By BARRY COMMONER and RICHARD DALY

WHAT IS THE HARM OF NUCLEAR TESTING TO HUMAN INHERITANCE?

THE POSSIBILITY that radiation from nuclear tests may cause hereditary defects in future generations is one of the most troublesome issues of this troubled time. The harm of high doses of radioactivity to inheritance in animals and plants has been well known for more than 35 years. Since massive testing of nuclear weapons began to spread radioactivity across most of the globe, concern that the smaller doses due to fallout might have a similar, if less striking effect in man has been widespread. It is impossible to cure this concern by removing its cause, for the radioactivity from nuclear testing, once released, cannot be eliminated from our environment until it slowly decays of its own accord.

Although the problem was first thrust upon us with the advent of large-scale nuclear testing more than fifteen years ago, the basic question, "Will it harm the inheritance of our descendants?" is only now beginning to be answered. Of more immediate interest is the further question: "If the hazard, once created, cannot be removed, what is the significance of the international agreement, now at its first anniversary, to ban nuclear testing in the atmosphere?"

Because of important advances in our understanding of the effects of radiation on human inheritance during the past few years, and extensive consideration of the problem by technical committees in the United Nations and within the United States, it is possible, at this time, to provide certain rather firm, if incomplete, answers to these questions. The chief answers are these: The nuclear weapons that have been tested so far will cause a proportionally small but definable increase in the number of human beings who are born with inherited defects during the next 10,000 years. If nuclear testing had continued beyond 1962, this number of defective births would have been significantly increased.

The original uncertainty as to whether radiation from fallout would have any effect at all on human heredity is understandable. When the problem first came to public attention about eight years ago, our knowledge of the basic connection between human inheritance and radiation was insecure at certain crucial points. Enough was known about the mechanism of inheritance in animals and man, and about the effects of radiation on it, to suggest that radiation from fallout would have some harmful effects on future generations. But no one was sufficiently sure of the facts to say how much damage would *certainly* occur. A hope remained in some minds that there might be no biological price-tag at all attached to nuclear testing.

The known, well-established facts at the time were these: In people, as in all animals and plants that reproduce sexually, inherited characteristics are transmitted from parents to child by the chromosomes that are present in the sex cells, the egg and sperm. Some of these characteristics, such as facial features, are very complex and although they are clearly affected by inheritance, we do not know just how this comes about. But other inherited characteristics, such as eye color, follow fairly simple rules of transmission from parent to child. In these instances, we know that the appearance of a particular characteristic in the child is regulated by a genetic factor, or gene, which occupies a particular position along the length of one of the 46 chromosomes carried in the cells of normal human beings.

Studies of inheritance, not only in man, but much more elaborately in experimental animals such as fruit flies or mice, have shown that a gene localized at a given place on a chromosome can exist in several, or even many, forms. So, the gene for eye color in man can occur in a type which induces blue eyes, or, alternatively, in a type which induces brown eyes. And at rather rare intervals such a gene may change its type — say from brown to blue eyes — or *mutate*. As a result many of the inherited differences among people, as among all living things, are due to such mutations. Once such a mutation occurs, it is passed on from generation to generation until all the individuals bearing it die without offspring. The mutation will not disappear as long as the individuals bearing it continue to reproduce.

Most chromosomes and the genes that they carry, occur in pairs; one member of the pair being contributed by the father, and the other by the mother. Some inherited characteristics will appear when the controlling gene is present singly; such genes are called *dominant*. When the characteristic appears only if a pair of the controlling genes are present, the gene is called *recessive*.

Added to the basic biology of inheritance was the important fact, first established by experiments in 1927, that x-rays and other forms of radiation, if sufficiently intense, greatly increase the frequency with which mutations appear. One cause of the natural mutation frequency is natural radioactivity from rocks and cosmic rays, to which we are constantly exposed.

Finally, it was well known, from a considerable number of laboratory studies, that the overwhelming majority of all mutations that arise in natural populations or in irradiated ones tend to be harmful, and either kill the organism or make it less likely to survive. Very few are innocuous, as is the change of a gene causing brown eyes to one causing blue eyes. In man, several hundred defects of various degrees of seriousness (see p. 25) are known to be due to specific, mutable genes. Therefore, whenever radiation causes an increase in mutations, the chances are overwhelming that these changes will be harmful ones. And so, in a general way, it was known that radiation has a potentially harmful effect on inheritance.

But it is not immediately apparent how this general knowledge about inheritance, and the effects of radiation on it, ought to be translated into a definite answer about possible genetic effects of radiation from fallout.

One important problem is the determination of how different dosages of radiation influence the frequency of mutation, and therefore the degree of biological harm. There have been two conflicting theories about the matter. According to one theory, very low levels of radiation do not increase the frequency of mutation, so that the total radiation to which a person is exposed needs to reach some *threshold* value before it begins to show any effect on inheritance at all. Since radiation dosages due to nuclear testing are rather low when compared to the intense radiation used to induce experimental mutations, this theory permitted the conclusion that nuclear testing might have *no* effect on human inheritance at all.

According to the alternative *linear* theory, there is no threshold in the radiation dosage effect, so that *any* amount of radiation, however small, will increase the frequency of mutation — and the resultant genetic harm — by an amount proportional to the total radiation received. In this case, even the low radiation dosages from nuclear testing would have *some* effect on the frequency of harmful mutations.

Although early experimental genetic studies of radiation appeared to follow the linear rule, they were based on radiation dosages much higher than those that might be given by radioactive debris from nuclear tests. Some uncertainty existed about which theory was applicable at the relatively low radiation levels actually encountered as a result of nuclear testing. However, by painstaking experiments with mice and fruit flies, geneticists pushed their studies to increasingly smaller radiation doses. Thus, in 1961, Dr. Bentley Glass, a geneticist at John Hopkins, using dosages of five roentgens — an amount which approximates the total radiation exposure, from all sources, of a person's sex cells during the span of the reproductive years — showed that the linear effect was operative even at these low dosages.[1] At the present time the linear theory of genetic radiation effects is accepted as established.

Geneticists have recognized therefore that radiation resulting from nuclear testing, however small or large it might be, would have some influence on the rate of mutations in the human population, would increase the total number of harmful mutations by an unknown amount, and thereby have some harmful effect on human inheritance.

But without further work nothing more definite could be said. For example, no estimates of the *number* of harmful mutations could be made, because it was not known what numerical increase in mutation frequency would result from a given amount of radiation. This relationship is usually expressed as the *doubling dose* — which is the amount of radiation that will just double the frequency with which a mutation occurs. This number is readily determined for experimental animals by measuring the frequency of mutations when animals are exposed to a series of different radiation dosages. From such experiments with laboratory animals, it was generally estimated that the doubling dose of radiation for man was probably somewhere between 10-100 rads with 30 rads being the most likely value. This means that a 30 rad exposure would double the incidence of harmful mutations, and that, in accordance with the linear theory, a three rad exposure would cause a ten per cent increase in such mutations.

But there is an important difference between the radiation exposure of experimental animals and the radiation exposure that people experience from nuclear testing. In most experiments, the animals are irradiated for short times; this means that the total dosage of radiation is received at high intensity, rather than at low intensity for a long time. On the other hand, the radiation from nuclear testing is due to long-lived radioactive atoms that are incorporated into the human body. As a result, the sex cells are exposed to chronic radiation, at low levels, but for a lifetime. Might the same total dosage of radiation have different effects on mutation rate when delivered in short intense bursts, then when delivered continuously but with a weak intensity? If so, the doubling dose based on experiments with laboratory animals could not be properly applied to the calculation of possible genetic harm to people from nuclear testing.

In 1958 an important experiment was reported by Dr. W. L. Russell from the Oak Ridge National Laboratory,[2] in which the effects of the same dosage of radiation on mutation frequency in mice was compared under two conditions: (a) delivered at high intensity for a short time, and (b) at low intensity for a long time. It was found that the long-time exposure at low intensity appreciably *reduces* the mutation-causing effect of a given dosage of radiation. Taking these and related experiments into account, the most intensive evaluation of this problem, reported in 1962 by the U. N. Scientific Committee on the Effects of Atomic Radiation[3] raised earlier estimates of the doubling dose for man and set it at about 240 rad. Because of other uncertainties involved in using animal data to estimate human responses to radiation, the Committee recommends that this figure be regarded as the most likely value, with possible values lying between 80 and 720 rad.

Thus, intensive scientific consideration considerably improved our knowledge of the genetic effects of radiation from nuclear testing. In particular, the clear establishment of the linear theory of radiation effects and the clarification of the doubling dose made it possible to calculate the number of harmful mutations that might be expected — provided that the actual radiation exposure from nuclear testing was known. And here, too, important scientific improvements were needed, and accomplished.

WHEN SOME OF THE BASIC FACTS about radioactive debris from nuclear tests were released from secrecy restrictions and made available to the scientific community, beginning in 1954-5, government reports stated that the chief long-lived radioisotopes of biological importance were strontium 90 and cesium 137. Strontium 90 concentrates in the bones, and since the sex cells are at some distance from the nearest bones in the body, radiation from this isotope was, according to the reports, of little significance. On the other hand, cesium 137 penetrates all the soft tissues of the body. It was therefore believed to be the only important source of radiation exposure to the sex cells.

With this conclusion in hand it was then possible to calculate the radiation exposure of human sex cells resulting from nuclear testing, for various measurements of the cesium 137 content of different populations had by then been made. It also appeared that the genetic harm from nuclear tests would not increase after a few generations — if nuclear tests were stopped. Because the half-life of cesium 137 is about 30 years, in each succeeding 30 year period the exposure from this isotope becomes halved and finally approaches the vanishing point. Also, the residence time of cesium 137 in the body is relatively short.

However, this turned out to be an over-optimistic view. In 1957, Prof. Linus Pauling in the U. S., as well as Soviet investigators, pointed out that another radioactive isotope — carbon 14 — until then given little consideration as a biological hazard, was also an important product of nuclear explosions. Unlike strontium 90 and cesium 137, carbon 14 is not part of the immediate radioactive debris of the nuclear fission reaction. Instead, this radioactive element is formed when neutrons, which are copiously produced by every nuclear bomb, collide with the ordinary nitrogen atoms that make up 80 per cent of the air. Carbon is an extremely common element in the body, so that carbon 14 is incorporated into all tissues and becomes a source of radiation exposure to the sex cells. Indeed, calculations, which have now been amply confirmed by U. S. agencies and the U. N. Committee, showed that the exposure of human sex cells to radiation from carbon 14 is several times greater than that due to cesium 137 over a long period of time. (See table of Radiation Doses.)

The carbon 14 discovery had another unfortunate effect on the estimates of what genetic harm would result from nuclear testing. So long as cesium 137 was believed to be the chief culprit, we could count on no further addition to genetic damage after a few generations. But, whereas the half-life of cesium 137 is 30 years, the half-life of carbon 14 is 5600 years. This means that even though nuclear testing is halted, additional radiation from carbon 14 — which accounts for about two-thirds of the total hazard — will last for thousands of years, and will be experienced not by a few generations, but by hundreds of generations.

THE DISCOVERY OF THE HAZARD to heredity from carbon 14 also means that the situation cannot be improved by the use of so-called "clean" nuclear bombs. Cesium 137, *strontium 90, and other constituents of fallout* are debris from the nuclear fission reaction, which is the power source used in older types of nuclear bombs. In modern hydrogen bombs the main explosive power comes from a *fusion* reaction of heavy hydrogen, which is set off by a fission trigger. Fusion bombs are usually much larger than the older fission bombs, but since the fusion reaction does not produce fallout from the material of the bomb itself, such bombs are sometimes called "clean." However, *every* nuclear reaction, whether fusion or fission, produces large numbers of neutrons, and therefore a large amount of carbon 14. So, when it became known that carbon 14 was the major source of the hazard to heredity from nuclear testing, it became clear as well that the danger could not be escaped by the use of "clean" bombs.

Thus, within the last few years we have finally achieved an apparently full accounting of how much radiation produced by nuclear explosions and taken up by the human body would be delivered to sex cells, where it can cause an increase in the frequency of harmful mutations.

Since the genetic harm is represented by the total number of mutations that occur in the population, the radiation dose we need to know is that received by the sex cells in all the reproductive members of the population. This can be estimated for one generation's reproductive period (30 years) and for the total period of time — many generations — in which this radiation will exist.

The following figures are given by the latest U. S. report on the subject by the Federal Radiation Council, for nuclear tests through 1962.

RADIATION DOSE TO SEX CELLS FROM NUCLEAR TESTING

Source	Dose to sex cells in a 30-year period	Dose to all human sex cells in the period of carbon 14 radioactivity (more than 10,000 years)
Fission Fallout	.085 rem	.085 rem
Carbon 14	.025 rem	.250 rem
TOTAL	.110 rem	.335 rem

These values, like most of those related to such complex problems are approximate, and represent broad averages for the entire world population. In some areas the radiation levels are much higher than the average; *in others they are much lower. Nevertheless,* these average values are sufficiently reliable to permit an estimate of how many harmful hereditary mutations of the type discussed above have been caused by nuclear testing to date, and how many more would have been brought about if the Test Ban Treaty had not halted such explosions.

For such a calculation, four values are needed:

1) The doubling dose.
2) The total dose of radiation to which the population is exposed over the time that such radiation persists.
3) The size of the population exposed to the radiation and the proportion of this population that is capable of reproduction.
4) The normal frequency (i.e., in the absence of added radiation) with which a particular hereditary defect appears in the population.

We have already indicated how the first two values can be obtained. Estimates of present world and national populations are of course available. However, to calculate carbon 14 effects we really need to know the size of the population thousands of years from now. But since this is a very uncertain figure, and would introduce considerable additional complications into the calculations, the growth of the population is usually ignored, and the calculations are based on the *present* population size. This gives a useful result. But it must be remembered that it is smaller than the actual one, for the number of harmful mutations will be greater if the population is larger, as it surely will be during the period of the carbon 14 hazard.

Finally, in recent years, geneticists have made intensive studies of the frequencies with which harmful mutations appear in human populations. According to a summary of this work in the recent Federal Radiation Council Report,[4] the total incidence rate of severe mental and physical defects which are exhibited at birth, or known to be hereditary, is about four or five per cent; i.e., such defects appear in about one in twenty or one in 25 births. But some of these defects are not hereditary, and others, although hereditary, are not of the type in which incidence is proportional to mutation rate. The FRC report estimates that serious defects which do reflect the mutation rate — and will therefore be influenced proportionally by a radiation-induced increase in that rate — have a frequency of about two per cent. Thus, the value of the radiation-sensitive natural frequency of seriously harmful hereditary effects is about two per cent.

Once the four values are known, the number of extra mutations which cause harmful hereditary diseases resulting from radiation exposure can be computed from a simple formula:

$$\text{Number of Extra Mutations} = \text{Population Size} \times \text{Natural Frequency} \times \frac{\text{Total Dose}}{\text{Doubling Dose}}$$

The use of this equation is somewhat complicated, for it must be applied separately to the effects of cesium 137 and of carbon 14 in order to allow for the vastly different half-lives of these two radioisotopes, and the consequent difference in the duration of their effects on inheritance.

Taking this complication into account, the equation, and the available values of the component factors, is used in the FRC report to arrive at the following estimate of the number of those severe hereditary effects known to depend on mutation rate, that are due to nuclear testing completed to date.*

Approximate total number of defective births due to nuclear testing through 1962

Population	
U.S. (190 million)	4,800
World (3.2 billion)	86,000

"The loss of even one human life, or the malformation of even one baby — who may be born long after we are gone — should be of concern to us all. Our children and grandchildren are not merely statistics towards which we can be indifferent."

— John F. Kennedy
July 26, 1963

Of course, it should be kept in mind that the number of genetically defective births that occur naturally is a much larger figure than that reported above. The effects of nuclear testing will increase defective births by only about .02 per cent of that larger figure.

During the next 30 years, the extra genetic damage will be due to that part of the radiation exposure that comes from cesium 137; but carbon 14 will have an effect for a very much longer time.

What would the picture be if the test ban had not been put into effect and atmospheric testing had continued, at the rate of the 1962 tests (the last year of testing before the Test Ban Treaty) for 3 more years, 1963, 1964 and 1965?

In this case, the following serious genetic defects would have been induced by nuclear test radiation:

Approximate total number of births with severe hereditary defects due to nuclear testing if continued through 1965

U.S. Population	9,000
World Population	170,000

And suppose that nuclear testing were to continue, at the 1962 rate, indefinitely into the future. Then *in each generation* (30 years) the resulting radiation would cause in the U.S., about 22,000 additional births marred by serious hereditary defects; and in the world population 300,000 such additional births would appear in each generation, and in future generations so long as testing continued.

Thus, the original uncertainty about the possible harm to human inheritance from nuclear testing, and the

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* A technical paper which describes how these calculations are made is available from CNI on request.

effect of the Nuclear Test Ban Treaty in reducing it, has given ground before recent scientific progress. It can now be stated, with the same degree of certainty that is attached to most other scientific knowledge, that there *will* be some genetic cost from past nuclear tests, that this cost would have been, by now, appreciably higher if the Test Ban Treaty had not been adopted, and that it would go higher still if nuclear testing were continued indefinitely.

But we also know, with the same degree of certainty, that the figures cited above are too low to reflect the *total* harm of nuclear testing on human heredity. Although it is certain that there will be harmful hereditary effects other than those accounted for in these figures, we cannot at this time describe their frequency with any useful degree of precision. The number of harmful mutations from nuclear testing reported above represents only the best known part of a considerably larger effect, most of which is still only vaguely understood. The known increase is like the visible part of an iceberg; we know that there is more to it, but cannot see what that might be.

The reasons why we can be sure that the cited figures are a minimum estimate of the genetic hazard are the following: In calculating the above effects, the influence of radiation was estimated only for a series of about 100 specific gene mutations which are sufficiently well understood to permit a useful calculation of the doubling dose. But it is known that this list includes only one-fifth to one-fourth of the total number of serious defects of possibly hereditary origin to which human beings are subject. For example, some serious defects, such as mongolism, are not due to specific gene mutations, but to abnormalities in chromosome number. There are also good grounds for believing that this larger class of defects, like the better-known group, is sensitive to radiation, and will therefore be increased in frequency as a result of nuclear testing. However, because there is at this time no effective way to estimate the doubling dose for many of these defects, we cannot say how much their frequency will increase because of nuclear testing.

Another reason why the above numerical estimates are minimum ones is that they do not take into account less serious hereditary defects, which although not responsible for drastic medical impairment, do hamper the individual's life and can shorten his life span. The FRC report estimates that these less serious defects outnumber the severe mutations by five to one. Again, these defects are so poorly understood that any attempt to calculate the influence of radiation from nuclear testing on them would be futile. Nevertheless, they are there, and since all genetic effects seem to be influenced by radiation, it is probable that these relatively minor defects, like the more serious ones, will increase because of nuclear testing. Radiation-damaged inheritance will also increase pre-natal deaths, but the numbers are difficult to estimate.

THERE IS ANOTHER PHENOMENON which is even less well known, but which may turn out to be of considerable importance in determining the full effect of nuclear testing on inheritance. All of the effects that we have discussed thus far are due to radioactive elements, cesium 137 and carbon 14 in particular, that are fairly uniformly distributed throughout the soft tissues of the body and even within the different parts of the cell. As indicated earlier, the possible effect of strontium 90, which is also a prevalent product of nuclear testing, has been ignored because most of this element is concentrated in bone tissue. However, in recent years it has been discovered that certain elements, in particular calcium, although not found in large amounts in soft tissue, become highly concentrated in certain parts of the cell. It turns out that much of the calcium in a cell is highly concentrated in *the chromosomes* where calcium appears to play an important role in the structure of these gene-bearing cell constituents. And in recent years, it has been discovered that the element strontium, which is chemically similar to calcium, is also highly concentrated in the chromosome.

These results raise the serious possibility of a totally new kind of genetic hazard from fallout — that strontium 90, becoming concentrated in the very chromosomes which carry the agents of inheritance, the genes, will subject them to a much more intensive irradiation than was previously thought possible from the overall distribution of strontium 90 in the body.

This possibility has recently been tested by an experiment in which genetic defects were sought for in mice after the male parents were artificially injected with stontium 90.[5] The results were positive. Strontium 90 concentrated in the chromosome appeared to cause a significant increase in genetic defects. This problem is too new to give us anything more than a general suspicion that it might also affect human heredity. Nevertheless, the possibility that this newly discovered effect contributes to the overall hazard of nuclear tests to human heredity cannot be ignored and must be studied further. It is still another reason why we must regard the numerical estimates of harm to human inheritance from nuclear testing as *minimum* estimates.

THE FOLLOWING ANSWERS can now be given to the troublesome questions about the hereditary effects from nuclear testing:

Is there any effect of past nuclear testing on the frequency of human defects?

Yes, some increase must be expected. The number of births afflicted with hereditary defects, which generally occur with a certain frequency in human populations, will be increased slightly because of radioactivity resulting from past nuclear tests. Radiation from past nuclear tests will continue to add new harmful mutations to the human population over the next 10,000 years or more — until the extra radioactive atoms produced by nuclear tests decay.

How large is the increase in hereditary defects due to nuclear testing?

Meaningful numbers can be calculated only for a part of the effects of nuclear test radiation on heredity. For these (severe defects caused by specific gene mutations) we can expect, in the world population, some 85,000 defective births — in addition to the much larger number of such births that occur anyway — as a result of past nuclear testing. Additional defects will occur in numbers that cannot be estimated accurately, but which may be five to ten times greater than those due to specific mutations.

How has the nuclear test ban affected this situation?

If the test ban had not been established, and nuclear testing in the atmosphere had continued in 1963, 1964 and 1965 at the rate of the 1962 tests, the number of hereditary defects due to testing would have been approximately doubled. If nuclear testing had been continued indefinitely at the 1962 rate, testing would add, in each human generation, several hundred thousand individuals with serious hereditary defects due to specific mutations, and a larger number with hereditary defects of other types.

How "significant" are the harmful effects of nuclear testing on human heredity?

While this question is often asked of scientists, it cannot be answered scientifically. In one sense the effects expected from nuclear testing are "small" because they represent an increase of only a fraction of a percent in the defective births which occur in human populations under ordinary circumstances. But although this hazard is *proportionally* a small one, the entire world population is exposed to it. Considered in terms of the numbers of individual lives that will be affected, which ranges into the many thousands, the effect is not "small." The important point is that such evaluations are not at all matters of science. They are judgments which each individual must make for himself, in keeping with his own ethical, moral, or social outlook.

QUESTIONS ABOUT THE EFFECTS of nuclear testing on human inheritance — and the answers — are important to people all over the world. The idea that those now living on the earth have a responsibility toward the health and well-being of those who will succeed them cuts broadly across national boundaries and political differences. We all need to make our own judgments based on the now plain fact: nuclear testing, undertaken by some of the earth's present inhabitants to gain certain immediate benefits will force some members of future generations to pay the cost in hereditary defects.

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By ROBERT KARSH

Some of Man's Hereditary Defects

A WIDE VARIETY OF DISTINCTIVE TRAITS are genetically controlled by specific mutant genes which periodically express themselves in human populations. About 100 such traits that run the gamut from inconsequential to major abnormalities were listed by the U. N. Scientific Committee on Effects of Atomic Radiation. In toto, these genetically controlled traits appear in 11,212 of every million babies. They appear 7,993 times in every million persons of all ages. This means that the difference between these numbers, or 3,219 deaths in every million population, are attributable to genetic defects.

To be found in the long list of hereditary traits are such common benign conditions as a type of baldness (*alopecia areata*) which will appear in 700 of every million individuals and multiple bone spurs (*exostoses*) which are genetically forecast for 400 in every million. At the other extreme is the congenital trait of *obstructive hydrocephaly*. In this condition the fluid-filled cavity inside the brain cannot drain properly. The brain and skull swell to accommodate the growing blocked cistern and more often than not death results. This type of hydrocephaly appears in 1,230 of every million births, but only 25 survive per million population.

In between these extremes are a host of specific traits of varying severity. *Osteogenesis imperfecta* is a condition of extraordinarily fragile bones. It has an incidence of 60 per million births and 25 per million population; the mortality rate is high. Certain types of *deaf mutism* are hereditary. They appear in 46 per million births and 46 per million population; that is, these individuals carry their defect throughout life without a mortality disadvantage (their *socio-economic* burden is well known). Congenital *cataracts* (poor vision due to a birth defect in the lens of the eye) appear in 160 per million births. Certain cataracts which appear later in life (pre-senile and senile types) are predestined in 2000 per million births.

All of the above traits fall into the category of dominants. Only one of a gene pair controls the expression of the abnormality. In the category of recessive traits, it is necessary for both genes in the pair to be afflicted. Relatively benign conditions due to recessive mutations are *albinism* (absence of pigment in skin and eyes) which appears in 130 per million births and high *myopia* (severe nearsightedness) in 150 per million births. More serious are such traits as *gargoylism* in which deformities of the skeleton, brain, heart, liver, spleen, bowel and eyes are intermingled to result in a bizarre appearance and short life. Gargoylism appears in 20 per million births and 4 per million population.

Phenylpyruvic oligophrenia, another recessive trait, will serve as an example of how the gene expresses itself. This type of mental defect has an incidence of 100 per million births. The parents of the afflicted infant are both carriers of the defective gene (heterozygous, i. e., only one of the gene pair is mutant) and free of disease. The infant has the defective genes paired. The defect means that a specific enzyme which is essential to normal metabolism (phenylalanine hydroxylase) fails to be produced in the child. The enzyme deficiency blocks the metabolic removal of excess amounts of a particular food constituent (phenylalanine) and this effect in turn leads to severe mental deficiency. This disease has received much publicity recently because a simple test is available for its detection in the newborn. Once this disease is recognized, phenylalanine in the infant's diet can be reduced and, it is hoped, more normal development will then be possible.

Thus far we have given examples of traits due to defective genes carried in the 44 chromosomes which are not involved in sex determination. Analagous conditions result from defects of genes carried on the additional pair of sex chromosomes; these are sex-linked recessive traits. The classic example in this category is *hemophilia* or bleeder's disease, which appears in 100 per million births, and 66 per million population. The disease appears in males, but is carried in females.

Inheritance carried by defective genes may express itself in a wide spectrum of traits that range from the individual who is merely different to the one who is sick or doomed.

By JOEL ALAN SNOW and ALVIN W. WOLFE

RADIOACTIVITY IN ARCTIC PEOPLES

For the first time since weapons testing began, radioactivity in the bodies of people in an international population group is exceeding radiation protection guides.

In 1962, the cesium 137 in the bodies of Alaskan Eskimos and some other Arctic peoples was as much as 100 times the U. S. national average. In 1963, the Arctic levels of this radioactive fission product were 50 per cent higher than in 1962. This summer, 1964, levels doubled over 1963, with some maximum values exceeding Federal Radiation Council protective guidelines. There are indications that this contamination will continue to increase in the next few years, despite the ban on atmospheric nuclear testing. A remarkable combination of geographical and ecological factors has produced a possible hazard hardly envisaged until recently. More than a hundred thousand people may be affected.

On August 31, Senator Bartlett of Alaska called attention to the high radiation levels in Eskimos, and asked:

"How much longer can we expect contamination levels to rise in the Arctic? How much higher can we expect them to go? . . . What would they have been if testing had continued? What would become of the Eskimos and the caribou of the north if testing were to be resumed on a major scale for many years?"

This article will discuss the reasons for the high cesium 137 in Arctic peoples, and will propose some answers to Senator Bartlett's questions.

THE CESIUM STORY

Physical Distribution[1]

Fallout is not distributed evenly around the globe due both to the location of test sites and to meteorological conditions. Areas in the northern hemisphere between 30° and 60° with heavy rainfall have experienced the highest contamination. Arctic areas receive about one-fifth as much fallout as the midwestern U. S. There are seasonal differences in fallout, too; it is more extensive in spring when rainfall is heavy than at other times of the year.

Strontium 90 and cesium 137 have been of particular radiological interest, due to the large quantities of these two isotopes produced by weapons testing, their long physical half-lives, and their chemical similarity to elements normally incorporated in the human body.

These isotopes are produced at a late stage in the explosion of nuclear fission devices, being themselves decay products of primary fission products. At this stage any fragments are highly vaporized. The strontium 90 and cesium 137 particles can remain in the stratosphere for relatively long times if injected by an air burst. The particles are uniformly distributed in a band at a given latitude, and finally come down to earth in rain and snow. The stratosphere thus acts as a reservoir which accumulates the particles produced in explosions and distributes them gradually to the surface of the earth. Measurements have indicated that roughly two years is required for half the stratospheric content to be transferred to earth. Since strontium 90 and cesium 137 have half-lives of about 30 years, the radioactivity of the particles remains high even after it reaches the ground.

Danger of Fallout to Man

The fallout particles on the ground produce radiation much less intense than the normal background radiation due to cosmic rays and other natural sources. However, they become a potential hazard when they enter the human body in significant amounts. To do this, they must pass from the soil or vegetation upon which they fall, through edible plants and animals, culminating in man. In addition, the human body takes up only those radioelements that are chemically similar to or identical with elements normally incorporated in the body. This last condition severely limits the spectrum of hazardous radioelements. Strontium chemically imitates calcium, and is thus deposited in bone; cesium imitates potassium, and is taken up primarily in muscle tissues. When food contains both strontium and calcium, the body prefers calcium; but when both cesium and potassium are present, the body prefers cesium.

The fallout is subject to attrition from a number of sources throughout this cycle. Much of it is absorbed directly into soils or dissolved in bodies of water resulting in low volume concentrations. Much of that which falls on plant surfaces is washed away. Though some uptake into plant systems from the soil occurs, most of the dosage that reaches man arises from the surface contamination remaining on plants used as foodstuffs by animals and man. Plant-eating animals and fish generally excrete much of the material which they take in. In addition, diets are usually varied enough that foods which do have relatively higher fallout concentrations may not constitute a large proportion of the total food intake.

In the ecology of many Arctic peoples, however, almost all these mitigating factors are inoperative, and the fallout is routed to man with remarkable efficiency.

The Arctic Food Chain

Reindeer lichens are plants which have no real roots. They are attached to the ground by simple fibers which have no function in nourishing the plant. They get none of their nourishment from the ground, all of it from the air.

In 1959 it was found by Gorham, the Canadian botanist, that the unusual properties of reindeer lichens (principally Cladonia and Cetraria species) lead to high concentrations of fallout.[2] The special June, 1961 CNI study on Project Chariot[3] included a detailed study of the possible effect that lichens might have in leading to high strontium 90 concentrations. Relatively high strontium 90 concentrations in plants, animals, and human bone had already been measured.[4] In the summer of 1961 the first large cesium 137 doses were measured in Lapps.[5] Since then, various studies have been carried out by both U. S. and Scandinavian authorities, confirming the efficacy of the cesium 137 concentrating cycle.

Lichens exhibit remarkable resistance to climatic extremes, but their growth is extremely slow. A three inch high "reindeer moss" (Cladonia) may be 35 years old. In areas protected from high winds or on the forest floor, a dense mat of reindeer lichens may be found. They are thus unusually suited for the collection of radioactive debris from the air, which is then incorporated directly in their structure. Lichens present now may thus be expected to contain virtually all the fallout deposited upon them since the first weapons testing in 1945. In addition hardy grasses and sedges can accumulate significant, though much lower, fallout concentrations.

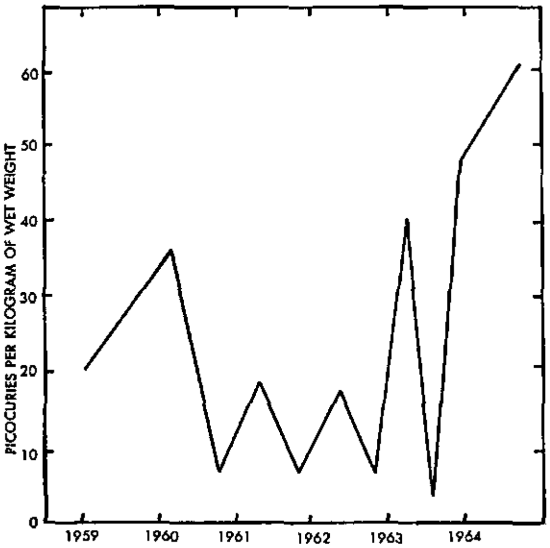

Fig. 1. Seasonal variations in cesium 137 in the bodies of reindeer.

Reindeer, caribou, moose, and deer may all subsist in Arctic regions at least part of the time on lichens, but for reindeer (and their American equivalent caribou) lichens constitute the main forage for almost nine months of the year. Only in summer do the animals eat plants which are relatively less radioactive: grass, sedges, leaves of willow, etc. Even so, their second most important food, sedge, is also relatively high in radioactivity. Consequently, the intake of radioelements by reindeer far exceeds that of any other animals. The cesium 137 goes into muscle, replacing potassium, while the strontium 90 goes primarily into bones, replacing calcium. Some strontium 90, however, is found in reindeer and caribou meat.

Measured levels of cesium 137 activity in reindeer meat show both the way in which activities have grown, and the seasonal variations due to changing diets (Fig. 1). When a reindeer changes to a less radioactive diet in the summer, more than half the cesium 137 in its body is removed in one month by natural elimination.

In addition to reindeer, smaller animals exhibit heightened cesium 137 levels. Moreover, aquatic food chains incorporating radioactivity have also been shown to exist, though activities per kilogram in fish of prey are small fractions of those in reindeer.

Reindeer travel in herds consisting of hundreds of members each; often with long established migration patterns between general areas, dictated in part, perhaps, by the character of the topography, or the snow cover. Since they virtually denude an area where they forage, they must move on continually to new areas rich in lichens — and radioactivity.

Most Lapps, many Eskimos, and certain other Arctic peoples, depend primarily upon reindeer for the necessities of life. The hides become clothing, the fats fuels, and the meat the principal food. The meat, laden with cesium 137 and strontium 90 may be cured, stored in burrows below the permanently frozen part of the earth, on outdoor platforms or dried for later consumption.

Studies of Eskimos and Lapps

Starting in 1961, studies of cesium 137 and strontium 90 in man, and in the entire Arctic biosphere have been conducted. Cesium 137 emits a gamma ray with a definite energy so the cesium in the body can quite accurately be determined by placing the entire individual in an especially designed counter which "sees" only this energy. Though certain corrections must be made, the technique is rather readily standardized. A summary of such measurements is given in Table I. For comparison, various radiation protection guides are given at the bottom of the Table.

As can readily be seen, maximum values are now near to or exceed recommended values by any of the listed standards, while individual guides are being approached. The "population average" protection guide is set lower than the individual guide to allow for individual variations within the group averaged.

A Laplander or Eskimo may eat about 100 kilograms (220 pounds) or more of reindeer meat in a year and can thus be expected to accumulate very substantial cesium 137 doses. The time required for half of the radioactive material to be removed from the human body by natural causes is roughly 100 days, but since the reindeer meat is eaten through much of the year, the

Table I. CESIUM 137 IN THE HUMAN BODY (in nanocuries*)

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Location	1961 Mean	1961 Max.	1962 Mean	1962 Max.	1963 Mean	1963 Max.	1964 Mean	1964 Max.	Source
ALASKA									
Anaktuvuk Pass			421	790	630	1,240	1,170	2,200	1,2,3,9
Kotzebue			138	518	150	732			2,3,9
Barrow			52	166	60	177			2,3,9
FINLAND									
Inari Lapps	261	790	307		646		1,105	2,660	5,6
Lapps							890		5,6
NORWAY									
Rural			91.8	162.5					7
SWEDEN									
Lapps	300		392		490				5,6
CANADA									
(Toronto)	33		24		56				8
U. S. (average)	4.8		3.9						2
FINLAND									
(urban)	54		17.9		16.4		33		5

Radiation Protection Guides for Cesium 137 in the Body (in nanocuries)

	Individual	Population Average
National Council on Radiation Protection	3,000	300
International Commission on Radiological Protection	3,000	300
Federal Radiation Council	3,000	1,000

1. Speech by Senator Bartlett of Alaska, *Congressional Record*, Aug. 31, 1964.
2. *Science*, 142:64, 1964.
3. AEC pubs. HW-77609 (Sec. 2).
4. AEC pubs. HW-76000.
5. AEC pubs. NP-13894.
6. AEC pubs. NP-13985.
7. *Nature*, 200:278, 1963.
8. *Can. J. Phys.* 41:1281, 1963.
9. *Science*, 144:859, 1964.

* A nanocurie is one-thousandth of a microcurie. See p. 40 for explanation of these measurements.

variations in body burden are much less pronounced in man than in reindeer. Due to the seasonal variation in concentrations in meat, measurements of cesium in people made in the summer (as most have been) are not necessarily representative of the whole year. Fig. 1 would imply that measurements which have been made in the spring would be considerably higher.

The details of the seasonal variation in man are not well established, and data have been taken at different times of the year. Burdens for females tend to be roughly half those for males, and those for children roughly one third the male average. Local variations in Alaska and Lapland alike depend directly on the percentage of meat in the diet.

Despite the fact that the information in Table I is incomplete, many general trends may be observed. The Anaktuvuk (Eskimo) and Inari (Lapp) people show the highest dosages and these dosages are very similar. The Anaktuvuk and Inari both utilize reindeer/caribou extensively for food. Kotzebue is a western coastal village in which marine life plays a significant dietary role, and Barrow is a village in which seafood plays a dominant role, though caribou are still eaten. Dosage levels in Barrow are ten times lower than Anaktuvuk levels. The columns 1961-1964 present measurements reported in sources listed at the right.

The data seem directly to reflect the processes described in previous sections. The dependence of dose on diet is seen from the Alaskan data (and is further verified by more extensive Finnish studies[7]). The general distribution of high cesium levels among Arctic peoples is substantiated by the 1962 data, though no USSR measurements seem to be available.

That similar food chains have a corresponding effect is attested to by measurements in 1963 indicating body burdens of about 120 nanocuries in Athapascan Indians at Fort Yukon,[8] whose diet consists principally of moose.

Strontium 90 Concentrations

Similar current data on strontium 90 concentrations do not seem to be available. However, a simple guess is possible based upon the finding in 1962 that some Eskimo caribou eaters had bone concentrations more than four times higher than the U. S. average concentration.[9] At that time the average level in bones of children in the U. S. was 2.9 strontium units and the estimated level in Eskimo bone was 12 strontium units.[9] The ecological factors for cesium 137 are similar enough to those for strontium 90 that the same percentage increase should occur. This would lead to a maximum value of about 36 strontium units in 1964 which approaches the RPG of 50 strontium units. One can also make one estimate based on the change in the U. S. average value which rose to 11 in 1963. If Eskimo levels remained four times higher, strontium 90 in Eskimo bone may have reached 44 strontium units.

Strontium 90 would be far more a problem if the milk of reindeer or caribou were consumed in quantity. However, it is known that the strontium 90 concentration in cow's milk in some parts of Finland markedly exceeds U. S. levels,[10] primarily since the poor pasture requires that the cows graze over a wide range, taking in the fallout that has been deposited over a large area. In cases in which lichens are used as supplementary cattle fodder, the strontium 90 and cesium 137 levels should both be markedly elevated. The Finnish investigator, Miettinen[7], gives a 1960 value for strontium 90 in Lapps as 7.5 strontium units. Using the same reasoning as above we would expect 1963 levels to be about 23 strontium units, and 1964 levels about 28 strontium units. At any rate Alaskans and Lapps, and presumably other Arctic peoples, have received a radiation dose from strontium 90 which should be more thoroughly investigated, particularly since it is added to high doses from cesium 137.

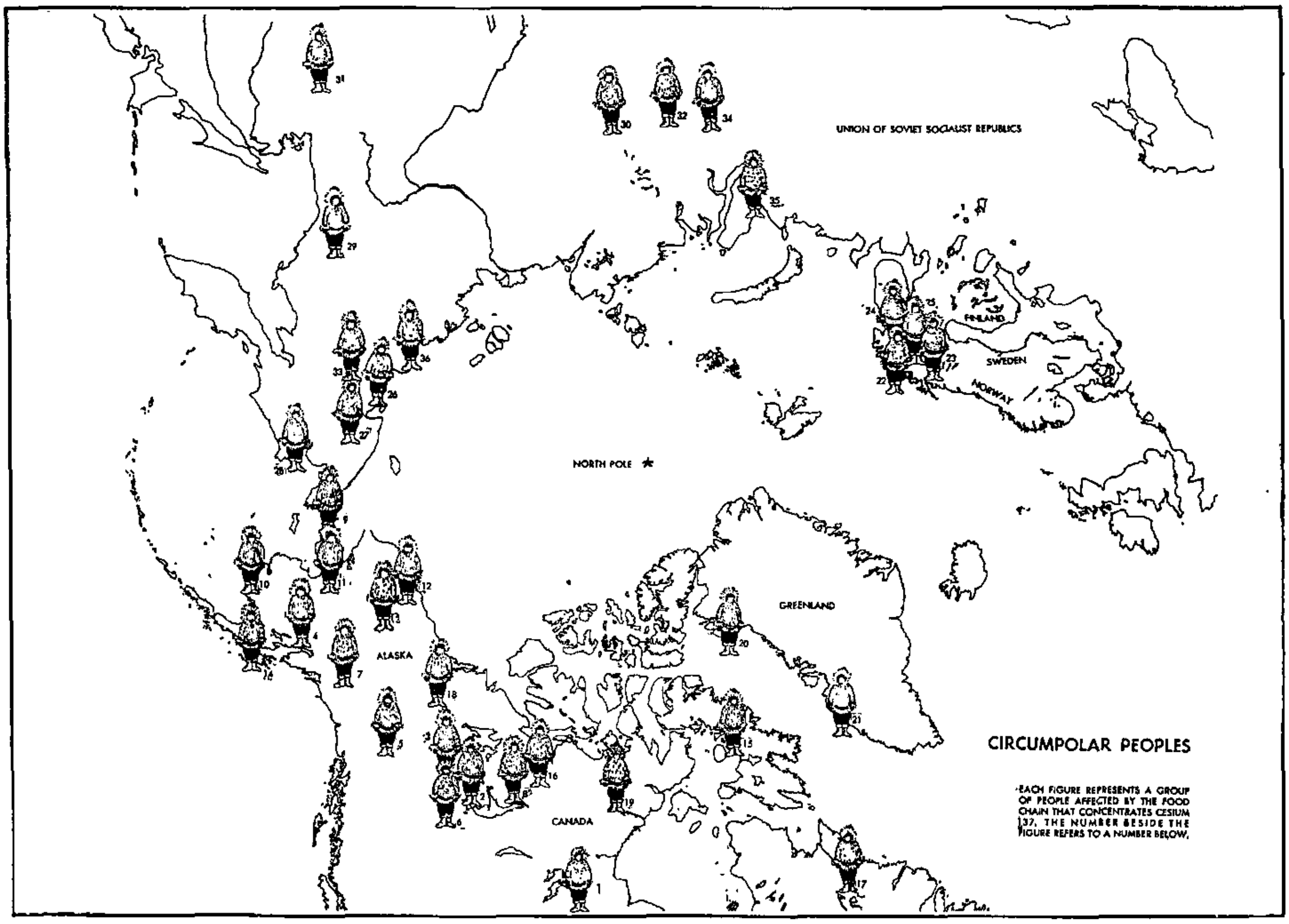
Natural Sources

Further evidence of the dramatic effect of the Arctic food chain is seen from study of the naturally occurring derivatives of radium, lead 210 and polonium 210, which are present in traces in the atmosphere, and have half lives of 19.4 years and 140 days respectively. The effective dose to Lapps due to these radionuclides has been estimated at 120 millirem per year.[7] This is comparable to the dose received from cesium.

POPULATIONS SUBJECT TO HIGH RADIATION

Because measurements of whole body radiation in the Arctic have been reported from only a few Eskimo and Lapp communities, the impression has been that the lichen-caribou-man food chain is characteristic of only a few people. Actually, this way of life, so efficient in concentrating certain radioactive isotopes, is followed with varying intensity by at least 27 anthropologically distinguishable populations.

In addition to the Lapps in Sweden and Finland and nine varieties of Eskimo in Greenland, Canada and the U. S., there are six North American Indian groups in Canada (Northern Chipewyan, Dogrib, Hare, Kutchin, Slave and Yellowknife) and eight Asiatic peoples in the U. S. S. R. (Chukchee, Chuvantsy, Evenki, Ket, Koryak, Omok, Samoyed, and Yukaghir) who use caribou or reindeer as a major source of food. The lichens are of course distributed over all the circumpolar lands, and the reindeer/caribou in these lands



CIRCUMPOLAR PEOPLES

·EACH FIGURE REPRESENTS A GROUP OF PEOPLE AFFECTED BY THE FOOD CHAIN THAT CONCENTRATES CESIUM 137. THE NUMBER BESIDE THE FIGURE REFERS TO A NUMBER BELOW.

Circumpolar Peoples	Population		Caribou or Reindeer	Freshwater or Seafood
NORTH AMERICAN INDIAN		4,150		
1. Chipewyan	1,000		X	
2. Dogrib	750		X	
3. Hare	750		X	
4. Ingalik			?*	
5. Kutchin	700+		X	X
6. Slave	800		X	X
7. Tanaina			?	
8. Yellowknife	150		X	
ESKIMO				
9. Asiatic	1,100		?	X
Alaska		15,882		
10. Aleut			?	X
11. Bering Sea			?	X
12. N. Alaska Coast			X	X
13. N. Alaska Inland			X	
14. Pacific-Chugash	200		?	X
Canada		9,493		
15. Baffinland			X	X
16. Copper			X	X
17. Labrador	1,000		?	X
18. Mackenzie	800		X	X
19. Netsilik			X	X
Greenland		24,498		
20. Polar			?	X
21. W. Greenland			X	X
LAPP		33,600		
22. Norwegian	20,000		X	X
23. Swedish	8,500		X	
24. Soviet	1,800		X	
25. Finnish	2,300		X	
ASIATIC PEOPLES		73,475		
26. Omok	500		X	
27. Chuckchee	11,500		X	
28. Chuvantsy	704		X	
29. Eveni	9,400		?	
30. Evenki	24,500		X	
31. Gilyak	3,700		?	
32. Ket	1,428		X	
33. Koryak	6,300		X	
Samoyed				
34. Ostyak (Selkup)	3,000		X	
35. Yurak	12,000		X	
36. Yukaghir	443		X	
Total numbers known to rely on caribou or reindeer in their diet, or probably using it to a considerable extent		161,098		

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* ? Indicates extent of dependence on caribou/reindeer could not be ascertained.

depend to some degree upon lichens for fodder. On both continents reindeer/caribou are found in areas not included in our survey (e.g. Mongolia) but their dependence on lichens does not appear great enough to produce the effect which here concerns us. The total number of reindeer/caribou in the world is not available to us, but the reindeer population in the Soviet Union alone is reported as approximately 2,000,000, so that this is not the rare animal it is frequently thought to be by Americans.[11]

The total human population which may reasonably be expected to demonstrate the high radiation counts for cesium 137 actually measured in a few Eskimos and Lapps mounts to approximately 110,000 when all the circumpolar peoples are considered. (The table below the map shows a higher total because it includes peoples whose reliance on caribou is less or is not known with certainty.)

The Lapps

There are currently approximately 32,000 Lapps, the vast majority of whom are heavily dependent on reindeer. This particular dependence is greater among the 12,000 Lapps in Sweden, Finland and the Soviet Union than it is among the 20,000 in Norway, where other food, such as that from the sea, is available.[12] Thus, a conservative estimate of the population exposed to the cesium 137 radiation through the lichen-reindeer-man food chain would be approximately half of the total number, or 16,000.

The Eskimos

A majority of the approximately 50,000 Eskimos depend on caribou or reindeer for at least a portion of their diet. Among fifteen identifiable Eskimo groups, six only are not reported to use caribou: The Polar Eskimo of Greenland, those of the Labrador Coast, and the Aleut, Pacific, Bering Sea, and Asiatic Eskimos. These six relatively small groups are the ones which give us our popular picture of Eskimo life: they use aquatic animals more than land animals, they use kayaks and umiaks on the sea, and some build snow houses. In fact, the nine Eskimo groups that use caribou are more numerous, and it is these that participate in the ecological arrangement so efficient in introducing cesium 137 into the human body. Kaj Birket-Smith[13] points out that the Eskimo on the Tundra of north-central Canada is as dependent on caribou as the Mountain Lapps is upon his reindeer herd.

While precise population figures for each Eskimo group are not available at this writing, an estimate of 30,000 for those groups which use caribou or reindeer more heavily than they use sea food seems reasonable. In this category are placed the North Alaskan Inland Eskimo, the Mackenzie, Copper, and Netsilik Eskimo, and some Baffinland and West Greenland Eskimos. The high dose reported in Table I above comes from a population that is North Alaskan Inland (or Nunamiut), while the lower doses, from Kotzebue Sound and from Pt. Barrow, are from populations classified as North Alaskan Coast, where sea food is more important.

North American Indians

In the sub-arctic regions of Canada, generally on the forest-tundra border, live a number of Indians whose economics include use of caribou.[14] Westward from Hudson Bay live some Chipweyan peoples, perhaps 1000, and then 800 Slave Indians; north of them, the Yellowknife Indians, perhaps no more than 150 now and 750 Dogribs; to the west of these, some 750 Hare and to the Alaska border another 700 Kutchin. Thus in the District of Mackenzie and in Yukon Territory, are some 4000 people potentially subject to high radioactivity. To our knowledge, no measurements have been taken on these populations.

Asiatic Peoples

East of the Lapps are many different cultural groups who have in common a heavy reliance on reindeer for subsistance.[15]

First there are two major Samoyed groups, the Yurak Samoyed who number approximately 12,000, and the Ostyak Samoyed or Selkup numbering about 3000. The Samoyed live just south of the Soviet test site at Novaya Zemlya. Their immediate neighbors, the Ket, are less numerous, totaling but 1400. The Evenki, frequently referred to as Tungus, include 24,500 persons for whom reindeer herds are the important possession. Another small group, 500 Omok, must be included. Passing over the numerous Yakut and Eveni to whose diet reindeer does not make an important contribution, we come to the Yukaghir, an anthropologically significant reindeer breeding group on the Arctic circle despite their small number, about 400. To the north and east of them, live 11,500 Chukchee, in contact with the North American Eskimo. South of the Chukchee, but still in lichen-reindeer territory, live 700 Chuvantsy and 6300 Koryak. Lichen-eating reindeer is a substantial item in the subsistance economy, then, for slightly more than 60,000 people in the Asiatic U.S.S.R.

Putting all the figures together - - 16,000 Lapps, 30,000 Eskimos, 4,000 American Indians, and 60,000 North Asians - - we find 110,000 people living in the circumpolar area, and subject to the same conditions which have produced doses of radiation exceeding the RPG.

Table II. ESTIMATED CESIUM 137 IN THE BODIES OF ARCTIC PEOPLES IN THE FUTURE

Location	If no further testing				Had testing continued	
	1965		1968		1965	
	Mean	Max.	Mean	Max.	Mean	Max.
Alaska						
Anaktuvuk Pass	1,480	2,740	1,760	3,410	2,420	4,300
Kotzebue	320	1,540	412	1,820	470	2,980
Barrow	88	1,240	94	280	112	340
Finland						
Inari Lapps	1,440	2,190	1,720	3,560	2,400	4,900

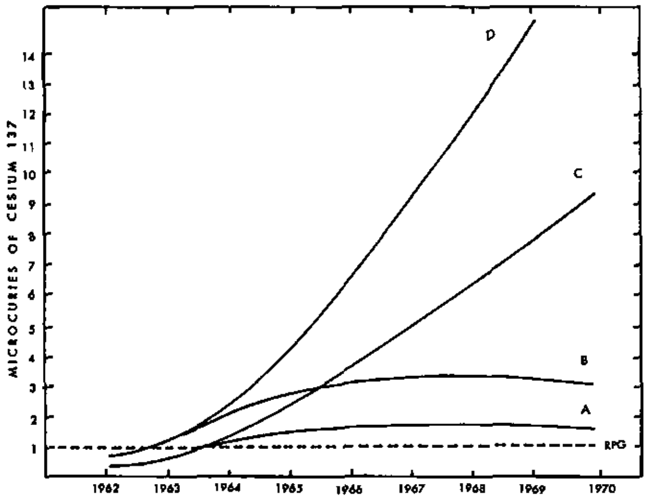

Fig. 2. Predicted levels of cesium 137 in the human body, Anaktuvuk Pass, Alaska.

A. Average levels, no further testing.
B. Maximum levels, no further testing.
C. Average levels, continued testing at 1962 rate.
D. Maximum levels, continued testing at 1962 rate.

THE OUTLOOK WITH AND WITHOUT TESTING

ATMOSPHERIC TESTING ceased two years ago, yet the cesium 137 levels in the Arctic peoples continue to climb. This is due to the time it takes for fallout to descend from the stratosphere, and to the time it takes for it to move through the food chain. While the far northern peoples have received a dose of cesium 137 from the 1961-62 testing, reflected in the increased levels measured in 1963 and 1964, much of the cesium 137 from 1961-62 testing has yet to reach man.

How much longer can we expect contamination levels to continue to rise in the Arctic? How much higher can we expect them to go?

We can now answer Senator Bartlett's first questions by saying that the cesium 137 levels in the bodies of Arctic people will probably continue to rise until 1968. They should begin to drop off slowly in 1969 or 1970. This is shown in Fig. 2, Line A, and in Table III.

It can be estimated that the levels in Anaktuvuk will reach *an average* of approximately 1500 nanocuries, 50 per cent above the protection limit set by the Federal Radiation Council and five times that of the National Council on Radiation Protection and the International Commission on Radiological Protection.

Although these estimates are believed to be conservative, they cannot be considered precise.

Maximum values in individuals will probably reach about 3500 nanocuries. This is also well past all protection guides, as shown in Line B.

What would levels have been if testing had continued?

If testing had continued at the 1962 rate, through 1965, cesium 137 in the bodies of Anaktuvuk people would be expected to average 5,000 nanocuries by 1967. This is shown in Line C. The same line shows that indefinite continuation of testing at the 1962 rate would bring the average up to 9,000 nanocuries by 1970, nine times the FRC guide, and thirty times the guides of the National and International bodies on Radiation Protection.

Line D, indicating the maximum levels in individuals if testing continued, goes completely off our graph in

1968 at a level of 14,000 nanocuries, almost five times the protection guides.

In the event that tests begin again, the same pattern evident following the moratorium would ensue: First, no effect because of the time it takes for the radioactivity to descend and move through the food chain, then a quickening climb, as indicated by Fig. 2.

CONCLUSIONS

As long as the people of the Arctic continue to eat the same food, relationships such as these will hold and dosage levels will be high. The food chain could be altered by provision of an alternate fodder for reindeer, by developing new food sources, or by resettlement of the peoples. Any such solution would profoundly affect the cultures of all the peoples in the circumpolar area. The data indicate that at least two fallout constituents (strontium 90 and cesium 137) should well exceed the suggested maximum levels over the next few years in peoples who may already be subject to high natural radiation. A full evaluation of the total exposure to these people from all possible sources would thus be desirable, so that any possibility of damage can be assessed.

Evidently peculiarities in the natural environment may exist which can lead to unforeseen potential hazards. The very biological conditions which permit these Arctic people to survive in the face of a hostile environment have led to their exposure to contamination by radioactive fallout.

CARIBOU

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By ROBERT WURTZ

RADIOIODINE | *its ups and downs*

THE TEST BAN has virtually eliminated fallout of iodine 131. Unlike strontium 90, cesium 137, or carbon 14 fallout, which continue for years after the testing has ended, iodine 131 fallout stops within weeks after the testing stops.

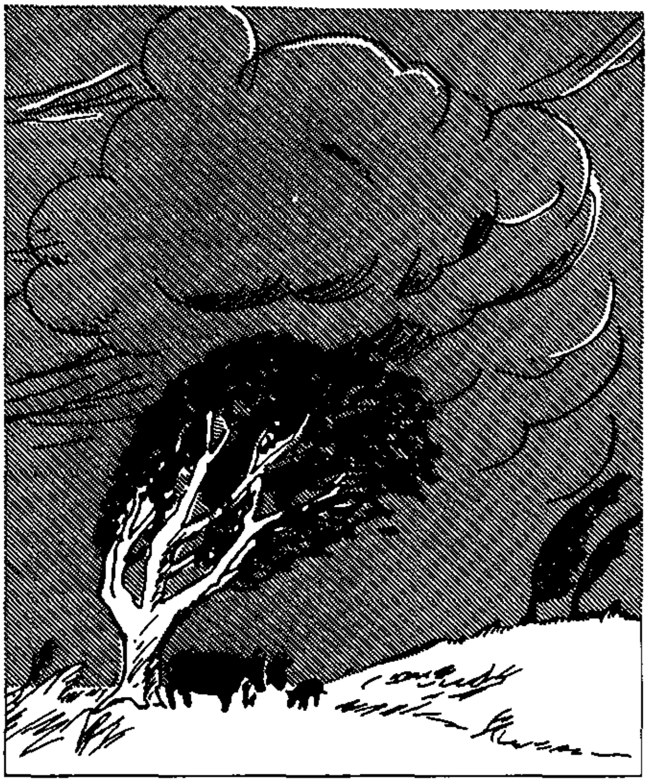
The characteristic which sets iodine 131 apart from these other fallout products is its short half-life. One-half of its radioactivity decays every eight days. Within a month, 95 per cent of its radioactivity is lost. Therefore, when testing in the atmosphere ended, no further iodine 131 was released; that already produced was gone within a month.

Radioactive iodine is produced as a gas in every nuclear explosion, and when the explosion is above ground, it is carried into the atmosphere with the other nuclear debris. Part of this iodine 131 remains in the lower atmosphere. Fallout from this low level can descend in a few days, so the iodine 131 can reach the ground before it has had time to decay in the atmosphere. The fallout does not occur uniformly. Instead, rain carries the radioactivity to the ground in far higher amounts in some places than others. These areas of high radioactivity, the size of counties or states, are termed "hot spots."

Once on the ground, the iodine 131 enters our diets largely through milk. When the pasture is contaminated, cows consume large quantities of iodine 131 in the grass they eat. This radioactive iodine is concentrated somewhat in the milk produced. The milk in turn is speedily transported to market so that the path from bomb to atmosphere, to grass, to cow, to milk, to table is readily traversed before the radioactive iodine has had time to decay.

Once the milk is ingested, the iodine is concentrated in the thyroid gland just as is non-radioactive iodine. There the radioactivity may produce damage to thyroid cells and this damage may eventually manifest itself in the development of thyroid cancer. This radioactivity presents a greater hazard to infants and children than to adults partly because children in this country generally drink more milk than adults and, therefore, tend to get more iodine 131. But even the same quantity of iodine reaching the smaller thyroid gland of the infant would have a higher probability of damaging the thyroid cells because the radiation is concentrated in a smaller mass. Finally, the infant's thyroid may be more sensitive to cancer-induction by radiation. Thyroid cancer has been observed in children after a single exposure to 150 rads,[1] a far larger dose than has been received from fallout. The smallest dose capable of inducing cancer is not known, but it is generally assumed that the frequency of induced cancer may be proportional to dose, even down to very low levels of exposure. On the assumption that there is no threshold, it has been estimated that if one million infants were exposed to one rad of thyroid radiation, 35 would be expected to develop thyroid cancer.[2]

PEOPLE LIVING IN SOME AREAS in the United States have received doses in this range by drinking milk contaminated by iodine 131. CNI has estimated[3] that during



Iodine 131 fallout does not occur uniformly. The vagaries of wind and weather conditions bring the radioactivity to the ground in far higher amounts in some places than in others. These areas of high radioactivity, which may be the size of counties or states, are called "hot spots."

1952 and 1953 one to ten rad doses or more to infant thyroids may have occurred in a number of "hot spots" including areas near Salt Lake City, Utah; Boise, Idaho; Great Falls, Montana; Grand Junction, Colorado, Albuquerque, New Mexico; and points as far away from the Nevada test site as Boston, Massachusetts and Troy and Albany, New York. Infants in the New York areas are estimated to have received doses to the thyroid as high as 30 rads.[4]

Local fallout near the Nevada test site is likely to have produced even higher fallout levels of iodine 131. Children in Washington County, Utah, for example, are estimated to have received thyroid doses in the 5 to 100 rad range or higher on at least seven occasions since 1952.[3]

In addition to these areas in which there have been estimated doses above a rad on specific occasions, children in many other places are known to have received tenths of a rad from iodine 131 in their milk. In 1961-1962 alone, before testing stopped, children in eight cities: Spokane, Wash.; Omaha, Neb.; Salt Lake City, Utah; Wichita, Kan.; Minneapolis, Minn.; Des Moines, Iowa; Kansas City, Mo. and Palmer, Alaska, received about half a rad and a number of other cities were exposed to more than a quarter of a rad. While these doses to the thyroid are considerably smaller than the doses cited above, they are still greater than the dose received from natural background radiation. As has been noted, since it is generally accepted that even small doses of radiation can be harmful, these smaller doses may also cause biological damage.

Should nuclear testing in the atmosphere resume, iodine 131 fallout would also resume. If testing were at the same rate as in 1962 with explosions at the same test sites, there is every reason to believe a similar iodine 131 pattern would be repeated. Hot spots would again occur, probably in many of the same areas. With the new fallout would come further biological damage to the thyroids of children. The new risk of damage would be added onto that received prior to the test ban even though the earlier radioactive iodine has long since decayed. As the radiation exposure of the thyroid accumulates, the risk of thyroid cancer increases.

RADIATION GUIDELINES

Before the test ban went into effect, iodine 131 was the only isotope in fallout which approached or exceeded the Federal Government's guidelines for radiation exposure. What these guidelines are, and how they have been changed for iodine 131, illustrate the difficulties encountered in establishing and executing radiation protection standards. These guidelines indicate what countermeasures against iodine 131 fallout the government may be expected to take, if testing resumes and iodine 131 again appears in the diet.

Up to the late 1950's, it was assumed that there was a radiation dose below which biological damage did not occur and above which it would occur — that is, there was a threshold. Setting safety standards then was an easy matter: keep the dose received below the estimated threshold. But now it is generally assumed that there is no threshold and that the possibility of biological damage exists even down to the lowest levels of exposure. Consequently, there is no limit to exposure that can be established as "safe." How, then, are standards to be derived?

Radiation standards are now *balances*. They balance the estimated biological damage of radiation to the human population against the benefits to society to be derived through the use of radioactivity. The scales to determine the balance are read by the Federal Radiation Council. This council consists of cabinet-level officials of the government, including the Secretary of the Department of Health, Education, and Welfare, the Secretary of Defense, and the Chairman of the Atomic Energy Commission. The facts for the scientific side of the balance are provided by scientific advisors. Since the FRC makes the assumption that there is no threshold, what is provided is essentially an estimate of the biological risk at various radiation levels. The benefits from the use of radioactivity are presumably determined by the FRC but there is no explanation of how this is done. This body also determines the balance between risks and benefits, but again there is no explanation offered as to how the balance is drawn.

The FRC expressed the balance point between risk and benefit as the Radiation Protection Guide (RPG). The guide was defined as "a radiation dose which should not be exceeded without careful consideration of the reasons for doing so," and the council suggested that "every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable."[6] The FRC went on to establish for the general population (as distinguished from radiation workers) a guide for each of several varieties of radiation. For iodine 131, the guide was set at 0.5 rad per year. In addition, to help maintain radiation doses as far below the guide as possible, the daily guides were set at levels of radiation which, if continued, would reach the guide level in a year. A daily level of radiation in milk of 100 picocuries would, within a year, produce a dose to thyroid of 0.5 rads, the RPG. The FRC also recommended that control procedures to reduce the intake by humans be initiated when iodine levels in milk reached the 100 picocurie per day level, and added that sharply rising trends above this level would suggest strong and prompt action.

In the spring and summer of 1962, a period of active nuclear tests, iodine 131 levels in a number of cities rose sharply and entered the range which required active countermeasures. In the following cities the accumulated dose of iodine 131 for a year exceeded 0.5 rad, the RPG: Des Moines, Iowa; Minneapolis, Minnesota; Kansas City, Missouri; Salt Lake City, Utah and Palmer, Alaska.[7,8] While local authorities in several areas, Utah and Minnesota in particular, instituted control actions, the Federal Government neither instituted controls nor recommended any of the protective actions called for by the radiation guides. Finally, in September of 1962, the chairman of the Federal Radiation Council, Secretary of Health, Education and Welfare Celebrezze, stated that the guide did not apply to fallout. This apparently relieved the FRC of the burden of recommending that countermeasures be taken, but it also raised a new problem. If the guides did not apply to fallout, no protection guides were available for the source that produced the radiation hazard affecting the most people — nuclear testing.

Twenty times safer?

This quandary remained until August of 1964 when the Federal Radiation Council issued a new report and new guidelines for the isotope that had exceeded the old guides. The guide for iodine 131 was placed at ten rads, twenty times the previous level.[9]

The balance point between risks and benefits for iodine 131 was altered. The same assumptions about children one year of age being the critical segment of the population, and about their thyroid gland size and uptake of iodine 131 were made in the new report as in the old report. No new evidence is presented to indicate that the health risk side of the balance has changed.

On the other side of the balance, a new factor has been introduced. The new factor does not deal with benefits to society; these presumably remained unchanged. The factor added was consideration of "the impact on public well-being associated with alterations of the normal production, processing, distribution or use of food," which would result if countermeasures were taken. The effect of the control procedures themselves now played a part in the balance. The Federal Radiation Council recognized two such countermeasures for iodine 131 as being the most effective, with a minimum of undesirable consequences. These are: 1) diversion of fresh milk affected by fallout to the production of dairy products such as butter or cheese which can be stored until the iodine 131 has decayed; 2) substitution of stored feed for fresh pasture until the iodine 131 in the pasture has decayed. The implication of the new FRC action is that these countermeasures have such great "impact" that the guide for iodine 131 must be set twenty times higher than previously.

The name of the guide was also changed from Radiation Protection Guide (RPG) to Protective Action Guide (PAG). While protective action is recommended whenever the projected dose would reach this new guide level, the countermeasures are not to be instituted at a particular level as was the case for the old guides. Instead, countermeasures might be initiated at lower levels or might not be initiated until a higher level of radiation had been reached depending on the "total impact" of the countermeasures. This sliding scale used to determine when countermeasures should be initiated is of critical importance in reducing iodine 131 uptake. Because of the rapid rise of iodine 131 in milk and its rapid decay (see Fig. 3, p. 10) preventive measures must be taken promptly to be effective. Yet without a predesignated level for initiation of countermeasures, delays are likely, and consequently increased and unnecessary iodine uptake might result.

The effect of the new and higher guide for iodine 131 can be appreciated if we consider the situation had atmospheric testing continued and iodine 131 fallout occurred as it did in 1962. No area where iodine 131 was found in milk would approach the new guide level, whereas in 1961-62 milk in five cities exceeded the old guide level. The sharply rising peaks of iodine 131 in milk no longer have any alerting significance, and presumably no countermeasures would be instituted. By contrast, in 1962, countermeasures were called for in many cities according to the old guide level and dry feed was used in Utah and prepared for use in Minnesota to prevent excessive iodine uptake. Should the iodine 131 fallout occur around the Nevada test area at levels comparable to those estimated to have occurred previously, even the new guide might be exceeded. But in this case, countermeasures apparently may or may not be called for, depending on evaluation of their "total impact."

OTHER SOURCES OF RADIOIODINE

With the cessation of atmospheric testing, there remain a number of other potential sources of iodine 131 contamination. An underground nuclear explosion may release some of its radioactivity into the air. This venting has occurred a number of times in the past and has been suggested as a source for some of the high iodine levels in milk reported in 1962.[10] Since the test ban went into effect, four cases of venting have been reported. The most recent of these was on March 13, 1963. No iodine 131 was found in the milk at monitoring stations after this venting and the highest level reported from a single farm was 70 picocuries per liter. Cows were on dry feed. As an experiment, three cows were taken off dry feed and fed fresh cut green feed. Iodine 131 in their milk reached a peak of 420 picocuries per liter.[11]

Fallout of iodine 131 and other isotopes would also occur if nuclear explosions were used in excavation projects as proposed in Project Plowshare. (This will be discussed in a forthcoming issue of *Scientist and Citizen.*)

Nuclear accidents at reactors and other atomic energy installations may also release iodine 131 into the air. For example, the Windscale reactor accident in England released a large amount of iodine 131 — 27,000 picocuries — which was spread over adjacent farm land. Milk from the area was destroyed but had the milk been drunk it is estimated that the thyroids of infants would have received 17 rads with consumption of about one quart of milk per day from the affected area.

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The Story of the Baby Tooth Survey

By YVONNE LOGAN

THE PROPOSAL made by Dr. Herman Kalckar for an International Milk Teeth Radiation Census was brought to the Committee for Nuclear Information in the fall of 1958 by its Vice President, Dr. Alfred S. Schwartz. The Committee, then only a few months old, voted to launch the project in the St. Louis area.

The participation of thousands of people — including the children of the community — in a scientific research project would be something completely new. But the situation, in which millions of people were being exposed to low level radiation, was also new, and demanded a new kind of relationship between scientist and citizen. The only way to find out whether parents would take the time and trouble to fill out the necessary information and send in their children's teeth was to ask them.

The Committee was fortunate in enlisting as the Director of the new Baby Tooth Survey, Dr. Louise Z. Reiss, an internist who volunteered full time to the project for almost three years. An enthusiastic response to the idea was elicited from the deans of the St. Louis and Washington University Schools of Dentistry, and they in turn were instrumental in forming a Scientific Advisory Group to guide the program. A group of researchers from Washington University applied to the United States Public Health Service for a grant to finance the strontium 90 analyses and the collection program was inaugurated.

A good deal of sheer faith was needed to get under way. A very hopeful estimate of the number of teeth that might, with diligent husbandry, be expected from the St. Louis area was 50,000 a year. Close to this number would be needed to provide adequate samples for the early, less radioactive years. The program must be set up speedily or this early, irreplaceable material would be lost.

Crucial to the success of the Survey was the cooperation of all the schools in the area — city and county, public, parochial and private. The superintendents were approached and each gave his assurance that the forms carrying the necessary information which must accompany each tooth could be distributed through the elementary schools under his direction. These assurances were testimony not only to Dr. Reiss' persuasiveness but to the respect in which the community held the Committee for Nuclear Information.

This respect also made it possible to recruit the many volunteers vital to the continuance of the program. The grant for the analyses was approved, but the delivery of forms, the clerical processing of the teeth, publicity, printing, etc. had to be accomplished with very limited funds from CNI and, later a three-year $10,000 grant from the Leukemia Guild of Missouri and Illinois. Individuals and groups responded to the appeal for help.

The enthusiastic community cooperation that launched the project continues to carry it on successfully today. Busy young mothers, shut-ins and retirees send each contributing child a button proclaiming, "I gave my tooth to science," an Operation Tooth Club membership card, a new tooth form and a "thank you." The envelopes are stuffed at a school for retarded children. Cataloguing — transferring the teeth to numbered envelopes and making out duplicate cards when more than one tooth comes in with a form — is divided chiefly between the men at St. Joseph's Hill Infirmary and women of the St. Louis Dental Auxiliary. The last step before the teeth go to the laboratory is classification and must be done by a dentist. Even these busy professionals come to the aid of the Survey as volunteers.

During the weeks of the semi-annual Tooth Roundups, public service time is given generously by radio and television stations to publicize the needs of the Survey. Mayor Raymond Tucker has proclaimed Tooth Survey Week. Last December the Veiled Prophet queen, St. Louis' traditional reigning beauty, celebrated the Survey's fifth birthday with a party at Children's Hospital.

A large model of a tooth (with a child inside) gives out forms in department stores. And, most important, dentists are reminded by letter and at conventions how helpful it will be if they make the forms available in their offices.

So well known has BTS become that letters from children, addressed simply "Tooth Fairy, St. Louis," reach their destination at the CNI office.

Since May of 1963, a supplemental grant from the U. S. Public Health Service has financed the collection activities. This grant is administered by the Washington University research team of Drs. Harold Rosenthal, John T. Bird and John E. Gilster and pays for printed material, as well as the salaries of a secretary and part time executive director. Dr. Reiss' connection with the Survey ended with her publication of the first findings in November, 1961, but the procedures set up by the original committee continue with undiminished success.

Nearly 160,000 teeth have been collected, and the Survey has gradually expanded into an area within a 150-mile radius of St. Louis. Comparative studies are beginning to be made on teeth from Indiana and Michigan. In the latter state, the Research Committee of the Ann Arbor Women for Peace has sent over 1000 teeth and collections are being made in Kalamazoo (where the Survey is conducted by the Kalamazoo Scientists' Committee for Radiation Information), in Detroit and Lansing. There are hopeful beginnings in California and fullfledged independent surveys in New York and the Gulf Coast area. The latter project, under the cooperative sponsorship of the American Chemical Society and state dental societies, has collected over 5000 teeth in its first year. Activity in the country has become so widespread that the chairman of the Committee for the New York Baby Tooth Survey has called for a conference during the coming year to provide an opportunity for the coordination of the combined efforts of the various groups conducting baby tooth surveys. Outside of the United States, citizens in Japan and Canada have received help from the St. Louis project in setting up their own surveys, and German scientists have published information on strontium 90 studies on baby teeth.

As the Baby Tooth Survey nears the completion of its sixth year, it finds itself internationally accepted as a method of measuring strontium 90 absorption and looking forward to more years of usefulness as such a "counter." Teeth from children born in 1959 are just beginning to come in, since this natural fallout does not occur until five years after birth; it will be 1969 before absorption in 1964 can be measured. Predictions are difficult, but if the support of the public and government are maintained, and there are no further nuclear tests in the atmosphere, we will be able to learn from baby teeth the rate of decrease in strontium 90 absorption into the early 1970's.

Background Information

MEASUREMENTS OF RADIOACTIVE MATERIAL

CURIE—a measure of the activity or strength of radioactive material. It is expressed in terms of particles emitted per second, or disintegrations per second. One gram of radium has an activity of one curie, and represents a very large quantity of radioactivity.

MILLICURIE—one-thousandth of a curie.

MICROCURIE—one-millionth of a curie.

NANOCURIE—one-thousandth of a microcurie.

PICOCURIE—one-millionth of a microcurie; also called a MICROMICROCURIE.

STRONTIUM UNIT—One picocurie of strontium 90 per gram of calcium. Ten strontium units would mean ten picocuries of strontium 90 per gram of calcium.

OTHER DEFINITIONS

GRAM—A unit of mass commonly used in scientific work. It is very nearly the mass of one cubic centimeter of water, or about one-thousandth of a quart.

HALF-LIFE—The half-life of a radioactive nucleus is the time during which it has a 50:50 chance of disintegrating. Given a collection of nuclei of strontium 90, the half-life of 28 years is the time during which half of them will have emitted their radiation and decayed. At the end of a second 28-year period, half of the remainder will have decayed, and so on.

ISOTOPES—Isotopes are the different possible forms of the same element. They have identical chemical properties and differ only in their nuclear properties. In particular, they differ in the weight of the nucleus.

CESIUM 137 is a radioactive isotope of the element cesium.

STRONTIUM 89 and STRONTIUM 90 are radioactive isotopes of the element strontium.

FISSION—the splitting or disintegration of uranium or plutonium atoms, releasing energy, producing radioactive particles.

FUSION—the recombination of light atoms, such as hydrogen (at temperatures of about 100 million degrees centigrade) releasing energy, and producing a copious output of neutrons.

LITER—A measure of capacity in the metric system equal to 1.0567 liquid quarts.

MEGATON—One million tons. As a measure of the energy released by a nuclear explosion, it means energy equal to that released by one million tons of TNT.

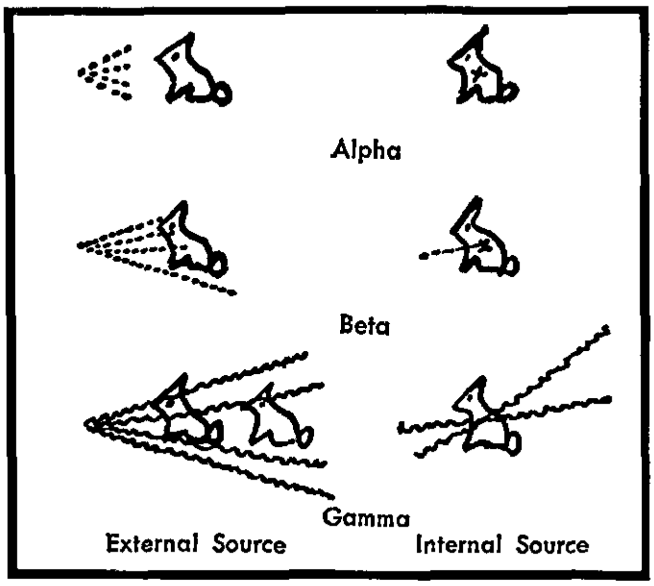
MEASUREMENTS OF RADIATION EXPOSURE

ROENTGEN—the standard unit for the measurement of x-ray exposure. The amount received by the skin in an ordinary chest x-ray is about .02 roentgen.

REM (abbreviation of roentgen equivalent man) that quantity of ionizing radiation which produces the same effect in man as one roentgen of x-rays.

RAD is a unit of radiation exposure which is very close to the rem. It is defined as that amount of radiation which will impart 100 ergs of energy to one gram of irradiated material.

INTERNAL AND EXTERNAL RADIATION



Fission products may emit alpha, beta and/or gamma radiation, and these may affect plants and animals (including humans) from without or from within. Shown here is a schematic comparison of these types of radiation. Alpha particles cannot penetrate far into matter, and therefore do not represent a danger unless they are absorbed by the body. Beta particles have a little more penetrating power, but are also dangerous primarily when absorbed. Gamma radiation has great penetrating power, and is therefore dangerous both outside and inside the body.

(Adapted from Odum, E. P. "Fundamentals of Ecology," Fig. 144, p. 454. W. B. Saunders Company, New York, 1959, and reprinted "War and the Living Environment," *NI*, Sept.-Oct., 1963.)

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