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CONTENTS

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HEALTH IMPLICATIONS OF FALLOUT FROM NUCLEAR WEAPONS TESTING THROUGH 1961

The Federal Radiation Council has considered available information on radiation doses and possible health effects of atmospheric nuclear weapons testing. Before discussing the estimates made in this report in detail, it is appropriate to point out the difficulties of being precise in this field.

Although a large and expanding program for measuring radiation levels at a number of locations throughout the United States has been in effect for a number of years, the application of such data to the whole country, to an extended time period, or to the entire population involves assumptions than can not be completely validated. Furthermore, while a considerable body of information has been accumulated on the effects of radiation on animals and man, the possible effects of low doses delivered at low dose rates are insufficiently known to permit firm conclusions about the extremely low exposures resulting from fallout. Current experimental techniques are not good enough to detect biological effects at the low levels of worldwide fallout from nuclear tests.

Any possible manifestations resulting from fallout radiation will not be unique, for all of the diseases and disabilities known to be caused by radiation also occur for other reasons. Whatever effects might be produced by fallout could only be reflected in statistical increases in the number of conditions already present in the population. Any individual effects would be so diluted by space and time that they would not be recognizable among the much larger number of identical effects arising from other causes, among which they would be interspersed.

Finally, any proper understanding of estimates in this field must take into account the many different ways in which similar or even identical data can be expressed. Many of the apparent differences among scientists arise from different forms of presentation. Two approaches have been used. One estimates the risk of damage to a single person. This risk is extremely small in comparison with others which people normally accept. The second approach considers possible effects on a large population for a year or a generation or for several generations totaling hundreds of years. Even a very small proportion of affected individuals will, in a very large population for a long period of time, amount to an impressive total number of individuals.

Estimated Radiation Exposure from Testing

Any consideration of possible health effects from fallout must begin with the radiation doses to which people are exposed as a result of such tests.

A sharp distinction must be made between the devastating effects of "local" fallout in a nuclear attack on an unshielded population and the effects of fallout from weapons testing. Weapons testing creates far smaller total amounts of fission products so that its fallout is far less than that which would result from nuclear war. Furthermore, the tests are planned to avoid local fallout or to confine it to locations where it will have minimal effects. Hence, in weapons testing the problem is largely confined to delayed fallout which decays greatly in the upper atmosphere and is dispersed at low concentrations over the earth's surface. This report is concerned primarily with the effects of such delayed fallout.

Dose estimations must take into account exposure from all sources; external, and internal through ingestion of food and water and inhalation. Some radioactive elements may concentrate to different extents in various parts of the body. Those which tend to concentrate in a certain organ will selectively irradiate that organ. Thus a thyroid dose, for example, represents the sum of the whole-body dose from a variety of substances plus the extra dose from iodine-131, an element which tends to concentrate in the thyroid gland. In addition, some elements are taken up more effectively at one age than another. For example, the proportion of strontium-90 retained in the growing bones of children is greater than that retained in the bones of adults ingesting the same foods. Furthermore, different sources of radiation give off different kinds of radiation having different biological effects, so that doses cannot be directly compared. These points should indicate the difficulty of referring to any one exposure level from a particular source without identifying what kind of a dose and what part of the body is involved.

Estimates of doses from fallout from tests through 1961 in millirems, a unit of ionizing radiation dose, are given in Table I and discussed further in Appendix "A". Because of uncertainties and the variety of necessary assumptions, these estimates are expressed as ranges of values within which the average exposure over the United States is expected to lie. The values given apply to the United States, and are somewhat higher than those for most of the rest of the world. Doses to the whole-body and reproductive cells represent an average for all age groups in the entire population. Doses to bone and bone marrow are average values for those who were infants at the time of highest concentrations of the particular isotopes irradiating these organs; values averaged for all age groups will be lower.

The half-life of radioactive iodine, the principal source of the thyroid dose, is only 8 days and the peak dose rates persist for a relatively short period of time. For this reason thyroid doses are not included in the table. Doses to the thyroid from the major past tests were estimated to have ranged from 100 to 200 millirems per year during and immediately following periods of testing. These values apply only to individuals who were infants at the time of highest concentration of radioactive iodine. The average value for all age groups was about a tenth as much. Although data from which thyroid doses during 1957-58 can be estimated are limited, it is likely that there was much geographic variation, and in some limited areas of the United States the average thyroid doses were probably many times the national average.

The whole-body dose due to the carbon-14 produced by all tests through 1961 has been included but not separately listed in Table I. It is estimated to total from 10 to 15 millirems during the first thirty-year period. The dose rate will decrease much more rapidly than would be predicted on the basis of the carbon-14 radioactive half-life of 5,700 years because of the absorption of the radioactive carbon dioxide from the atmosphere into the ocean. After about 200 years the dose rate from carbon-14 will have been reduced to a total of about 0.75 millirem during a thirty-year period.

To put these dose levels in some perspective, Table I compares them with exposures from natural background and with the Radiation Protection Guides of the Federal Radiation Council. The comparisons indicate that doses from fallout have generally been a small fraction of the Guides for population groups.

Background radiation arises from naturally radioactive materials such as carbon-14 and potassium-40 in the human body, radium in the earth's crust, and cosmic radiation from outer space. Man has always been exposed to these radiations. Natural background radiation varies from place to place, both with elevation and with radioactive content of local materials. In the United States these values have been observed to range from 70 to 200 millirems per year. The value for background radiation given in Table I is a weighted average for the entire United States population.

The estimated values given in Table I for whole-body exposures from fallout are considerably less than the exposures from natural sources. Over a period of 30 years the average whole-body dose from all testing through 1961 will be between 60 and 130 millirems compared to 3,000 millirems from background. Thus testing through 1961, including the contribution from carbon-14, will, over this thirty-year period, increase exposures over natural background by less than five percent. Seventy-year average bone doses, when similarly compared, are increased less than ten percent. Any further testing will, of course, increase the exposure.

The fact that exposure from Some sources is generally accepted without question should not in itself be a reason for accepting exposure to added levels of man-made radiation. However, comparison of exposure levels with those of natural background does provide some indication of the significance of increases from fallout. One normally considers variation in exposure from natural sources to be of little significance. For example, a resident of the East Coast contemplating a move to a high-altitude location in the West is unlikely to know or attach any importance to the fact that his exposure to background radiation will be appreciably increased—morethan twenty-five percent at elevations above one mile.

Another basis of comparison is the radiation exposure received from medical diagnostic procedures in the United States. It has been estimated that a person in the United States will accumulate a genetically effective dose of the order of 1,000 millirems over a thirty-year period. There are, however, wide fluctuations in the exposures to the reproductive cells from the diagnostic procedures.

Estimates of Biological Effects

Much available evidence indicates that any radiation is potentially harmful. However, effects become increasingly difficult to demonstrate below 10,000 millirems, and impossible to detect by present techniques at the very low dose levels from fallout. Nevertheless, it is virtually certain that genetic effects can be produced by even the lowest doses. These effects in the children of exposed parents and all future generations may be of many kinds, ranging from minor defects too small to be noticed to severe disease and death.

In the case of somatic effects, i.e., effects directly on the persons exposed, the evidence is insufficient to prove either that there is a dosage level below which no damage occurs (the "damage threshold" hypothesis) or that there is some risk of damage at any dosage level, no matter how low (the "no threshold" hypothesis). It may well be that some effects are of one kind, some of the other. Dose rate is important; a protracted dose is much less effective than the same total dose given in a short time.

Estimates have been made by national and international groups of scientists of the number of possible adverse health effects that might occur from various exposure levels. Tables II and III apply some of these estimates to the exposure levels from all testing through 1961 to indicate the possible adverse health effects in the United States population that might result from this testing. United States figures have been used because knowledge of dose levels and of health effects occurring in the absence of testing is more complete for this country than on a worldwide basis. For convenience in expressing the concepts and calculations in this report, the population of the United States has been taken as approximately one-tenth of the population in the same latitudes of the northern hemisphere, and as one-twentieth of the population of the entire world. The figures in Table II on the possible number of adverse health effects from testing through 1961 may be multiplied by 10 to provide a rough estimate of comparable worldwide effects with the exception of carbon-14, for which a factor of approximately 20 must be applied.

Table II and Appendix "B" give numerical estimates of the effects of fallout on one category of genetic effects—severe physical and mental defects. This category includes the hereditary component of such things as congenital malformations, blindness, deafness, feeblemindedness, muscular dystrophy, hemophilia and mental diseases.

In Table II the estimated numbers of radiation effects are given as three values. The upper figure is the best estimate based on radiation-induced mutation rates in mice, and on the spontaneous incidence of these defects in man. The other figures represent the range within which the true value may reasonably be expected to lie.

As shown in the table, about ten percent of the number that may result in all time from weapons tests through 1961 are estimated to occur in the first generation—the children of parents exposed to this fallout. The remaining ninety percent occur in decreasing numbers in succeeding generations. Somatic effects appear only in the irradiated individual himself, and not in his offspring. The manifestations of particular concern are leukemia and other types of cancer.

The radiation dose from carbon-14 is spread over an enormous period of time extending through many thousands of years. The number of mutations from carbon-14, when exposure over all time is considered, is estimated to be greater than from other radioactive elements produced in nuclear detonations. These mutations will, however, be distributed over a much longer time with a much smaller number in any one generation.

In addition to the gross defects listed in Table II, there may be an unknown but probably a considerably larger number of mutations with less obvious effects such as minor physical abnormalities, mild diseases, impairment of physiological functions, and reduced resistance to infection or other stresses of life. Part of this damage will result in a lowered probability of survival at various ages.

Reduced viability of this kind has been consistently found in mouse experiments. The best data on mice are for the infant and embryonic deaths. To the extent that mouse data can be applied to man, the results indicate that the radiation-induced mortality of embryos and infants in the first generation after irradiation is probably larger, perhaps five times larger, than the number of induced defects of the type estimated in Table II. Numerical estimates are not given for such effects because of uncertainties as to the comparability of these effects in mice and humans. This is the viewpoint of those who have done much of the experimental work in this field.

Mutations which have a mild effect on the individual may cause substantial damage in the aggregate. This is because the mildness permits these mutations, such as slight reductions in viability and other less obvious effects, to persist in the population longer than mutations with severe effects, and thus to affect a correspondingly greater number of persons. There are no data which would permit these effects to be assessed with sufficient accuracy to permit numerical estimates.

If, however, numerical estimates are made of all these genetic effects, both those which are likely and those which are more speculative, the aggregate of these estimates when counted as the total number of individuals affected throughout the world in future generations leads to very large numbers. Likewise, large numbers can be obtained when other effects or deaths from any cause are totaled over large populations and many generations. On the other hand, it must be emphasized again that whatever the genetic effects of fallout radiation from weapons testing through 1961 may be, the total effect will certainly be considerably less than that occurring inescapably from background radiation. This, in turn, is considerably less than the effects from other factors which determine the total natural mutation rate.

Estimates for two kinds of somatic effects, leukemia and bone cancer, are given in Table III. As mentioned earlier, it is not known whether or not there is a threshold dose below which these diseases are not produced. If a threshold exists, fallout radiation may produce no additional cases, and the lower limits of zero reflect this possibility.

The upper estimates in Table III are made by assuming the effect of a low dose, delivered at a low dose rate, to be proportional to the effect of a high dose delivered at a higher dose rate. The estimates for the upper limits are probably too high because no allowance had been made for the possibility that a given dose is less effective when received slowly over a long period of time. Thus the range of numbers given in Table III is reasonably certain to bracket the correct value.

There are other possible somatic effects of radiation such as malignancies (other than leukemia and bone cancer) and general effects such as life shortening. Among these malignancies is cancer of the thyroid, a possible effect from exposure to radioiodine. Table III includes no data on the possible incidence of this effect because ,estimates, like those recognized by national and international groups of scientists for possible leukemia and bone cancer effects, have not been made for cancer of the thyroid. However, from what little is known about the effect of radioiodine, including data obtained from human exposures at very high levels, the likelihood of any possible thyroid effects has been considered to be about the same as other malignancies for comparable exposures. Even less information is available as to possible increases in all these other effects than is available for leukemia and bone cancer.

To put these estimates of possible adverse health effects in some perspective, Tables II and III also include the total number of these same effects occurring in the United States from all causes.

Conclusions

We cannot say with certainty what health hazards are caused by fallout from nuclear testing. We expect there will be some genetic effects; other effects such as leukemia and cancer are more speculative and may not occur at all. We can observe that, compared to the number of these same adverse biological effects occurring wholly apart from testing, the additional cases that might be caused by testing are a very small quantity. We conclude that nuclear testing through 1961 has increased by small amounts the normal risks of adverse health effects.

APPENDIX "A"

EXPLANATORY MATERIAL ON DOSE ESTIMATIONS

The estimates of radiation doses attributable to fallout from tests of nuclear weapons given in Table I have been based on extensive observations and studies through 1961. These estimates include exposures from fallout which already has occurred and from material from past tests yet to be deposited. Estimates are based on measurements of radionuclides in air, rain, soil, water supplies, food, and people.

Table I gives estimates of radiation doses from fallout resulting from tests through 1961. The dose ranges given in this table represent estimates made using somewhat different but plausible assumptions concerning such factors as fallout distribution, the effects of weathering and shielding, and the movement of radioisotopes from the environment to man. It is believed that the best estimates that can be made at the present time would lie within the ranges given.

In the cases of whole body and reproductive cell exposures, radiation doses are relatively independent of age, except for the fact that children born in the past two or three years will have missed much of the exposure from earlier tests experienced by older persons. A large fraction of the dose to the whole-body and reproductive cells from a particular test may be received within a period of months after fallout occurs. The contribution of radioiodine to the dose to the thyroid gland is much larger in the case of infants than in older persons and is effectively complete within a few weeks after a nuclear test.

Radiation doses to the bone and bone-marrow from a particular test will be received at decreasing rates over a period of a lifetime. Early concentrations in the bone will be greatest for those children who are less than one year of age at the time that peak concentrations of fallout occur in food. The average bone and bone marrow doses to such children as estimated in Table I are much larger than the average to the whole population.

It is estimated that carbon-14 resulting from tests through 1961 will produce a radiation dose to the whole body including the reproductive cells of 10 to 15 millirems in the first 30 years, which is less than one percent of the 30 year genetic dose to the present population from natural background.

While carbon-14 decays very slowly with a radioactive half-life of 5,700 years, its availability as a source of radiation exposure initially decreases rather rapidly because of absorption of carbon dioxide from the atmosphere into the oceans. In a period of one or two hundred years, the exchange between the atmosphere and the ocean approaches an equilibrium with most of the carbon-14 in the oceans. This mixing will reduce the carbon-14 due to weapons tests to about two percent of the natural carbon-14 concentration in the atmosphere, biosphere and oceans. The radiation dose rate at this time will be about 0.025 millirem per year, or 0.75 millirem per generation. Although the dose rate is very small, it will continue at a rate which decreases with the radioactive decay of carbon-14 through hundreds of generations.

Doses to the whole-body and reproductive cells were averaged, weighted according to population; bone and thyroid doses were averaged over that portion of the population who were infants at the time of highest concentrations of relevant radioisotopes in the diet. Average doses to older children and adults, and thus to the total population, were smaller. Some local averages, particularly in the case of the thyroid, were much higher.

All one year doses are for the year, within the period covered, in which the highest yearly doses were received. The highest one-year doses to the whole-body and skeleton from tests prior to 1961 were experienced in 1958-1959. The highest one-year doses to the whole-body and to the skeleton from the 1961 tests are expected during 1962 and 1963.

TABLE I

Estimated Radiation Doses in the United States

(Doses expressed in millirem)

Tissue or organ	From all tests through 1961	From natural background	FRC Radiation Protection Guides* for normal peacetime operations Population groups
Whole body			
1 Year	10- 25	100	170
30 Years	60-130	3,000	5,000
70 Years	70-150	7,000	11,900
Reproductive cells			
1 Year	10- 25	100	170
30 Years	60-130	3,000	5,000
70 Years	70-150	7,000	11,900
Bone			
1 Year	30- 80	130	500
70 Years	400-900	9,100	35,000
Bone marrow			
1 Year	20- 40	100	170
70 Years	150-350	7,000	11,900

*The Radiation Protection Guide for whole-body exposure of individual radiation workers is 5,000 millirems per year.

APPENDIX "B"

DISCUSSION OF THE NUMERICAL VALUES IN TABLES II AND III

The estimates of genetic effect are based largely on the reports of the Committee on Genetic Effects of the National Academy of Sciences, contained in the Academy's 1956 and 1960 Summary Reports on the Biological Effects of Atomic Radiation. The Summary Reports concluded from the available scientific information that the genetic effects of exposure of a population to small doses of radiation are proportional to the average dose to the reproductive cells of potential parents.

The Committee reported that normally some four to five percent of children born have or will develop a severe physical or mental defect. Of these defective children about half, or two percent of the total number born, are thought to have traits whose frequency in the population is directly dependent on the mutation rate.

The Academy Committee utilized data on mutation rates in mice and estimated the effects on human populations, assuming that human radiation-induced mutation rates are the same as in mice. The 1956 Report estimated that if the parents of the present generation were exposed to 10,000 millirems, this average dose would give rise to some 50,000 additional defective children among 100 million children born. The total number for all future generations, assuming no change in the size of population, was estimated as 500,000.

Recent data have shown that radiation given at a very low rate produces fewer mutations than the same total dose given quickly. Since the earlier estimates were based on high dose rates, they should be reduced accordingly. The results from recent experiments with mice indicate that when both parents are irradiated the best estimate of the number of mutations should be only 1/6 as large as with high dose rates.

An application of these modified estimates to the reproductive cell exposures estimated to occur from past weapons tests, approximately 100 millirems over the first 30 years, leads to an estimate of 110 cases of serious inherited defects in the first generation of 130 million births. The estimates of radiation doses in Table I apply only to radiation received by the present population of the United States.

At least four physical phenomena contribute to making the radiation doses to future generations from these tests much smaller. In fact, in a few decades the exposure per generation from residual radioactivity produced by these tests will have dropped to less than one percent of the exposure to the current population.

In the case of the whole-body and reproductive cells, about 50% of the 30-year dose from tests through 1961 has resulted from exposure to radiation from relatively short-live gamma-emitting materials outside the body. As a result of radioactive decay, these will have essentially disappeared within a few years.

It is estimated that about 20 percent of the 30-year dose is from cesium-137 in the diet. Most of this results from the direct deposition of fallout on vegetation. When the deposition rate is low, the availability of cesium-137 is small. This factor, together with its short retention time in the body, makes this radioisotope a small contributor to internal irradiation. About 25 percent of the 30 year dose is due to cesium-137 outside the body. The dose rate from this source decreases with time, not only as a result of radioactive decay with a half-life of 27 years, but also because of decreasing availability due to migration into the earth or into streams, storm drains, etc. The dose rate from this isotope may be reduced by 1/2 to 1/10 after 30 years in addition to radioactive decay.

It is estimated that carbon-14 resulting from tests through 1961 will produce a radiation dose of 10 to 15 millirems in the first 30 years, about 10 percent of the 30 year genetic dose from fallout to the present population. The radiation dose rate, after equilibrium with the oceans has been reached, will be about 0.025 millirem per year, or 0.75 millirem per generation. Although the dose rate is very small, it is of interest because it will continue at a rate which decreases with the radioactive decay of carbon-14 through hundreds of generations.

In addition to its radiation effects, carbon-14 may produce mutations through disruption of the normal chemical structure of the gene when the atom of carbon-14 is converted into nitrogen. The contribution from this effect appears to be small in comparison to the radiation effect, and is too speculative to provide a firm basis for numerical estimates.

The current total incidence of deaths due to leukemia in the United States is about 12,000 per year and that of bone cancer is about 2,000 per year. These amount to average rates for all ages of 7 cases per one-hundred thousand persons and 1.1 cases per one-hundred thousand persons, respectively.

It is assumed that the incidence of these diseases as a result of exposure of the blood-forming tissues and the bone, respectively, to radiation is proportional to the exposure. Observations of number of cases of leukemia resulting from very large doses of radiation suggest that up to ten percent of the normal incidence of leukemia may be due to exposure to radiation from natural sources, amounting to an average of 7,000 millirems in 70 years. The same assumption has sometimes been made for bone cancer. These assumptions were made, for example, by the United Nations Scientific Committee on the Effects of Atomic Radiation (1958) in estimating an upper limit to the number of cases of leukemia and bone cancer that might be expected from low levels of exposure such as those from fallout from the testing of nuclear weapons.

On this basis, one could estimate that if an average lifetime exposure of 7,000 millirems to the blood-forming tissues of the population of the United States results in a total of about 84,000 cases of leukemia in the period of an average lifespan of 70 years, the average lifetime exposure to fallout could be expected to result in a total of up to 2,000 cases of leukemia, averaging about 30 per year. The average exposure to the population as a whole from fallout is estimated to be about 175 millirems to the bone marrow, about half the value calculated for infants, as shown in Table I. A corresponding estimate for the number of cases of bone cancer from a population weighted lifetime dose of about 450 millirems would give an upper limit of 700 cases in 70 years, averaging about 10 cases per year.

For comparison, there are about 1,700,000 deaths each year in the United States from all causes. Of these, up to about 1,400, or about 10% of the total due to leukemia and bone cancer from all causes, are attributed to radiation exposure from natural sources. The possible additional 40 deaths from these causes, as estimated above, illustrate the degree of risk to an individual from fallout in comparison to risks already present.

TABLE II

Effect of Fallout on the Number of Gross Physical or Mental Defects in Future Generations in the United States

(No allowance has been made for future increases in population)

(1) Estimated number of cases due to all causes (hereditary and non-hereditary) in children of persons now living	(2) Estimated number of additional cases in the first generation (children of persons now alive) caused by all tests through 1961		(3) Estimated total number for all future generations from all tests through 1961		(4) Risk to an individual of the next generation from all tests through 1961
	Fallout	Carbon-14			
4,000,000-6,000,000	100 Range (20-500)	10 (2-50)	1,000 (200-5,000)	2,000 (400-10,000)	1/1,000,000

The upper figures in columns 2 and 3 are best estimates based on radiation-induced mutation rates in mice, and on the spontaneous incidence of these defects in man.

The lower sets of figures represent the range within which the true value may reasonably be expected to lie.

TABLE III

Certain Malignant Diseases in the Next Seventy Years in the United States

	Estimated total number of cases from all causes (present incidence)	Estimated number of cases caused by natural radiation	Estimated number of additional cases from all tests through 1961	Risk to an individual of developing the disease due to all tests through 1961
Leukemia............................	840,000	0-84,000	0-2,000	0-1/100,000
Bone Cancer	140,000	0-14,000	0-700	0-1/300,000

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