

While the biological effects of the radiation surrounding us are not yet entirely understood, recent work in health physics and radiology has greatly clarified the problems which are involved.

everyday radiation

By Frederick P. Cowan

THE RAPID DEVELOPMENT of applied nuclear physics during the past decade has focused the attention of many people on radiation and radioactive materials. The fact that both are common constituents of our environment was realized by scientists working in the field soon after the discovery of radioactivity a half century ago. Many other scientists and the general public realize only vaguely or not at all that they are continually exposed to penetrating radiation of natural origin and that radioactive materials are found in small amounts in almost all substances including air, soil, building materials, and the human body.

In recent years the use of X-rays and isotopes in medicine, research, and industry has become increasingly widespread and the military applications of nuclear physics have been intensively developed. Accordingly, it is appropriate that all should have a general understanding of the nature of natural and man-made radiation including some concept of the magnitudes involved.

This matter of magnitudes is of extreme importance if one is to bring into proper perspective a wide range of radiation intensities ranging from those of cosmic rays to those associated with an atomic bomb. In the paragraphs that follow we will survey the natural background radiation, discuss some common examples of man-made radiation and briefly summarize the effects of radiation on human beings.

THE EARTH IS BEING BOMBARDED from all directions in space by radiation thought to consist predominantly of very high energy protons. In passing through the atmosphere these produce a multitude of other types of radiation, notably mesons, electrons, and photons. This complex mixture of radiations is known as "cosmic radiation" or "cosmic rays".

An intensive study of cosmic radiation has shown that its intensity varies only slightly with the time and longitude of observation, but that there is a strong dependence on geomagnetic latitude and elevation above sea level. For the northern portion of the eastern U. S., there is about one cosmic-ray particle per square cm per minute crossing a horizontal surface at sea level. This increases to five times that value at an elevation of 15,000 feet and to seventy-five times at about 55,000

feet elevation where the maximum intensity is found. The intensity decreases by only 10% at sea level in going to the equator but by 75% at the 55,000 foot height. The reason for these variations is found in the effect of the magnetic fields of the earth and sun on the primary particles approaching the earth from outer space.

Cosmic radiation accounts for a considerable fraction of the total background. The fraction will depend upon location and is not easy to establish since the initially hard cosmic rays degenerate in part to soft components at ground level which are not readily differentiated from similar components arising from local radioactive substances. A sea level figure of 70 or 80% is sometimes given but probably refers to the harder components and places where locally produced radiation is low. The cosmic radiation contains components whose energy values range from zero up to hundreds of billions of electron volts, with little being known about the upper limit. Cosmic-ray investigations are being pushed intensively at the present time and many details still must be clarified. However, the general features are well established and have been covered in a number of recent books.^{1, 2}

RADIOACTIVITY was discovered in 1896 by Professor Henri Becquerel, who demonstrated that uranium would fog a photographic plate. In the next few years it was learned that thorium and a new trace element, actinium, are also radioactive and that there are long series of radioactive substances associated with each. The atoms of each parent substance change successively from element to element by emission of alpha, beta, and gamma radiations until the whole series has been covered and a stable end-element is produced. The details of these series are fully covered in textbooks of atomic and nuclear physics and will not be discussed here. However, several members of the uranium and thorium series have particularly important effects on the radiation background and therefore a somewhat simplified data summary for these two series is given in Table 1. Standard notation is used to designate the various substances, but special symbols, used before a full understanding of the series had been reached, are given in parenthesis. For instance, ${}_{84}\text{Po}^{218}$ (RaA) is an

Table 1. Uranium and Thorium Series (branches omitted)

Substance	Radiation	1/2-Life	Energy (Max)	Substance	Radiation	1/2-Life	Energy (Max)
^{238}U (UI)	α	4.50×10^8 y	4.18 Mev	^{232}Th	α	1.39×10^{10} y	3.98 Mev
^{234}Th (UX ₁)	β (γ)	24.1 d	0.20	^{228}Ra (MsTh ₁)	β	6.7 y	0.053
^{234}Pa (UX ₂)	β (γ)	1.14 m	2.32	^{228}Ac (MsTh ₂)	β	6.13 h	1.55
^{234}U (UII)	α	2.6×10^5 y	4.76	^{228}Th (RdTh)	α (γ)	1.90 y	5.42
^{230}Th (Ia)	α (γ)	8.0×10^4 y	4.66	^{228}Ra (ThX)	α	3.64 d	5.68
^{226}Ra	α (γ)	1620 y	4.79	^{220}Em (Thoron)	α	54.5 s	6.28
^{222}Rn (Radon)	α	3.82 d	5.49	^{216}Po (ThA)	α	0.158 s	6.77
^{218}Po (RaA)	α	3.05 m	6.00	^{216}Pb (ThB)	β	10.6 h	0.36
^{218}Pb (RaB)	β (γ)	26.8 m	0.65	^{212}Bi (ThC)	β (γ)	60.5 m	2.25
^{218}Bi (RaC)	β (γ)	19.7 m	3.15	^{212}Po (ThC')	α	3×10^{-7} s	8.78
^{214}Po (RaC')	α	1.5×10^{-4} s	7.68	^{212}Pb (ThD)	—	stable	—
^{214}Pb (RaD)	β (γ)	22 y	0.026				
^{214}Bi (RaE)	β	5.0 d	1.17				
^{214}Po (RaF)	α (γ)	138 d	5.30				
^{210}Pb (RaG)	—	stable	—				

isotope of polonium with an atomic number of 84 and a mass number of 218 which has commonly been referred to as radium A. Values of half-life are given in years, days, minutes, or seconds and the maximum values of particle energies are given in millions of electron volts.

In addition to the radioactive substances forming the series just referred to, there are a number of isolated elements which are naturally radioactive. These are listed in Table 2. In each case it is a particular isotope of the element that is active and the activity is small because of the extremely large values of half-life. Since potassium is a common chemical, it is the most interesting of this group even though the radioactive isotope composes only 0.011% of the natural element. C^{14} is present in very minute amounts (16 disintegrations per minute per gram on the average corresponding to an isotopic abundance of 1.6×10^{-12}) but its occurrence has been studied extensively as a method for estimating the age of fossils and other organic deposits of great age. The isotopes given in Table 2 have been the subject of numerous careful studies but many of the constants and details of their decay are still in doubt. Data and references are best found in the extensive compilation of nuclear data put out by the National Bureau of Standards.³ The numbers in Table 2 have been chosen somewhat arbitrarily in some cases and are intended merely to indicate the general nature of these activities.

Natural radioactive materials are very widely distributed as constituents of the earth's outer crust. Uranium and thorium and their decay products account for most of the observed activity. Average figures⁴ have been given as:

Uranium 6 parts per million by weight
 Thorium 12 parts per million by weight
 Radium 2×10^{-8} parts per million by weight.

These are small concentrations, but it is interesting to note that surface soil, having somewhat less than half these average concentrations, will contain in a layer one foot thick and one square mile in area roughly one gram of radium, three tons of uranium, and six tons of thorium. With radium selling at \$16,000 a gram and uranium a scarce strategic material, it is unfortunate

that the huge quantities in ordinary earth and rocks are too dilute to be of practical value.

Natural radioactive materials and the geological implications relating to the age of the earth, temperatures in tunnels and mines, and the instability of the earth's crust were intensively studied during the early years of this century. Some of the contemporary treatises⁵ make interesting reading and suggest the tremendous scientific effort devoted to the new field of study in those days. The study of natural radioactivity is still being actively pursued, gamma-ray logging of oil wells being a recent practical application.

Table 2. Naturally Occurring Radioactive Isotopes Not Members of Series

Substance	Isotopic Abundance (atom %)	Half-Life	Radiation
^{14}C	Variable	5,600 years	beta—0.155 Mev
^{40}K	0.0119%	1.3×10^9 years	beta—1.5 Mev gamma—1.5 Mev
^{87}Rb	27.85%	$6-8 \times 10^{10}$ years	beta—0.27 Mev gamma—?
^{138}La	0.089%	2×10^{11} years	positron—? gamma—0.54, 0.81, 1.39 Mev
^{147}Sm	15.1%	10^{12} years	alpha—2.2 Mev
^{176}Lu	2.60%	2.4×10^{10} years	beta (33%)—0.2–0.4 Mev gamma (67%)—0.26 Mev
^{187}Re	62.9%	4×10^{12} years	beta—0.043 Mev

BEFORE PROCEEDING with a discussion of the activity of air and water it will be well to comment briefly on units of radioactivity. The curie is defined as a quantity of radioactive material in which



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The normally radioactive particles of dust in the atmosphere tend to be washed out by rainfall, as indicated in Fig. 1, which shows a comparison of precipitation and geiger counter readings during a single week. Temperature inversions in the air also have the effect of increasing the concentration of radioactive dust particles near the ground, as shown by the chart on the next page.

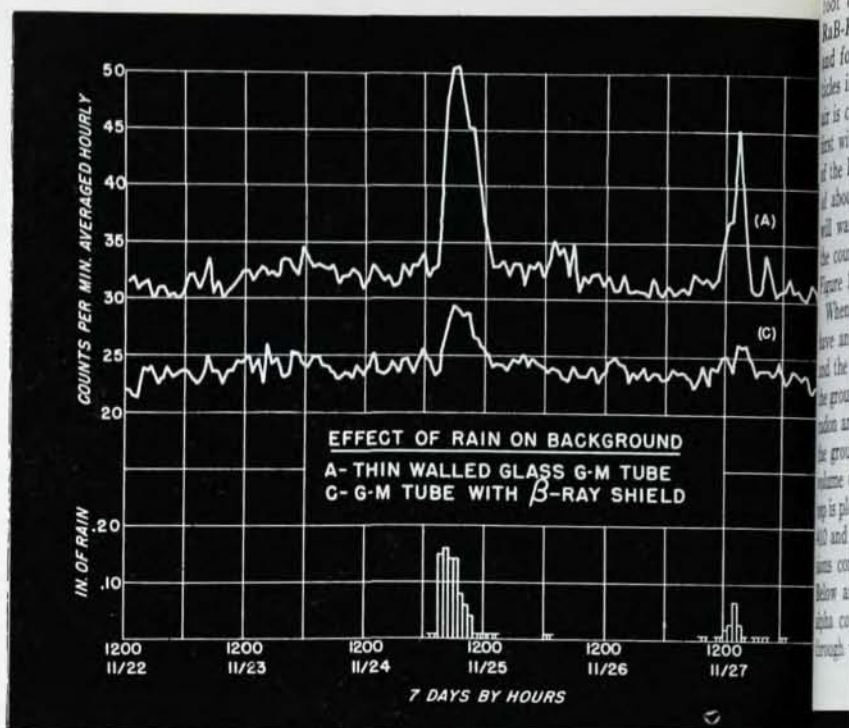


Fig. 1

3.7×10^{10} disintegrations occur per second. In this way quantity is expressed in terms of the activity rather than in terms of mass. Radium weighs very nearly one gram per curie, but other substances will weigh more or less depending on whether they have larger or smaller atomic weights and on whether their half-lives are longer or shorter. For instance, the chief isotope of uranium, U^{238} , weighs 2.9×10^6 grams per curie while the radioactive iodine currently used for therapy of thyroid disorders, I^{131} , weighs 7.8×10^{-6} grams per curie.

Another important radiation unit is the roentgen. This refers to the energy absorbed by air from a flux of X or gamma radiation and must not be confused with energy flux or wave amplitudes with which physicists are more familiar. Where particulate radiations or substances other than air are involved, an equivalent roentgen is used. There is no officially accepted definition of this equivalent roentgen and the exact viewpoint to be used in making one is a subject for current discussion if not controversy. The intent is to make the roentgen equivalent physical (rep) equivalent to the roentgen in terms of energy absorption. Thus one rep of any radiation will result in the same energy absorption in a substance such as tissue as we have in air for one roentgen of X or gamma radiation. This sort of a unit is appropriate since energy absorbed is one of the primary factors determining biological damage. Thus the roentgen and roentgen equivalent are units of radiation exposure or dosage.

Getting down to an actual definition, the roentgen is

"that quantity of X or γ radiation such that the associated corpuscular emission per 0.001293 gram (one cc at normal temperature and pressure) of air produces, in air, ions carrying 1 esu of quantity of electricity of either sign". This amounts to an energy absorption of 83.8 ergs per gram of air. There are a number of other interesting units with which physicists are not generally familiar and various problems associated with their practical measurement. For a more detailed discussion, the reader is referred to a paper of Robley D. Evans.⁶

THE AIR, like the ground, contains small concentrations of radioactive materials. These materials get into the air for the most part by virtue of the fact that among the decay products of the uranium and thorium in the ground are two radioactive gases, radon and thoron, designated in Table 1 as ^{222}Em and ^{220}Em respectively. The symbols Rn and Th are widely used for radon and thoron but Em (emanation) is a recent designation for all isotopes of element 86. Both gases diffuse out of the ground into the air, but because of its longer half-life a larger fraction of the radon escapes. Radon concentrations in the air are of the order of 10^{-10} microcuries per cc, but are subject to wide variations as are those of thoron which ordinarily amount to only a few percent of the radon concentrations. It is hardly necessary to point out that these are very small concentrations indeed; in fact, the value given for radon corresponds to only six disintegrations per minute per cubic

foot of air. The decay products of these gases, RaA-RaB-RaC etc., and ThA-ThB-ThC etc., are all solids and for the most part attach themselves to dust particles in the air. Thus, when a sample of dust from the air is collected on a filter paper, the activity decays at first with a half-life of about 40 minutes characteristic of the RaB-RaC combination and later with a half-life of about 10 hours characteristic of thorium B. Rain will wash down some of the air activity and increase the counts observed with a geiger counter as shown in Figure 1.

Whenever air temperature increases with height, we have an inversion of the normal temperature gradient and the normal stirring of the air near the surface of the ground by convection ceases. Under these conditions radon and thoron and their decay products collect near the ground instead of being dispersed through a huge volume of air. This effect is shown in Figure 2. At the top is plotted the temperature difference between points 410 and 18 feet above the ground. Temperature inversions correspond to positive values of this difference. Below are the counts per minute of beta-gamma and alpha counters placed close to a strip of filter paper through which air has been drawn.⁷ We see that there

is a close correlation between the observed peaks of activity and the occurrence of temperature inversions.

Drinking water owes its radioactivity to the fact that it has fallen through the air or filtered through the earth or both. Uranium, radium, and radon are the principal components, but the quantities present vary widely depending on local conditions. Concentrations as small as 10^{-15} to 10^{-10} curies per cc in the case of uranium and radium are common, but values as much as three orders of magnitude larger are found, particularly in the case of certain mineral springs. The concentration of radon behaves similarly, but is often considerably larger in curies per cc than that of uranium or radium. It is interesting to note that cow's milk has an activity of about 6×10^{-14} curies per cc due to the potassium that it contains. The various radioactive substances in sea water are overshadowed by the K^{40} present which has an activity amounting to one-third of a microcurie per cubic meter. It has been estimated⁸ that the oceans contain a total of 5×10^{11} curies of potassium-40.

WE COME NOW to consideration of the total background observed on the surface of the earth with radiation detecting instruments. This background is caused by cosmic radiation and by the radioactive materials in the air, the ground, and in the materials from which buildings and the apparatus itself are constructed. These latter factors will vary greatly in importance as compared with the cosmic rays depending on location. Plaster, in particular, often contributes substantially to the background inside buildings.

At Brookhaven National Laboratory prior to the start of the nuclear reactor, a full year's record of normal background was obtained from a chain of sixteen monitoring stations. The level as measured with a bakelite-walled ionization chamber averaged about 0.01 mr per hour. This is comparatively low compared with some regions and perhaps 0.01 to 0.1 mr/hr depending on location is a good general range of values to remember. 35 mg/cm² glass-walled GM tubes 10 cm long and 2 cm in diameter record about 30 counts per minute in the stations just referred to, but this counting rate is reduced to 25 c/m by an 83-mil brass shield and to 15 c/m by a 1½-inch lead shield. The counting rates of the dust-monitoring counters referred to above are caused for the most part by the thoron decay products, the time delay between collection and counting being 4½ hours for the beta-gamma counter and 7 hours for the alpha counter. Further details on this background monitoring program will be found in a current report by M. Weiss.⁹

When there is a heavy fall of snow, there is a noticeable drop in background caused by the fact that radon and thoron are prevented from escaping into the air. There are smaller variations connected with changes in air temperature and pressure or traceable to fluctuations in the cosmic radiation. The marked effects due to rainfall and temperature inversions have been noted above.

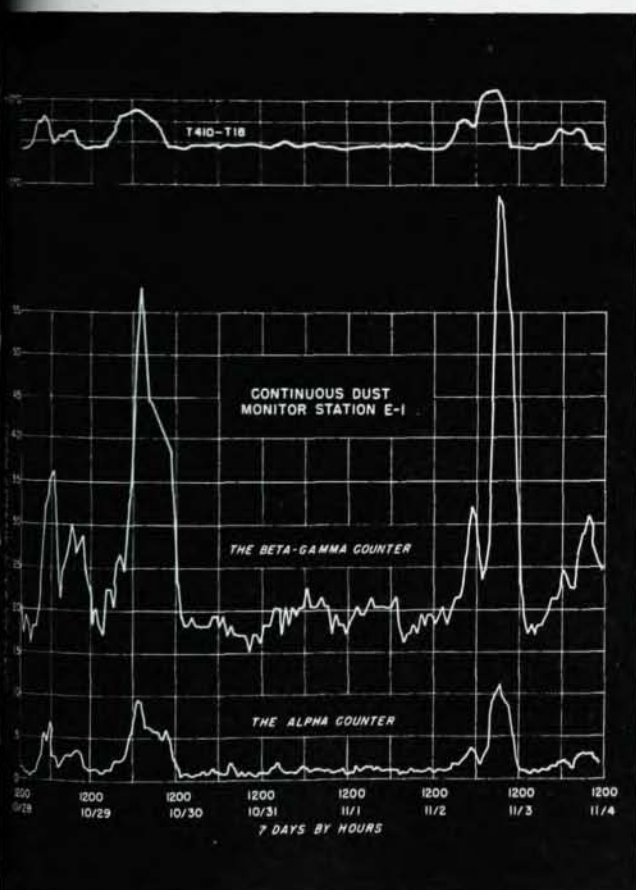


Fig. 2

It is perhaps pertinent to remark that the days of undisturbed natural background are gone, perhaps forever, as a result of the continuing detonations of atomic bombs. The southern hemisphere is only slightly affected since all bombs thus far have been north of the equator and there is only a relatively slow exchange of air between the two hemispheres. A rough idea of the extent of this disturbance to background may be gained by listing all the detonations to date as given in one of the news magazines¹⁰ and computing the residual activity. This has been done in Table 3 taking each

Table 3. Estimated Residual Activity Due to A-Bomb Detonations as of July 15, 1952

Serial Number	Date	Location	Residual Activity (July 15, 1952)
33	June 1952	Nevada	1.59 megacuries
32	June 1952	Nevada	1.42
31	May 1952	Nevada	1.19
30	May 1952	Nevada	0.83
29	April 1952	Nevada	0.65
28	April 1952	Nevada	0.59
27	April 1952	Nevada	0.50
26	Nov. 1951	Nevada	0.17
25	Nov. 1951	Nevada	0.17
24	Nov. 1951	Nevada	0.17
23	Oct. 1951*	Russia	0.14
22	Oct. 1951*	Russia	0.14
21	Oct. 1951	Nevada	0.14
20	Oct. 1951	Nevada	0.14
19	Oct. 1951	Nevada	0.14
18	Oct. 1951	Nevada	0.14
17	May 1951	Eniwetok	0.09
16	May 1951	Eniwetok	0.09
15	May 1951	Eniwetok	0.09
14	Feb. 1951	Nevada	0.07
13	Feb. 1951	Nevada	0.07
12	Jan. 1951	Nevada	0.06
11	Jan. 1951	Nevada	0.06
10	Jan. 1951	Nevada	0.06
9	Sept. 1949*	Russia	0.03
8	May 1948	Eniwetok	0.02
7	April 1948	Eniwetok	0.02
6	April 1948	Eniwetok	0.02
5	June 1946	Bikini	0.01
4	June 1946	Bikini	0.01
3	Aug. 1945	Nagasaki	0.01
2	Aug. 1945	Hiroshima	0.01
1	July 1945	Alamogordo	0.01

* Date announced

8.85 megacuries

bomb as of nominal size and using data from *The Effect of Atomic Weapons*.¹¹ Residual activity estimated in this way totals 8.8 million curies as of July 15, 1952. If this is thought of as spread uniformly over the surface of the northern hemisphere, it is easy to predict, using data from the same reference, that the normal gamma-ray background of 0.01 mr/hr mentioned above would be increased by about 3½% at three feet above the ground. Actually, of course, the real state of affairs is somewhat different. On the one hand deposition is far from uniform, being very much greater near

the test locations, while on the other hand considerable activity may still be airborne. Also, since most of the fission products are solids, the activity will usually be particulate in nature and locally higher levels will result. Radioactive particles are especially bothersome to manufacturers of sensitive films. A small number of particles that would have a negligible effect on the general background, if in direct contact with such films, can cause small dark spots that will spoil the films for many purposes.

The factors just discussed certainly mean that considerable disturbance in background has occurred in the U. S. While this change is hardly of ecological significance except in certain small areas, it must be taken into account by people doing low-level counting or tracer experiments and by the photographic industry.

THE PRESENCE of a natural background of radiation is a factor that must be constantly taken into account when using sensitive radiation detection instruments. The readings caused by background will be negligible for relatively insensitive instruments: for instance, a health physics survey meter with a full scale deflection of 20 milliroentgens per hour on the most sensitive scale. Frequently, however, it is desired to measure very small amounts of activity where the background readings must be subtracted and, in fact, will place a lower limit on the quantity that can be measured. Thick lead shields are normally used to reduce the background counts of geiger counters used for low-level measurements. This is very effective for most locally produced disturbances, but the cosmic rays contain penetrating components that can pass through even very thick shields. Thus, the background counts are reduced by a factor of two or three, but are not eliminated completely. Some additional reductions may be effected by surrounding the counting tube with other tubes and rejecting some of the spurious counts by means of anticoincidence circuits.

In making sensitive ionization chambers, care must be exercised to use materials having a minimum of contamination with the natural radioactive substances. Such contaminants result in an unwanted ionization current over and above the unavoidable minimum due to cosmic rays. Alpha particle counters are particularly sensitive to such contamination since they do not respond to beta or gamma rays and hence their background counting rates are extremely low unless alpha emitting impurities are present.

SINCE RADIOACTIVE MATERIALS are almost universally distributed in the earth, air, and water upon which man depends for life, it follows that the same materials will appear in the human body. The amounts of uranium and radium are very small, but the K⁴⁰ in the body is of considerable practical importance. An average human contains 245 grams of potassium of which 27 milligrams are the radioactive isotope K⁴⁰ (0.23 microcurie). Some of this potassium is continually being eliminated in the urine and thus the solid

residue obtained by evaporating a sample of urine has a radioactivity that is easily measurable. This is a real bother since one of the methods of determining whether possibly harmful radioisotopes have gotten into the body is to look for activity in the urine. The K^{40} masks the small concentrations of other substances that are significant so it must be removed chemically. In most cases the bulk of the inert solids in the urine must also be removed before the necessary sensitivity of detection can be achieved.

The rate of elimination of potassium from the body via the urine will vary widely, but 2 grams per day can be taken as a rough average figure. The specific activity of potassium is about 28 beta disintegrations per second per gram. Thus, the residue from evaporation of a 50 cc sample (taking 1200 cc as the daily elimination) will contain 120 beta disintegrations per minute. When counted in conventional equipment such a sample will show 20 to 30 counts per minute above background. This will effectively mask low levels of activity that one would hope to detect in this fashion. Even so, there is some value in simple evaporation of 50 cc urine samples in the case of acute inhalation or ingestion of a reasonably energetic beta emitter. Radioassay of such samples during the first few days following the incident may serve to set a rough upper limit on the seriousness of the exposure when more refined methods are not available.¹²

It is probably unnecessary to emphasize the toxicity of the natural radioactive materials of the radium and thorium series. They are substances foreign to the body, many of which deposit in the bones where they can do a maximum of damage. The danger of getting such substances into the body has been learned by sad experience.

There has been some interest in the possibility that background radiation has been responsible for certain abnormalities in humans caused by mutations of the germ cells. Such mutations certainly occur, but it is doubtful if the effect of background radiation at sea level is detectable in the presence of larger effects brought about by other causes. People in mountain areas will receive a larger dose, say of the order of one mr per day, but this is still a small amount and effects, if present at all, would be hard or impossible to find.

When we consider conditions at elevations of 50,000 to 70,000 feet such as may soon be used for airplane travel, much higher potential exposures are encountered. This situation has recently been discussed by several authors who have taken into account the increased cosmic-ray intensity at high elevations and the increased percentage of heavily ionizing particles with high relative biological effectiveness.¹³ The report cited estimates that the dose at the top of the atmosphere will be equivalent to about 70 mr per day of X or γ radiation. Another author gives a considerably higher estimate.¹⁴ The radiation inside an airplane will of course be modified by the shielding action of the plane's outer wall. It is probably safe to predict that this problem of cosmic-radiation dosage during high-

altitude flight will receive a lot more attention both from the theoretical and experimental points of view.

THUS FAR, except for a discussion of the effect of atomic bombs, we have been considering naturally occurring radiations. These result in continual small exposures and affect everyone but are of no appreciable biological significance. Much larger exposures result from the use of X-rays. Medical people use X-rays in two ways, for diagnosis or for treatment. The dosages that are used in the latter case are very high since the objective is to destroy diseased tissue. This is done with the minimum possible dose so as to avoid causing too much damage to nondiseased tissue. For such purposes exposures of hundreds or thousands of roentgens are given to limited portions of the body. For diagnostic purposes relatively small exposures are used as compared with the therapeutic ones. Table 4 gives some typical exposures that are received from modern diagnostic X-ray equipment.

Table 4. Typical Diagnostic X-Ray Exposures

14" X 17" chest plate	0.05 roentgen
photofluoroscopic chest	0.7 to 1.2 roentgen
extremities	0.25 to 1.0 roentgen
skull	1.3 roentgen
abdomen	1.3 roentgen
gastrointestinal series	0.65 roentgen per plate
lumbar spine, lateral	5.7 roentgen
pregnancy, lateral	9.0 roentgen
fluoroscopy	0.28 roentgen per second

The exposure received in a photo-fluoroscopic chest X-ray is a good magnitude to remember since it is approximately one roentgen. In this method a microfilm photograph is taken of a fluorescent screen that shows the chest radiograph. Almost everyone has had his chest X-rayed in this fashion either by his employer or at one of the free public X-ray centers. The philosophy of the use of X-rays for medical purposes, of course, is obvious. If the condition of the lungs or of a broken bone can be determined or if a malignant condition can be treated, then one is justified in exposing an individual to radiation that would be inadvisable for one who would not profit from it in any way. In the case of individuals whose occupations make it necessary for them to be exposed to small amounts of radiation, the X-ray exposure history is probably of more importance than in the case of ordinary people who do not have the possibility of some exposure in their work. The exposure accumulated depends very strongly upon the method of using the equipment. For instance, in fluoroscopy the careless use of long periods of observation with inadequate filtration will lead to very high dosages, whereas the use of a few well chosen short intervals will reduce the exposure tremendously.

Another type of X-ray machine which has become quite common in recent years is the shoe-fitting fluoroscope. If designed and used properly, such machines are no doubt safe. However, some machines do give excessive exposure to the feet. There is also a possibility

of serious overexposure from multiple use of the machine at a single visit to the shoe store while clerks may be overexposed as a result of scattering or if they place their hands in the beam during operation. For these reasons public health officials are inclined to oppose the use of such machines. Considerable literature is accumulating on this subject, but an article by Lewis and Caplan¹⁰ summarizes the data and gives a bibliography. Their conclusion is that during a twenty-second fitting, the feet of an individual will receive 10 to 15 roentgens exposure from the average machine, but that there have been cases as high as 100 roentgens.

RADIUM BEARING LUMINESCENT PAINT is quite widely used on watches and clocks. Of the order of one microgram of radium is found on the average wrist watch, while clocks and airplane instruments may run as high as 10 to 100 micrograms of radium. Considerable beta radiation escapes from the face of a wrist watch, but only gamma radiation from the back, and the dosage rate amounts to less than a mr per hour in most cases. However, in one instance that came to light at this Laboratory, it was learned that an individual had worn a radium dial pocket watch for 24 years in the same pocket with the face toward the body. A film measurement of the dosage rate and a suitable estimate of the length of actual wearing time revealed that a skin exposure of 1000 to 2000 roentgens had accumulated. This is presumably not serious since it was distributed over a long period of time and restricted to a small area of skin.

Radiation at the faces of airplane instruments may be as much as 5 to 10 mr per hour and there are many instruments with luminous dials in the cockpit of a large plane. However, at the pilot's position, levels of one mr per hour or less have been noted in several types of aircraft.

IN CONSIDERING THE BIOLOGICAL EFFECTS of radiation, it is necessary to distinguish between an acute exposure, i.e. one received in a matter of seconds or minutes, and one spread over a long time. In both cases there is a lag between the actual exposure and the resulting effects that may be a few hours, a few days, or many years. The details are the proper concern of the biologists and medical doctors but others can understand the general nature of the effects.

In regard to the acute exposures, although the data on humans is far from complete, there is a fair body of information. Table 5 is a convenient summary and

Table 5. Physiological Effects of Acute Whole Body Radiation Exposure

0-25 r	No immediate effects
25-50 r	Some effects on blood picture, no illness
50-100 r	Nausea and other effects in some
100-200 r	Radiation sickness, good recovery
200-400 r	Severe effects and increasing mortality
over 400 r	Fatal in most cases

should be borne in mind in planning and carrying out civil defense operations. This table deals only with manifestations appearing in the weeks immediately following exposure. In addition, long delayed effects may be anticipated.

Exposures spread out over long periods of time are difficult to evaluate. Such exposures, if sufficient in magnitude, will cause harmful changes in the blood forming tissue and the blood itself, increased incidence of cancer, shortening of the life span, loss of fertility, genetic changes, etc. A detailed discussion is hardly appropriate for this article but an engineering guide in controlling such exposures is furnished by the maximum permissible exposure limit which has been promulgated by the International Commission on Radiation Protection.¹¹ This consists of 300 mr per week of whole body exposure to X or gamma radiation as the basic limit with appropriate reductions in the case of certain other types of radiation, such as neutrons, to allow for their higher relative biological effectiveness. This exposure limit has been chosen as one that, while not guaranteeing zero damage over a period of 20 or 30 years, is thought to be low enough so that there will be no more harm to an individual than results from commonly accepted indulgences.

It is important for scientists to realize that the exposure limits just described are technically well founded and not overly conservative when applied as intended, i.e. for continuous exposure over long periods of time. Naturally, short periods of exposure can safely be higher. In case of civil defense emergency where the exposure will not continue indefinitely and where a statistically higher risk is acceptable, much higher exposure levels may be necessary although certainly not desirable.

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