signed to prepare the animal to leave its natal environment. Necessarily, in order to reproduce, the animal must eventually return, so completing its life cycle; and its return may be prepared for by a second metamorphosis, in some aspects the reverse of the first.

Our history as vertebrates is not dust to dust but water to water. From this point of view Nicodemus' great question can be given a broad and positive biological answer. Every animal can and must return to the "womb"—not, indeed, to be born again, but to bear the next generation. For a catadromous fish, the "womb" is the sea; for anadromous fishes and amphibia, a pond or stream; for land vertebrates, a uterus or egg. The question raises additional problems only for man, and then only when the sense of return is toward the womb of the mother rather than that of the mate.

References and Notes

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Hazard to Man of Carbon-14

What problems are encountered in the quantitative estimation of the biological hazards of carbon-14?

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Carbon-14 is an isotope of the chemical element carbon. As such, it forms the same chemical compounds and, as part of the organic molecules built around the carbon atom, becomes part of living tissue. Carbon-14, though virtually indistinguishable chemically from the other isotopes of carbon, is radioactive, emitting low-energy beta particles (0.05 Mev average) and having a half-life of about 5600 years. Therefore, carbon-14 is a potential hazard to man, for in his body it is emitting radiation that can affect living cells and, additionally, is itself undergoing change—transmutation—by decay to another element, nitrogen, of different chemical characteristics.

This article considers briefly some of the problems encountered in the quantitative estimation of the biological hazards to man of carbon-14.

Possible Mutagenic Effect of Carbon-14 Transmutation

Most discussions of the genetic effects of radioactive isotopes present in the body have considered only the effects of the radiation emitted during radioactive decay. However, the transmutation of radioactive atoms which have been

incorporated into the genetic material, deoxyribonucleic acid (DNA), may also result in mutations. Radioactive isotopes of carbon, phosphorus, and hydrogen must all be considered, but, since nuclear detonations may produce appreciable amounts of carbon-14, this long-lived isotope is of particular concern. On the molecular scale, mutations are believed to be changes in the chemical structure of DNA.

When a carbon-14 atom contained in DNA decays to nitrogen-14 by the emission of a beta particle, a mutation could result in two ways: (i) by a radiochemical change in DNA caused by either the beta particle emitted or by recoil of the nucleus and (ii) as a result of the carbon-14 to nitrogen-14 transmutation itself, which almost certainly would cause a chemical change in the DNA molecule in which it occurred. Since all DNA is contained in the chromosomes and is genetically active, it is possible that almost all such transmutations occurring in DNA would cause mutations. On the other hand, it is conceivable that the chemical changes caused by transmutation of carbon-14 in DNA would prevent the successful duplication of the DNA and hence would be lethal to the cell in which the transmutation occurred, with the result that no detectable mutations would be produced.

There are almost no data as yet on which to base an estimate of the magnitude of the transmutation effect. Experiments made to obtain such data must be carefully planned to differentiate between mutations produced by the two processes and are complicated further by the long half-life and low specific activity of the available carbon-14 isotope preparations. Certain microorganisms appear to offer the most promising experimental approach.

The natural carbon-14 content of the biosphere is given by Anderson (*1*) as 1.46×10^{-12} times the total carbon content. The three isotopes of carbon are uniformly distributed in the atmosphere and in living organisms, so one can estimate the contribution which the disintegration of carbon-14 makes to the total radiation dose. Since the transmutation of an element such as carbon or phosphorus in the chain of DNA is probably much more effective in producing biological damage, the carbon-14 content of DNA is of interest.

Mammalian diploid cells contain 6 to 7×10^{-12} gram of DNA per cell (*2*), and DNA is approximately 37 percent carbon. Therefore each diploid cell contains about 2.4×10^{-12} gram of DNA carbon. A carbon atom weighs $12/(6 \times 10^{23}) = 2 \times 10^{-23}$ gram, and each diploid cell's DNA should contain $(2.4 \times 10^{-12})/(2 \times 10^{-23}) = 1.2 \times 10^{11}$ atoms. The carbon-14 content is $1.2 \times 10^{11} \times 1.28 \times 10^{-12} = 1.54 \times 10^{-1}$ atom per cell in DNA. That is, on the average, about one in six cells should contain a carbon-14 atom in the DNA.

The probability that each cell would suffer a carbon-14 transmutation is given by dividing the average life of carbon-14 (about 8000 years) into 1.54×10^{-1}:

$$\frac{1.54 \times 10^{-1}}{8.0 \times 10^{3}\ \text{yr}} = 1.9 \times 10^{-5}$$

per year. The generative cells may be assumed, on the average, to have accumulated 30 years of this kind of damage at conception time. That is, the probability that any given generative cell has had a carbon-14 transmutation in its genetic material is 6×10^{-4}.

With a birth rate of 30 per 1000 and 2.5×10^{9} as the world population, the maximum genetic damage from carbon-14 transmutations in genetic material could result in the birth, each year, of $2.5 \times 10^{9} \times 3 \times 10^{-2} \times 6 \times 10^{-4} = 4.5 \times 10^{4}$ persons with mutated genes. This assumes a ratio of 1 for the fraction mutations/transmutations (M/T).

In his estimates of fission-product and carbon-14 hazards, Leipunsky (*3*) assumed an increment of carbon-14 due to 10 megatons of fusion equal to 4.1×10^{-3} times the present carbon-14 equilibrium value. Such a value would yield $4.1 \times 10^{-3} \times 4.5 \times 10^{4} \times 8100 = 1{,}400{,}000$ persons with defective genes due to the carbon-14 increment. One-half of these defects would occur in the 5600 years following the addition of the carbon-14 increment. It is possible that the value of 4.1×10^{-3} may be too large by a factor as great as 10. As was indicated by Libby (*4*), one-fourth of this value, or 10^{-3}, would be more correct. If we were to assume a reduction by a factor of 10, the figures would reduce to a total of 144,000.

The fractional increase per year cannot be given because of the exponential decrease in carbon-14, but the maximum fractional increase due to fusion-produced carbon-14, assuming immediate complete mixing, would be 184/45,000 in one case and 18/45,000 in the other. This ratio, of course, is valid no matter what the value of M/T.

Some limits on the possible values of M/T may be set. Although it is conceivable that more than one mutant gene might result from one transmutation, this is not likely to be a frequent occurrence. Only about one-half of the carbon atoms of DNA are in the chain, and a fraction of the remaining half may be less likely to cause mutations when decay takes place. More important, the decays may be so effective as to totally inactivate the cell, in which case no mutation will result. Therefore, the upper limit would appear to be set safely at less than 1.

There appears to be no logical or experimental basis on which to base an estimate of the lower limit of the fraction M/T. When inactivation of *Neurospora* and bacterial viruses was measured (see *5*), experimental values for phosphorus-32 decay were between 10 and 1000 times greater than values for the probability of inactivation by comparable amounts of ionization. There appear to be no data for production of mutations by transmutation of carbon-14 or phosphorus-32 in DNA. McQuade, Friedkin, and Atchison (*6*) have provided data on chromosome aberrations due to thymidine-2-carbon-14 incorporation in which the carbon-14 decay in DNA appears to be at least 9 or 10 times as effective as decay in cytoplasm. However, the data are inconclusive, as was pointed out by the authors themselves.

It is of interest to calculate the value of M/T which would result in a mutation frequency due to carbon-14 transmutation in DNA which is equal to the mutation frequency from the ionization produced by carbon-14 decay outside the DNA. This value is equal to the ratio of beta radiation mutations to the mutations resulting from carbon-14 transmutations in DNA on the hypothesis that $M/T = 1$. Leipunsky (*3*) estimated 49,000 mutations from beta radiation where our corresponding carbon-14 transmutation estimate is 1.44×10^{6}. This leads to $M/T = 0.034$ for the value for equal numbers of mutations for the two processes. If one uses more refined estimates of the carbon-14 beta radiation dose, this value would not be changed, since estimates of both the beta dose and the number of carbon-14 transmutations depend on the bomb-produced increment to the natural carbon-14 pool.

This ratio, 0.034, depends on beta-induced mutations of only one class, serious physical or mental defect, with an estimated normal frequency of 2 percent.

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If one includes all three classes of genetic damage considered by Crow (7), two of which are partially overlapping, the value of M/T necessary for equal transmutation and beta-induced mutation frequencies is 0.66.

It is therefore concluded that, on the basis of limited experience in other organisms and with other isotopes, it is not unreasonable to assume that the number of mutations due to carbon-14 disintegration in DNA could be at least equal to, and could probably exceed, the number caused by the carbon-14 beta radiation.

There is some evidence that genes in different species differ in size and complexity. For example, Carter (8) estimates that each gene in the mouse is 19 times as large as a *Drosophila* gene. This estimate is based on comparative mutation rates and the 29-fold greater DNA content per diploid cell in mice. If this conclusion is correct, the value M/T for any species can be accurately determined only by experiment on that species, and the effects in mice and other mammals may be very much more serious than those in microorganisms, for example. However, the greater DNA content could conceivably consist largely of "nongenic" DNA, in which carbon-14 decay would be less apt to cause mutation. Thus, it is possible to do no more now than guess at the broad limits of the ratio M/T.

Numerical Estimation of Genetic Damage to Human Populations

With the advent of atomic and nuclear energy, the question of genetic hazards has become a matter of great importance, of almost universal interest, and of no little controversy. In the past 2 years there have been three comprehensive statements of the present status of knowledge concerning the problem (9–11), and there will soon be a fourth (12). All of these statements agree about the seriousness of the problem, about the lack of sufficient knowledge of human spontaneous and radiation-induced mutation rates to provide accurate numerical estimates of the hazards, and about the desirability of minimizing the exposure of human reproductive cells to radiation during the reproductive period. The reports are in agreement also on the conclusion that the linear mutation-dose relation observed in the range of 25 to several thousand roentgens in a number of species must be considered to extend through smaller doses to zero. In other words, it is concluded that there is no dose of radiation so small that it is not genetically harmful.

Table 1. Estimates of damage from fallout calculated by J. F. Crow and presented at hearings of the Special Subcommittee on Radiation, U.S. Congress, in 1957 (7).

Kind of damage	No.	
	First generation	Total
A. Gross physical or mental defect	8,000	80,000
B. Stillbirths and childhood deaths	20,000	300,000
C. Embryonic and neonatal deaths	40,000	700,000

Since, therefore, the number of mutations induced is considered to be directly proportional to the radiation dose, it is possible to make crude numerical estimates of the hazards, provided information is available on the average dose to the gonads during the reproductive period. Many geneticists feel that it is unwise to make such calculations, since there is a very high degree of uncertainty in them and, consequently, the calculations may be quite misleading or may be misinterpreted. However, since such calculations have been and will be made frequently, it is important to recognize the assumptions on which they are based and the sources of uncertainy in the results.

The usual approach to the calculations involves use of the doubling dose, or that dose required to induce mutations at a rate equal to the spontaneous or natural rate. This dose is usually taken as 50 roentgens, although the National Academy of Sciences (9) and Medical Research Council (10) reports give only the range 30 to 80 roentgens. A draft of the more recent consideration by the United Nations Scientific Subcommittee (12) gives a range of 10 to 100 roentgens. This large factor of uncertainty must be constantly borne in mind when one is considering the results of such calculations.

The usual calculation is concerned only with rather gross, tangible genetic effects, as considered in the National Academy report (9), and ignores the completely recessive mutations or the probably much larger class of mutations with small effects which nevertheless are harmful. The estimates are therefore almost certainly underestimates of the total damage. It is also important to keep in mind the question of genetic equilibrium. With appropriate corrections for changes in population size, each unfavorable gene, no matter how large or small in effect, induced in a population must be balanced in a subsequent generation by an elimination of a gene descended from that gene; otherwise, the frequency of that gene will increase cumulatively. Reduced effective fertility is the mechanism by which such eliminations occur. This can be thought of as a reduction in the chance that individuals, starting at the time of fertilization of the egg, will complete normal reproductive cycles. Thus, in a population in equilibrium, the total of reductions in fertility could be estimated to a first approximation if all unfavorable mutations—regardless of the magnitude of their unfavorable effect—could be individually detected and counted.

Perhaps the most useful calculations which have been made are those of Crow in the Fallout Hearings (7). His estimates are shown in Table 1. All of these estimates assume a 30-year dose to the gonads from fallout of 0.1 roentgen, as estimated in the National Academy report (9), a doubling dose of 50 roentgens, and a stable world population of 2×10^9 births per generation.

The gross physical or mental defect estimate ignored all completely recessive effects and assumed a normal incidence due to spontaneous mutation of 2 percent. This category roughly corresponds to the "tangible genetic defect" category of the National Academy report (9) and is perhaps the most useful kind of calculation for comparative purposes. The arithmetic is simple:

$$\frac{(0.1\text{ r})}{(50\text{ r})}\,(0.02)\,(2 \times 10^9) = 8 \times 10^4\ (\text{total})$$

Stillbirths and childhood deaths were estimated from increased death rates in children of consanguineous marriages by Morton, Crow, and Muller (13), who give an estimate of 8 percent as the frequency at mutational equilibrium. As before, the total damage from 0.1 roentgen for a generation is obtained by

$$\frac{(0.1\text{ r})}{(50\text{ r})}\,(0.08)\,(2 \times 10^9) = 3.2 \times 10^5$$

This result was rounded to 3×10^5.

The estimates of embryonic and neonatal deaths were based on Russell's (14) observation of a 3 percent reduction in litter size of mice at 3 weeks of age when the sires had been exposed to 300 roentgens. If both parents received 0.1 roentgen, the effect would be 0.2/300 as great. Hence, the estimated first-generation effect is

$$\frac{(0.2)}{(300)}\,(.03)\,(2 \times 10^9) = 4 \times 10^4$$

If it is assumed that 6 percent are expressed in the first generation, as estimated for stillbirths and childhood deaths, the total damage is approximately 6.7×10^5, which rounds to 7×10^5.

It is interesting to observe at this point that, although the numbers 80,000, 300,000, and 700,000 are large and obviously serious when it is remembered they assume an average gonadal dose of only 0.1 roentgen per generation, the estimated increase in the first generation in each case is only 10^{-4} of the normally occurring abnormalities. So small an increase would be impossible to detect experimentally. It is this apparent contradiction—large absolute numbers but small fractional increases—which leads to much of the controversy on this important question.

It is important to remember also that the second and third categories of damage are not mutually exclusive: stillbirths and infant deaths are included in both.

It is a simple matter to adjust Crow's figures for other doses or population sizes. This is illustrated in a later section, after a discussion of the gonadal exposures due to bomb-produced and natural carbon-14.

However, attention is again directed to the large uncertainty, perhaps as large as a factor of 10, in the doubling dose; this uncertainty, coupled with uncertainty in the spontaneous mutation rates, makes any conclusions that are drawn from such calculations correspondingly uncertain with respect to absolute magnitude. Even so, such calculations can be useful for comparative purposes, since these uncertainties affect each calculation equally and hence essentially cancel out. Therefore, the largest uncertainty in such comparisons derives from the calculations of the relative gonadal doses and, in the case of certain isotopes, our almost complete lack of information about the magnitude of the transmutation effect. It should also be borne in mind that estimates of "serious physical or mental defect," in Crow's terms (*7*), or of "tangible genetic defect," in the language of the National Academy report (*9*), do not measure the total genetic damage because certain categories of genetic damage are omitted from these calculations.

Biological Hazards

The natural occurrence of carbon-14. Carbon-14 is produced in nature in amounts estimated (*9*) to be from 7 to 10 kilograms per year by the absorption of cosmic ray neutrons in the atmosphere. It exists in the atmosphere as radioactive carbon dioxide and as such takes part in the over-all carbon cycle of the earth, mixing with ocean water (existing there as a carbonate or bicarbonate) and with the biosphere (plants and animals) and entering man. Because carbon-14 appears to have existed naturally for millions of years or more, it now exists on earth in essentially a constant quantity (*15*): whatever is made each year only compensates, approximately, for what decays. Estimates of the amount of naturally existing carbon-14 in the total earth reservoir (ocean, biosphere, and atmosphere) range from about 56 to 81 metric tons by weight (*3, 9, 15*).

The approximate distribution of the 56 to 81 metric tons of natural carbon-14 in the earth's reservoir is shown in Table 2 (*9*). Because the distribution as well as the quantity of natural carbon-14 is important, Table 3, based on data presented by Arnold and Anderson (*15*), is presented to give an estimate of the distribution of *all* carbon in the earth's reservoir.

In all precise estimates of the natural background radiation dose to man, the contribution of natural carbon-14 is included, although its contributions to the estimated annual background dose of 100 to 150 milliroentgens (*9, 16*) is only about 1 percent (*16*).

Production of carbon-14 by nuclear weapon explosions. All nuclear weapons involve in their nuclear reactions the production of neutrons. Some of the neutrons are used in fission chain reactions resulting in the formation of radioactive fission products such as strontium-90, iodine-131, and cesium-137. The neutrons themselves would be of no concern, from the standpoint of hazards, were it not for the fact that some of them escape from the weapon to the outside environment. These neutrons of various energies are eventually captured; it is estimated that, for an air burst more than a few hundred meters above the ground, more than 95 percent of the neutrons eventually react with the nitrogen nuclei of the atmosphere and produce carbon-14. If the detonations are on the surface, then roughly one-half of the neutrons would not be absorbed in nitrogen atoms to make carbon-14 but, by the same token, would induce radioactivity of relatively short half-life in the soil.

For United States nuclear weapons of all types (*17*), roughly equal numbers of neutrons escape per unit of energy yield ("kiloton" or "megaton"). Therefore, two nuclear weapons, regardless of type but of the same yield and detonated under the same conditions, will produce roughly equal amounts and types of neutron-induced radioactive materials, including carbon-14, if the burst is such that neutrons escape to the air.

In a recent speech, Libby (*4*) stated: "At a rate of 2.5 neutrons [escaping] per 200 Mev of energy release, one megaton would generate 3.2×10^{26} carbon-14 atoms. The best estimate, keeping in mind that a substantial amount [of the carbon-14 produced] falls back as calcium carbonate, would be that about 10^{28} carbon-14 atoms have been introduced into the atmosphere [from weapon testing to date], mostly into the stratosphere. The estimate of 2.5 neutrons per 200 Mev energy released is higher than an earlier estimate based on an assumed 15 percent escape efficiency [(*17*)], the later value being based on firmer information. It also attempts to weigh fusion and fission as they have actually occurred."

Leipunsky (*3*) has assumed for his fusion weapon one employing only deuterium-tritium fusion reactions and allowing all neutrons produced to escape to their environment. His estimate of the number of escaping neutrons per 200 Mev may be too high by a factor of 4 to 6 compared with like estimates for U.S. weapons.

The calcium carbonate represents an addition to the earth's carbon-14 reser-

Table 2. Approximate distribution of natural carbon-14 in the earth's reservoir.

Reservoir	Carbon-14	
	Metric tons	Percent
Atmospheric CO_2	0.96	1.69
Terrestrial living matter plus humus	2.2	3.88
Ocean: total organic matter	3.8	6.7
Ocean: total inorganic matter	49.8	87.8
Total	56.8	100.07

Table 3. Estimated distribution of all carbon in the earth's reservoir.

Reservoir	Percent
Atmospheric CO_2	1.47
Terrestrial living matter plus humus	2.83
Ocean: total organic matter	8.61
Ocean: total inorganic matter	87.2
Total	100.11

Table 4. Estimates of total genetic hazards of bomb-produced and natural carbon-14 and natural background radiation. (To estimate the hazard for the next 5000 years, divide these numbers by 2.) Categories B and C are partially overlapping.

Bomb C^{14} to date (dose: 0.008 mr/yr)		Natural background radiation			
		Carbon-14 (dose: 1.5 mr/yr)		Total (dose: 150 mr/yr)	
Persons (No.)	Fraction of total population affected	Persons (No.)	Fraction of total population affected	Persons (No.)	Fraction of total population affected
		A. Gross physical or mental defect			
1.0×10^5	1/5,340,000	1.92×10^7	1/27,800	9.6×10^8	1/556
		B. Stillbirths and childhood deaths			
3.8×10^5	1/1,400,000	7.2×10^7	1/7,400	3.6×10^9	1/148
		C. Embryonic and neonatal deaths			
9.0×10^5	1/593,000	1.63×10^8	1/1,785	8.4×10^9	1/64

voir too, but in a chemical form such that the radiocarbon cannot exchange readily with the biosphere. One might note that 3.2×10^{26} carbon-14 atoms is about 7.4 kilograms and that 10^{28} carbon-14 atoms is about 230 kilograms. The addition of 230 kilograms (0.23 metric tons) of bomb-produced carbon-14 to date thus means an addition of 0.3 to 0.4 percent to the total carbon-14 reservoir.

However, this addition is not instantaneously uniform throughout the whole reservoir, for equilibrating time must be taken into account. All of the bomb-produced carbon-14, at the time it is produced, is in the atmosphere except for the direct fallback of calcium carbonate. The bomb-produced carbon-14 present in the atmosphere as carbon-14 dioxide can exchange with the biosphere and with the ocean. The higher the concentration of carbon-14 in the atmosphere, the higher will be the resulting concentration in plants after exchange. Eventually the exchange with the ocean will reduce the atmospheric level of bomb-produced carbon-14 concentration and so will reduce the opportunity for exchange with plants. Hence one is dealing with a transient, not an equilibrium, situation, and merely computing the fractional increase in the total carbon-14 reservoir caused by adding bomb-produced carbon-14 may not give a good measure of the impact of the bomb-produced carbon-14 on man but would tend to give too low an estimate. Libby states (*18*), "Bomb tests to date have produced enough carbon-14 so that when it has come to mixing equilibrium it will have increased the amount naturally present in all living matter by one-third of 1 percent"; and, "In the years before equilibrium with the deep ocean is reached—about 500 years—the level will temporarily rest at about a 3 percent increase. . . . This is after the first period of perhaps ten or twenty years before dilution in the top layer of the ocean and with living and dead organic matter occurs, when the increase will be about 20 percent." Finally, he says, "Because the lifetime of radiocarbon is very long —8000 years on the average—the equilibrium situation is the more significant." For the carbon-14 already produced by bombs, the average dose increment over 8000 years is about 1.7 times the average dose increment calculated on the assumption of immediate equilibrium.

Carbon-14 dose to man. Libby (*16*) estimates the dose to man from naturally occurring carbon-14 as 1.5 milliroentgens per year. If no further bomb carbon-14 was produced, this dose rate might be as high as 1.8 milliroentgens per year during the next 20 years or so; after that time it would gradually drop off to a new equilibrium value of 1.505 milliroentgens per year. The average dose rate over 8000 years would be about 1.508 milliroentgens per year, yielding a total dose increment due to bomb-produced carbon-14 of 64 milliroentgens.

These dose estimates suggest that the present bomb-produced carbon-14 hazard to man is not only small but virtually undetectable: a 0.5 percent increase in a dose rate that itself is only 1 percent of the natural background radiation dose to man. Why, then, is bomb-produced carbon-14 possibly a concern? The answer is that genetic mutation rates, and possibly some somatic-effect incidence rates [for example, leukemia (*19*)], are considered to be linearly proportional to total dose. On this basis, therefore, any increase in the dose to man implies a corresponding increase in the burden of mutations in the population, and possibly an increase in certain somatic effects such as leukemia.

Numerical estimation of the genetic effects of bomb-produced carbon-14. By means of the methods discussed earlier, it is easy to compare the estimated genetic effect of the carbon-14 produced by nuclear detonations to date with the estimated effects of the naturally occurring carbon-14 and the total natural background radiation (Table 4). The natural background radiation of 150 milliroentgens is essentially that estimated in the National Academy report (*9*). The natural and bomb-produced carbon-14 doses have been discussed above. An average life of carbon-14 of 8000 years and a stable world population of 2×10^9 are assumed. The genetic effects estimated for the carbon-14 radiation dose are doubled to take into approximate account the transmutation effect, as discussed earlier. Depending in part upon whether absolute numbers or fractional increases are considered, different persons may place different interpretations upon the figures given in Table 4. Furthermore, individuals differ in their viewpoints regarding the genetic effects in the next few generations as opposed to effects over the next 8000 years.

Leipunsky (*3*) has published estimates of the genetic and leukemogenic hazards of nuclear weapons. As noted earlier, he assumed a very high neutron escape per 200 Mev of energy released—a figure that may be high by a factor of 4 to 6 as compared with actual neutron escape from U.S. weapons. Except for the fact that he ignores the transmutation effect of carbon-14, his calculations of the genetic hazards appear to be valid for the doses he assumed, although he made computations for only the gross physical or mental defect category. There also appear to be errors in Leipunsky's calculation of the leukemogenic hazards—a calculation based on the as yet unproved linear relationship between dose and leukemia incidence postulated by Lewis (*19*). Since leukemia resulting from strontium-90 (the major fission product contributing to the bone dose) would be largely of bone-marrow origin, Leipunsky's use of Lewis' (*19*) values for probability of leukemia from bone-marrow and lymphatic-system irradiation resulted in estimates twice those obtained when the appropriate value for the probability as given by Lewis is employed. Finally, Leipunsky's calculation of both the bone and gonadal doses may be questioned because of his assumption

that the internal cesium-137 dose is proportional to cumulative, rather than annual, deposition of fallout and by his consideration of cesium-137 as the only contributor of external gamma radiation. Except for these differences in assumptions affecting the estimates of dosages, including assumptions about the number of neutrons escaping to air, we are in general agreement with Leipunsky's calculations.

Conclusions

1) Subject to large uncertainty, the transmutation effect of carbon-14 atoms contained in the genetic material of the human body could lead to about the same number of genetic mutations as the radiation effect from carbon-14.

2) Genetic damage estimates are subject to large uncertainties and should be used in this light.

3) Because nuclear weapon detonations have already produced radioactive carbon-14, the number of persons in the world likely to have genetic or other abnormalities from carbon-14 radiation will be increased. Expressed as a fraction, the increase from bomb testing to date is very small, but the total number of persons likely to be affected in the next 8000 to 10,000 years may not be considered small by some persons.

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News of Science

De Hevesy to Receive $75,000 Atoms for Peace Award

George Charles De Hevesy of the Research Institute for Organic Chemistry, Stockholm, Sweden, has been named winner of the second $75,000 Atoms for Peace Award for his discovery and development of tracer techniques in chemistry, biology, and medicine. The Hungarian-born chemist and teacher, who received the Nobel Prize in 1943, was selected unanimously from a list of 111 nominees representing 19 countries throughout the world. De Hevesy will attend presentation ceremonies in New York City in January 1959.

The award was announced by Detlev W. Bronk, president of the Rockefeller Institute and the National Academy of Sciences, and chairman of the Board of Trustees of Atoms for Peace Awards. In tribute to De Hevesy, Bronk said:

"His willingness to accept a failure in a chemical experiment as a starting point for new explorations led to the first use of radioactive isotopes as tracers in chemical studies. His application of this discovery to biological systems has revolutionized our concept of the biochemical processes in living organisms.

"He was the first to apply both natural and artificial isotopes to the study of plants and animals; he introduced the use of stable isotopes and he was the first to explore the possibility of creating radioactive substances within the system being studied by means of neutron bombardment.

"These discoveries, now adopted in laboratories and hospitals all over the world, are certainly among the most important advances in the peaceful use of atomic energy in our time. In the fields of chemistry, biology, geology, and medical research and therapy, the results of De Hevesy's contributions are continually being extended and widely utilized.

"His own work has continued undiminished and the output of scientific papers from his laboratory in Stockholm is both copious and significant."

Born in Budapest in 1885, De Hevesy took his doctorate at Freiburg in 1908. After a period of study in Switzerland and Germany, he went in 1911 to work with Ernest Rutherford in England. Here he failed to separate radium D from lead. This failure resulted in De Hevesy's development of the use of the radioactive element (now known to be an isotope of lead and not readily separable from it by chemical means) as a tracer for lead, first reported in 1912.

From 1913 to 1920, at the University of Budapest, first as a lecturer, then as professor of physical chemistry, De Hevesy continued his studies of lead in organic and inorganic compounds using the tracer technique. In 1920 he joined the Institute for Theoretical Physics in Copenhagen. Here, with the physicist D. Coster, he discovered the chemical element hafnium.

In 1933 he applied the tracer technique to the study of chemical processes in plants. This was the first use of the technique in living systems. As new potential isotope tracers became available, De Hevesy extended his techniques to include the use of heavy water in 1934 and of artificially radioactive elements in 1935.

He also pioneered the activation of radioactive compounds within the system being studied by means of neutron bombardment.

Since the second World War, De Hevesy has worked both in Copenhagen and Stockholm. His publications since 1950 include more than 50 papers. He is author or coauthor of four texts on radioactivity and its uses in chemistry, biology, and medicine.

The Atoms for Peace Award was created as a memorial to Henry Ford and