particle tracks (enlarged 2000 diameters) emitted by a grain of radioactive dust. Man-made radioactivity (right) in the*

potassium, thorium, and uranium. The lunar soil composition was established in a preliminary way by the Russian experiments on their satellite Luna-10, which orbited the moon in March 1966.

Since then, of course, man has managed the colossal achievement of bringing back samples of the moon's surface. These were checked for their gamma-ray emission in a specially designed radon-free room, 15 meters below the ground (similar to the room in Figure 8). As a result of these measurements, we now know that the concentration of thorium and uranium in these moon samples is much like that of similar rock on earth. The radioactive potassium concentration in the Apollo-11 samples, however, proved to be much lower in the lunar surface material than for earth rocks or even meteorites. Furthermore, there were definite amounts of radioactive aluminum, sodium, scandium, and other radioactive elements, which are not naturally present on earth.



atmosphere produced this nuclear-emulsion photograph. This radiation source is a fission product produced in a nuclear explosion. The enlargement is 1200 diameters.

Their presence on the moon is explainable on the basis that the lunar surface material has been exposed to cosmic radiation for at least several million years, thus generating these unusual radioisotopes, which are only artificially available on earth.

During the measurements Luna-10's distance from the moon varied from a 350 km minimum to a 1000 km maximum. Gamma rays were detected with scintillation counters. The uncertainty in the measurements—and therefore the accuracy of the conclusions—arises from the fact that the counts resulting from the moon's radioactivity were only 10% of the total recorded. The remainder came from cosmic radiation and background scatter from the spacecraft.

An interesting sidelight to the moon's continual bombardment by radiation from space is the very reasonable suggestion by scientists of the Westinghouse Electric Corporation that the energy stored during bombardment on the night (and cold) side of the moon is released by the sun's rapid heating in the form of visible light. It is well known that many imperfect and impure crystalline materials, such as quartz or fluorite, will trap (at impurity centers) the electrons resulting from ionizing radiation and later, when heated rapidly, release these electrons to recombine with ions and produce light. The light intensity is proportional to the total radiation exposure. This phenomenon is called thermoluminescence and is the basis for a modern system of radiation dosimetry or exposure measurement that has begun to supersede the conventional film badge for radiation safety, and as pointed out before, is superior for long-term environmental studies. The Westinghouse scientists now estimate that the moon's thermoluminescent intensity may amount to as much as one-third of the reflected sunlight in the same region!

A thrilling prospect for a very practical application of the natural lunar radiation background is the possibility of using the energy trapped in the moon's soil during the lunar night. Moon settlers might well tap a vast storehouse of energy on the dark side of the moon. By the end of the lunar night, the bombarded material possesses 6 kilowatt hours per pound, or more energy than is stored in coal. The dust could be fed into an insulated chamber to generate heat for a lunar base or to produce electricity by heating a thermoelectric generator.

RELAX AND ENJOY IT

I started this little treatise by saying that life on this planet has always been insulted by radiation. In fact, it is postulated that it is the very existence of radiation that has produced the evolution of the myriad species we have today. It is certainly true that radiation-induced mutations which became involved in natural selective forces produced forms of life that are uniquely fitted for survival in the environments to which they have thus become adapted.

The academic question always arises: Will genetic damage by radiation alter homo sapiens? As we don't know, and there really isn't much we can do about it anyway, let's hope the changes, if any, will be for the better. Goodness knows we can certainly bear to be improved. The point is that, with the addition of sheer knowledge, man has the imagination to eventually control his environment. Let me summarize what we now know in the form of some tables.

What we don't know is always infinitely more than what we know. All we can begin to talk about are experiments in the immediate future. As we do them and gain more knowledge, new frontiers open up.

Table IV
DOSE RATES DUE TO EXTERNAL AND INTERNAL IRRADIATION FROM NATURAL SOURCES IN NORMAL AREAS

Source	Dose Rates (mrad/yr.)*
External irradiation	
Cosmic rays at sea level	0
Ionizing component	28
Neutrons	0.7
Terrestrial radiation	50
Cosmic rays at 20,000 feet	1500 (= 1.5 rad/yr.)
Cosmic rays near top of atmosphere	30 rad/yr.
Internal irradiation	
Potassium-40	20
Rubidium-87	0.3
Carbon-14	1
Radium-226, -228	1
Hydrogen-3 (Tritium)	2
Average total dose to body	100

*Rad is an acronym for *r*adiation *a*bsorbed *d*ose. It is the basic unit of absorbed dose of ionizing radiation. A dose of 1 rad means the absorption of 100 ergs of radiation energy per gram of absorbing material. 1 millirad = 0.001 rad. (A roentgen of gamma rays will deposit almost 1 rad in tissue.)

Table V
NON-OCCUPATIONAL ARTIFICIAL EXPOSURES

Source	Dose or Rate
Wrist watch dial, approx. 1 microgram of radium, gamma rays	1 mr/hr
Airplane instruments–pilot position	1 mr/hr
Shoe fitting (20 sec)	10 r
Diagnostic X ray	
14 X 17 chest plate	0.1 r
Photofluorographic chest	1 r
Extremities	0.5 r
G1 series (per plate)	1 r
Pregnancy	9 r
Fluoroscopy	15 r/min
Dental (per film)	0.5 r
Radiation Safety Guide for Population	0.5 r/yr.
Radiation Safety Guide for Radiation Worker	
Extremities	75 r/yr.
More sensitive body organs	5 r/yr.
Skin and thyroid	30 r/yr.

Certainly one experiment that needs doing is to measure the slow neutron intensity on the moon before our astronauts get there. This might be done by sending a package of ^{6}Li thermoluminescent material on a lunar orbiting spacecraft and periodically heating it on command from the earth. The luminescence could then be read electronically and be telemetered back as a quantitative signal.

We are continually being washed by neutrinos* from the sun. Neutrinos are almost weightless neutral particles, which penetrate matter so easily that the intensity of neutrinos on the night side of the earth is estimated to be only 10% less than the sun side. Very complex and sophisticated apparatus has been devised to detect these elusive "critters" but a great deal still needs doing. Elaborate experiments have been planned under the Himalayas to gain the advantage of a mountain as an absorber. One experiment actually will consist of a 30-foot cubical room containing a scintillating liquid and electronic light converters, which will be like television picture tubes 3 feet in diameter. These detectors will be serviced by frogmen! However, we need to know more about this wash of neutrinos; who knows—they may provide a communication system through the earth that won't depend on the weather or booster stations.

*See *The Elusive Neutrino,* another booklet in this series.

Another area that needs a great deal of research is the component of extraterrestrial radiation that consists of the so-called *strange* particles* resulting from catastrophic high-energy collisions. Radiobiologists are keenly interested in the effects of such high-energy interactions, and we will have to take inventory to determine the exposure.

Finally, let me end by saying that to know is satisfying, but learning to know is fun, and designing experiments to pin down information is even more fun than just learning. When you can leave the lab and investigate the world around you what more can you ask?

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*A class of very short-lived elementary particles that decay more slowly than they are formed, indicating that the production process and decay process result from different fundamental reactions. They include K-mesons and hyperons.

PHOTO CREDITS

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Figure

3	Observatoire du Pic du Midi (left); cloud chamber (right) from *Cosmic Rays,* A. W. Wolfendale, Philosophical Library, © 1963, reproduced by permission.
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6	Indiana University
8	Cornell University
9	Dr. Charles E. Miller
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25	Air Force Cambridge Research Laboratories

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JACOB KASTNER received his Ph.D. in physics from the University of Toronto and has specialized for many years in radiation and radioactivity research. He was formerly a research physicist for the National Research Council of Canada and for the General Electric Company, and was director of research for the Picker X-Ray Corporation. Since 1962 he has been associate physicist in the Radiological Physics Division at Argonne National Laboratory in Illinois. Dr. Kastner is conducting research on measurement of background radiation levels in Lake Michigan and elsewhere, and on the effects of plant growth and seasons on natural radioactivity.

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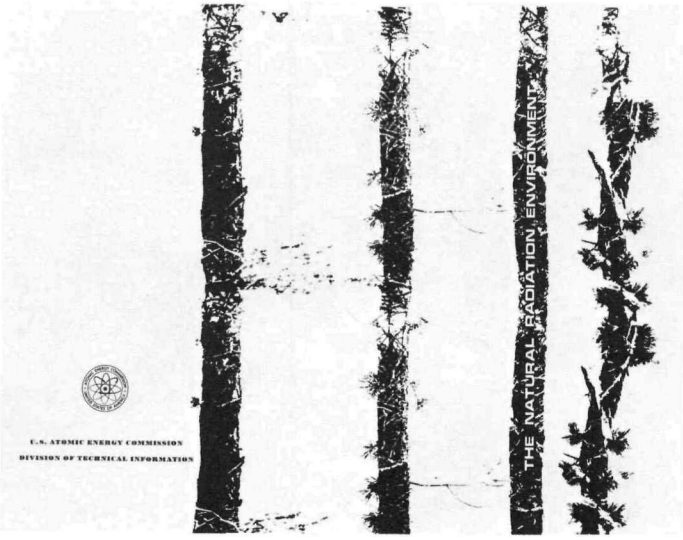

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