REPORT NO. 4

ESTIMATES AND EVALUATION OF FALLOUT IN THE UNITED STATES FROM NUCLEAR WEAPONS TESTING CONDUCTED THROUGH 1962

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FEDERAL RADIATION COUNCIL

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SUMMARY

As a sequel to a similar report last spring, the Federal Radiation Council has again made a full study and analysis of fallout expected in the current year from nuclear tests in the past. In this case the report covers fallout expected in the next few years from Soviet and United States tests conducted to date.

Although absolute fallout levels in the U.S. in 1963 will probably be substantially increased over 1962 if rainfall is normal, they will still be in relative terms far short of figures which would cause concern or justify counter-measures. Cumulative whole-body radiation doses from all past tests is estimated to be 110 millirems in 30 years, which is about one-thirtieth the exposure from natural sources such as soil, rocks. and building materials. The special cases of iodine-131 and strontium-90. the two radio-nuclides of most concern to the public, have been thoroughly reviewed and specifically included in the general conclusion. The Council concludes that the health risks from radioactivity in foods, now and over the next several years, are too small to justify countermeasures to limit intake of radionuclides by diet modifications or altering the normal distribution arid use of food, particularly milk and dairy products.

The substantial increase in absolute amounts of fallout is due primarily to Soviet nuclear tests. The amount of fission yield in the thermonuclear test explosions is a measure of the quantity of strontium-90 and other fission products produced by the tests. The total yield of thermonuclear explosions is a measure of the carbon-14 produced. Since the Soviet Union ended the three-year moratorium by resuming nuclear tests in 1961, Soviet testing has produced 85 megatons of fission yield, and U.S. testing 16 megatons.

This report updates weapons testing information to include all tests conducted through 1962. The USSR conducted atmospheric tests at levels of 120 megatons (MT) total yield and 25 MT fission yield in 1961; 180 MT total yield and 60 MT fission yield in 1962. A few of the underground tests conducted by the U.S. in 1961 resulted in some venting to the atmosphere. The U.S. conducted a series of atmospheric tests in the Pacific at a level of 37 MT total yield and 16 MT fission yield in 1962 plus a few low yield tests at the Nevada Test Site.

Measurements of strontium-90 in food supplies and the total diet in the U.S. show that the levels rose from a value of 4-8 strontium units (SU) in 1961 to 8-13 SU in 1962, and may rise to a peak value of 50 SU in 1963. The predicted concentrations of strontium-90 in milk for 1963 are twice the values observed in 1962 and about 4 times the values observed in 1961. The strontium-90 concentrations in human bone are expected to rise from an observed value of 2.6 SU in 1961 to 7 SU in 1964. The presently estimated radiation dose to bone from all past tests is about 465 millirems in 70 years, which is about one-twentieth the exposure from natural sources. It should be noted that these presently predicted values are no greater than those which were predicted in the FRC Report No. 3 as likely to result from all tests conducted prior to 1962. This is because the measured levels are lower than originally predicted.

It was estimated in 1962 that carbon-14 resulting from tests conducted through 1961 would give an average per capita radiation dose to the whole-body including the reproductive cells of 10 to 15 millirems in the first 30 years. It is now estimated that the carbon-14 produced by testing conducted in 1962 will produce a comparable radiation dose in the first 30 years. When the carbon-14 now in the atmosphere has equilibrated with the oceans, the natural levels will be increased by about 4 percent instead of the 2 percent previously reported.

As an addition, FRC Report No. 3, "Health Implications of Fallout from Nuclear Weapons Testing through 1961," is attached for reference.

SECTION I

INTRODUCTION

1.1 The Federal Radiation Council evaluated the health implications of fallout from nuclear weapons testing conducted through 1961 in its Report No. 3 issued in May 1962. Since that report was prepared, additional atmospheric testing of nuclear weapons has been conducted by the USSR and U.S. governments. The purpose of the present report is to:

a) Update the information concerning the scale of weapons testing programs conducted by all nations;

b) Summarize the radiation doses experienced in the past and expected in the future;

c) Evaluate the change in the inventories of long-lived radionuclides in the stratosphere and on the ground resulting from these tests;

d) Predict the probable levels of fallout that may be expected in 1963 and subsequent years in the food supplies of the nation; and

e) Draw conclusions about the suitability of food products for human consumption in view of the predicted levels of radionuclides.

1.2 The predictions of future fallout levels from testing conducted through 1962 are based on the information available through March 1963. The estimates of doses received in 1962 are based on extensive measurements of the radionuclide concentrations in air, rain, soil, water supplies, food supplies, and people.

SECTION II

HISTORY OF NUCLEAR WEAPONS TESTING

2.1 The atmospheric testing of nuclear devices inevitably introduces radioactive nuclides into man's environment. The existence of many of these products is transitory due to the process of radioactive decay. Other species, notably carbon-14, are so long-lived that they can be considered as a permanent man-made modification of the environment. Historically, major attention has been focused on the production and distribution of strontium-90 and cesium-137, both of which can lead to radiation exposure over the full lifetime of persons now living. Of the shorter-lived radionuclides, iodine-131 has been emphasized.

2.2 The production of strontium-90 and other fission products depends on the fission yields of the devices. The production of carbon-14 depends on the total fission plus fusion yields of the devices.

2.3 Table 1 summarizes the fission and total yields of atmospheric testing conducted by all nations through December 1962. As of January 1959, the strontium-90 inventory was estimated to be 9.2 megacuries produced by the detonation of 92 megatons of fission yield, 40 megatons of which had been detonated in 1957 and 1958 1/. Of this inventory, it was estimated that 3 megacuries had deposited as "close in" fallout near the test sites. Of the 6 megacuries then available for worldwide deposition, 3 megacuries had been deposited as worldwide deposition, and 3 megacuries were still in the atmosphere. The available inventory as of May 1961, taking into account the decrease of 2.5 percent per year for the radioactive decay of strontium-90, was estimated as 5.2 to 5.3 megacuries strontium-90. Of that quantity, 4.2 megacuries had deposited on the ground and 1 megacurie was still in the atmosphere. Less than one-quarter of this atmospheric burden was in the lower stratosphere in the northern hemisphere.

2.4 The USSR detonated an estimated 120 megatons of total yield in 1961 of which about 25 megatons were due to fission yield. The estimated radiation doses from this series were presented in FRC Report No. 3, "Health Implications of Fallout from Nuclear Weapons Testing through 1961."

2.5 The United States and the Soviet Union conducted tests in 1962 at levels shown in Table 2. U.S. and Soviet tests do not contribute equally to fallout exposures in the U.S. not only because of the difference in fission yields, but also because the distribution and rate of deposition vary with the geographic location of the tests and the altitude to which the weapon debris is carried. The amounts of fission yield injected into the stratosphere by the U.S. and the USSR in 1961 and 1962 are shown in Table 3. The total of 57 megatons fission yield injected into the lower stratosphere in 1961 and 1962 dominates the inventory available for worldwide deposition in 1962, and in the next few years.

1/ 10 megatons of fission yield produce approximately 1 megacurie of strontium-90.

TABLE 1

Approximate Fission and Total Yields of Nuclear Weapons
Conducted in the Atmosphere by All Nations

(Yield in Megatons)

Inclusive Years	Fission Yield Air	Fission Yield Surface	Total Yield Air	Total Yield Surface
1945 - 1951	.19	.52	.19	.57
1952 - 1954	1	37	1	59
1955 - 1956	5.6	7.5	11	17
1957 - 1958	31	9	57	28
Subtotal	37.8	54	69.2	104.6
1959 - 1960	TEST		MORATORIUM	
1961	25 1/		120	
Subtotal	63	54	189	105
1962	76 1/		217	
TOTAL	139	54	406	105

1/ The small yield tests conducted in Nevada do not contribute significantly to the worldwide distribution of strontium-90 to which this summary is related

TABLE 2

Approximate Fission and Total Yields of Atmospheric
Tests Conducted in 1962

(Yield in Megatons)

	Fission Yield	Total Yield
U.S.	16	37
USSR	60	180
TOTAL	76	217

TABLE 3

Approximate Fission Yields Injected into the
Stratosphere in 1961 and 1962

(Yield in Megatons)

	Lower Stratosphere 1/ (MT)	Upper Stratosphere 1/ (MT)	Total (MT)
USSR (1961)	17	8	25
USSR (1962)	30	30	60
U.S. (1962)	10	1	11

1/ The lower stratosphere occupies the first few tens of thousands of feet above the tropopause and the upper stratosphere continues to about 150,000 feet. The tropopause, on the average, is located at 30 - 40,000 feet in the temperate and polar zones and 50 - 55,000 feet in the tropical and the equatorial zones. Debris injected above 150,000 feet is omitted from this table.

SECTION III

ATMOSPHERIC TRANSPORT AND DISTRIBUTION OF FALLOUT

3.1 The future course of fission-product deposition in man's environment resulting from past nuclear detonations can be estimated either from a knowledge of the amount and distribution of these products in the atmosphere at some recent date or from an estimate of the time, place, and amount injected into the atmosphere by the various test series. These data can be utilized in conjunction with the experience and knowledge gained over the past decade in analyzing fallout phenomenology. Studies of the movement and deposition of debris from past test series, using short-lived isotopes and unique radioactive tracers to identify the sources of the debris, have added to our understanding of the role of the atmosphere in determining the ultimate distribution of fission products on the surface of the earth.

3.2 Although the exact mechanisms involved in the transfer of debris from the stratosphere to the surface of the earth are not completely understood, the general features of the distribution on the ground are known from the available fallout data. These data show that precipitation is the most important mechanism in depositing material on the surface, and that there are both a latitudinal variation, with most deposition in temperate latitudes, and a seasonal variation with maximum deposition in the spring,

3.3 On January 1, 1963, the accumulated levels of strontium-90 deposited over the United States varied from about 100 to 125 millicuries per square mile in the "wet" areas (areas of greatest annual precipitation) to 40 to 50 millicuries per square mile in the "dry" regions. Figure 1 shows the continental United States; the areas considered as "wet" are closely hatched, "dry" areas are unshaded, and intermediate precipitation regions have widely spaced hatching.

3.4 Utilizing sampling data obtained by the Defense Atomic Support Agency's STARDUST Program, it is possible to compare the burden of strontium-90 in the lower stratosphere in early 1963 with the burden approximately a year earlier. Experience indicates that debris present in January up to 55,000 feet will appear in the fallout of the coming year. Figure 2 shows the strontium-90 concentration up to 70,000 feet, the ceiling of the sampling aircraft, in early 1963. The stratosphere below 55,000 feet in the northern hemisphere contained about 2 megacuries of strontium-90 in early 1963, while about 1 megacurie was observed in the same region in early 1962. Thus, the 1963 fallout is expected to be about twice that of the stratospheric component in 1962, as shown in Table 4. About 80 percent of the stratospheric burden available for fallout in 1963 came from testing conducted in 1962. The apparent age of the 1963 spring fallout is expected to correspond to a mean production time of mid-September 1962. An independent analysis of the input of strontium-90 based on the fission yields given in Table 3 agrees with the estimates in Table 4.

3.5 In Table 4 the annual fallout estimates from weapons tests already conducted have been extended, with considerable uncertainty, to future years. Since the half-life of strontium-90 is 28 years, it decays at the rate of 2.5 percent per year. By 1966, radioactive decay of the accumulated strontium-90 should exceed deposition, resulting in a gradual lowering of the strontium-90 values in succeeding years.

3.6 The possibility exists that fallout estimates can be in error by a factor of two for the year 1963 and by more than a factor of two in subsequent years. The uncertainties in the estimates of fallout are largely due to data limitations, incomplete understanding of atmospheric behavior, and year to year weather differences.

FIGURES

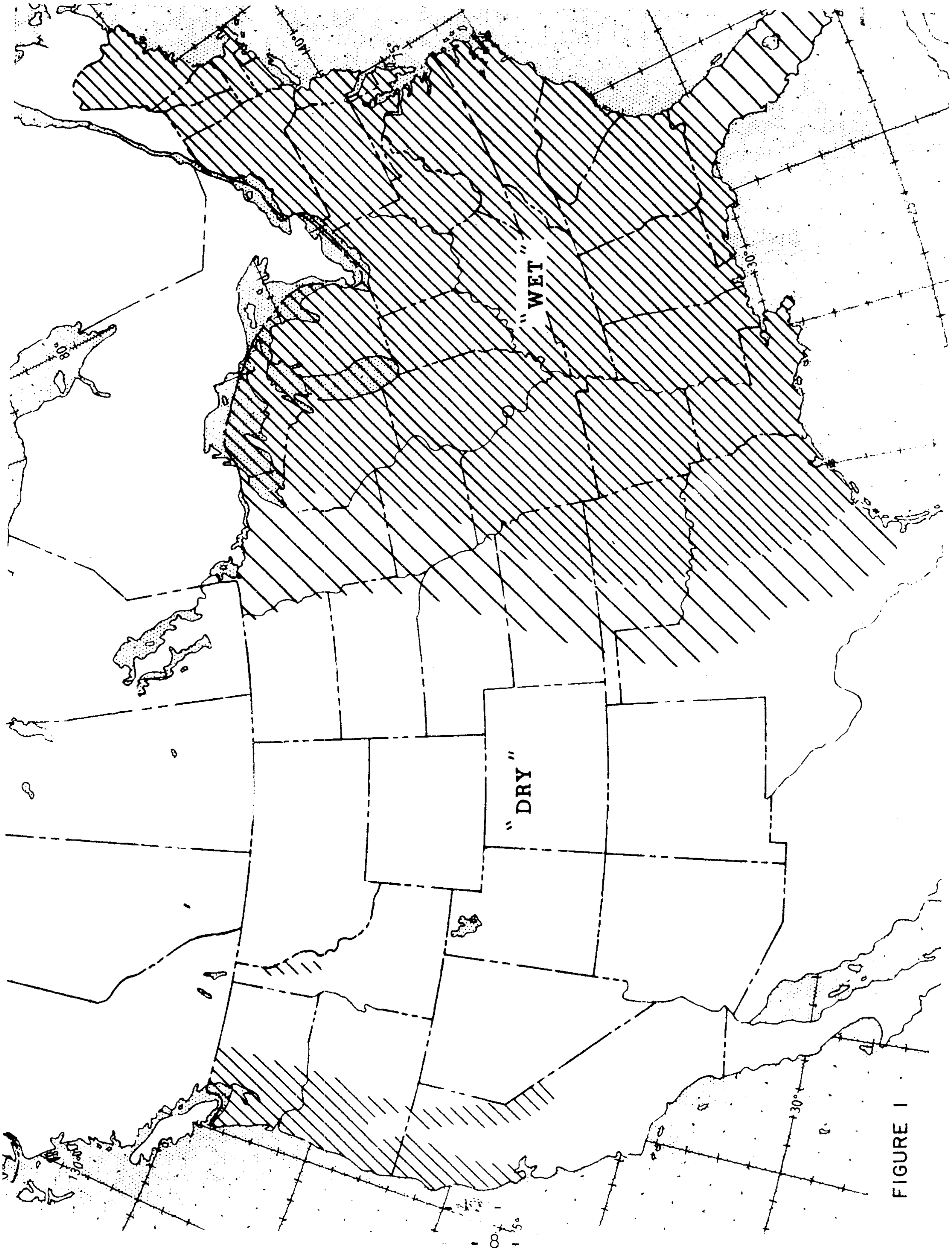

FIGURE I

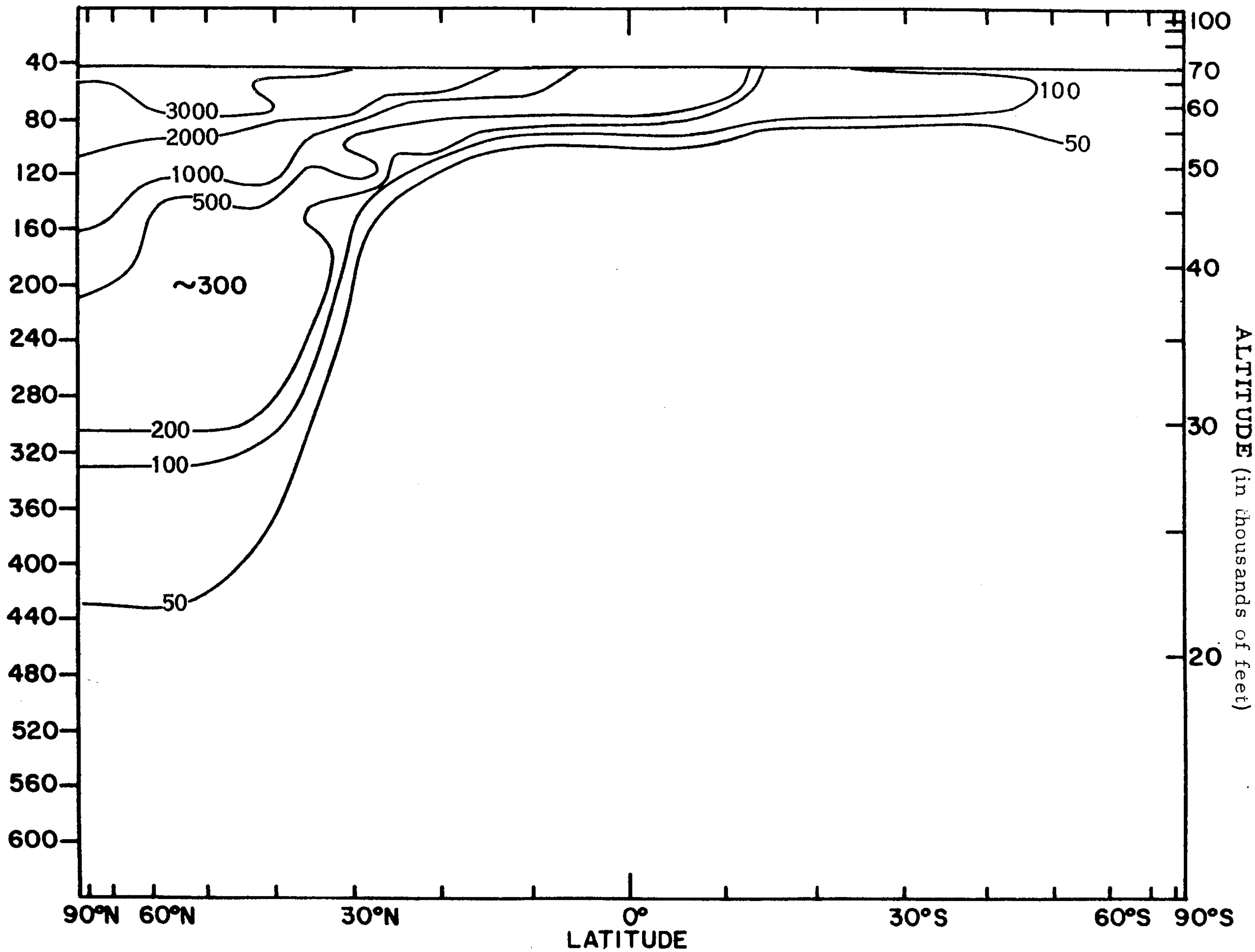

FIGURE 2 MEAN DISTRIBUTION OF STRONTIUM-90 OBSERVED BY THE STARDUST PROGRAM

TABLE 4

Expected Annual Deposition of Strontium-90 in the United States
(millicuries per square mile)

	Most Probable Value	Variability Within Area
Deposition During 1962 (Stratospheric Component Only)		
"Wet" area	25	15-35
"Dry" area	10	5-15
Accumulated Deposition to January 1, 1963		
"Wet" area	110	100-125
"Dry" area	45	40-50
Expected Deposition During 1963		
"Wet" area	50	30-60
"Dry" area	20	10-30
Expected Deposition During 1964		
"Wet" area	20	10-25
"Dry" area	8	5-10
Expected Deposition During 1965		
"Wet" area	10	5-15
"Dry" area	3	2-5

NOTE: In each year, it is expected that about 70% of the annual fallout will occur in the first six months of the year.

SECTION IV

RADIONUCLIDES IN THE DIET AND IN PEOPLE.

4.1 Estimates of radiation doses received from fallout must take into account exposures from all sources including sources external to the body and those which enter the body by inhalation and ingestion. There is a special interest in those radionuclides that enter the body through the diet. This section considers that part of fallout debris which is found in the food supplies of the nation.

4.2 The most significant contributors to the internal dose to man from fallout radionuclides are strontium-90, cesium-137, iodine-131, strontium-89, and carbon-14. The shorter lived nuclides iodine-131 and strontium-89 are significant in fallout only over the first few months following a test; the others are of importance over many years. Information concerning the appearance of these nuclides in the diet and in man is provided in the following paragraphs.

Strontium-90

4.3 Strontium-90 is a long-lived radionuclide (half-life of 28 years) with chemical properties similar to calcium. It deposits in bone where it has a long residence time. Its concentration in the human body is determined by radiochemical analyses of bone specimens obtained surgically or at autopsy. Since strontium-90 emits only beta particles, the skeletal content cannot be measured externally by instrumental methods. It enters the body in the total diet; milk, wheat products, and vegetables are the main contributors.

4.4 Historically, strontium-90 has been considered the most potentially hazardous component of radioactive fallout and has been the most widely studied. Measurements of its concentration in human bone specimen are the most direct approach to dose estimation, but the time lags in body uptake and in the collection and analyses of specimens are a handicap in maintaining knowledge of current concentrations in the skeleton. However, past experience allows reasonably reliable estimates of strontium-90 in new bone 1/ from total dietary intake, from the strontium-90 content of milk, or from fallout deposition measurements.

4.5 The confidence with which estimates of strontium-90 concentrations in new bone can be made from a knowledge of the strontium-90 levels in the diet has increased since the 1959 Congressional Hearings on fallout. Prior to that time, diet information was largely derived from milk sampling and from a few other items, but the bone sampling was not correlated with diet samples.

4.6 Beginning in late 1959 the Atomic Energy Commission's Health and Safety Laboratory (HASL) established a quarterly survey in New York City, San Francisco, and Chicago based on food consumption. Consumers Union collected and analyzed complete diets of teen-agers for two weeks in 24 cities in November 1959 and similar collections have been made up to the present time. The U.S. Public Health Service (USPHS) monthly institutional diet sampling program involving the age groups 8 to 20 and now covering institutions in 22 states began in March 1961. The Food and Drug Administration (FDA) set up a total diet sampling program in May 1961, and continued regional sampling of major food items.

4.7 Because of these expanded programs, estimates of dietary strontium-90 levels have been greatly improved since 1958. Studies of the relationships between fallout deposition levels and the strontium-90 levels in diet and milk have provided a basis for predicting future levels of strontium-90 in several dietary components and in total intake. These prediction models take into account both the uptake by plant roots from the total accumulated deposition in the soil, and the foliar uptake of fallout deposited during the growth period. Other factors, such as the length of the growing season and differences in agricultural practices also lead to variations in radionuclide concentrations in man's food supplies even though the levels of fallout deposition appear to be similar. Thus, the observed radionuclide levels in milk and other foods per millicurie of strontium-90 deposited per square mile are somewhat higher in the southern part of the U.S., than they are in the north. Similarly, the food chain of lichen-caribou-man, which is characteristic of the Far North may sometimes lead to transient levels in food for a given level of fallout deposit many times higher than corresponding levels in the "wet" areas of the U.S.

1/ New bone is the bone being formed from the dietary components. In the adult it is only that bone being re-formed or exchanged metabolically, and is a small fraction of the skeleton. In the growing child new bone represents a much higher portion of the skeleton.

4.8 Studies of strontium and calcium metabolism show that the ratio of strontium-90 to calcium in new bone may be estimated as about one-fourth of the ratio in the diet, since the body uses calcium preferentially over strontium. This metabolic discrimination against strontium may be less in infants, but the strontium-90/calcium ratio in new bone will not be greater than that of the diet.

4.9 Based on these considerations and on fallout predictions for 1963, 1964, and 1965, as as described in Section III, predictions of strontium-90 levels in total diet, diet components, and bone have been made.

Total Diet

4.10 Table 5 shows the strontium-90/calcium ratios in the U.S. total diet obtained by measurements made from 1959 through March 1963, and values predicted in the future for the total diet in the "wet" and "dry" areas of the U.S. Following the peaks of 13 to 18 SU (Strontium Unit-See Glossary) reached in 1959 as a result of 1958 weapons tests, the levels dropped by 1961 to 4 to 8 SU. The rise at the end of 1962 and early 1963 resulting from tests in 1961 and 1962 will continue to a predicted maximum of 50 SU in 1963.

4.11 These predicted values resulting from tests conducted through 1962 can be compared with measurements made since 1959 only on the basis of average levels for broad regions. Measurements made in the pasteurized milk network during 1961 and 1962 indicate that the average annual concentration of strontium-90 in milk produced in the "wet" area of the U.S. is about 1.5 times greater than the annual average for milk produced in the "dry" area. The maximum difference between the lowest station in the "dry" area and the highest station in the "wet" area in 1962 was about a factor of 10 for the radionuclides of interest. The average annual intake of radionuclides in some regions may be about 3 times higher or 3 times lower than the overall national average. 1/ The data from Table 5 show that the annual intake of strontium-90 in a diet representative of a typical person in the U.S. dropped from about 15 SU in 1959 to a low of about 6 SU in 1961 before the resumption of nuclear testing. The large increase predicted for the year 1963 was not generally evident in measurements made through March. However, the maximum fallout rates are expected to have occurred during the months of April and May, so surveillance measurements of nuclides such as cesium-137 and strontium-89 should show sharp increases by June if these predictions are approximately correct. The decrease in subsequent years reflects the diminished fallout rates predicted for those years.

Diet Components

4.12 The percentage contributions of four major diet categories to the diet weight, strontium-90 and calcium intakes for the tri-city diet studies of the Health Safety Laboratory are shown in Table 6. It is apparent that an attempt to substitute other diet items for milk would decrease calcium intake more sharply than strontium-90 and in fact increase the strontium-90/calcium ratio of the diet. A number of studies have shown that conservative estimates of the strontium-90/calcium ratio in the total diet may be made by multiplying the ratio of strontium-90/calcium in milk for a particular locality by 1.5. The strontium-90/calcium ratio in milk may be the same as that in the diet during periods of fresh fallout.

4.13 The levels of strontium-90 in milk measured in the past, and predicted for the future are shown in Table 7. The measured values of strontium-90 in the milk supply of New York City were about 9 picocuries per liter of milk in 1959 and dropped to a low of 8 picocuries in 1961. The concentration rose to a value of about 14 picocuries per liter of milk in 1962 and is projected to average about 30 picocuries per liter in 1963 and then drop to values of about 17 picocuries per liter by 1965. It should be recognized that Table 5 considers the total diet which contains food from several areas, while Table 7 is concerned with milk alone. The relationship that the strontium units in the total diet equal 1.5 times the strontium units in milk was derived when this relationship was stable. The predictions in Table 5 cannot be derived from Table 7 since, as already noted, the relationship changes during periods of fresh fallout.

4.14 The levels of strontium-90 in wheat and in white flour measured in the past and predicted for the future are shown in Table 8. Wheat levels are more dependent on the fallout rate component than are milk levels and thus they vary over a wider range.

1/ This information is of interest since previous estimates have presented the analyses in terms of the national average, whereas an attempt is being made to analyze the "wet" and "dry" regions separately in this report.

4.15 The levels of strontium-90 in wheat are among the highest found in important food items. The maximum level resulting from past weapons testing is expected in the 1963 wheat crop and may average as high as 250 picocuries of strontium-90/kilogram in harvested wheat. Milling, distribution, and storage practices bring about much lower levels in major dietary wheat products, and also make it unlikely that levels of strontium-90 ingestion through wheat products in any particular area will differ much from the national average.

4.16 From 70 to 80 percent of the wheat consumed by humans in the United States is in the form of bread made from white flour. This wheat is produced almost entirely on the Great Plains from Texas to North Dakota and Montana, and the concentration of strontium-90 has differed little from the national average in any past year. Most of the remaining wheat is consumed in the form of other baked goods and is produced primarily east of the Mississippi River or in the Pacific Northwest. Less than five percent of the wheat consumed is in the form of whole wheat bread or cereals, and very little is in the form of bran. Although the latter products contain a higher concentration of strontium-90 than white flour or whole wheat, the relatively small quantities consumed prevent them from becoming major contributors of strontium-90 in the total diet.

4.17 Water, meat, fish, poultry, eggs, sugars and fats contribute negligible amounts of strontium-90 to the diet. Fruits and vegetables contribute about one-third of the total intake of strontium-90, which is quite comparable with their weight intake. These figures are based on the foods as prepared for eating; slightly higher values are found in the raw unwashed items.

4.18 The levels of strontium-90 measured in the past and predicted for new bone in the future are shown in Table 9. The predicted value for new bone is taken as one-fourth the predicted strontium-90/calcium ratio in the total diet in order to indicate the concentrations being deposited in the skeletons of the younger age groups. However, as pointed out in FRC Report No. 2, the mean bone dose is a better estimate of risk inasmuch as a larger volume of tissue is affected. Calcium and strontium-90 in new bone is continually redistributed as the result of normal bone metabolism, so the observed values in the skeleton would be expected to be lower than the maximum concentration in new bone during a relatively short period of time (i.e., one year). Thus the calculated concentrations of strontium-90 in new bone in 1963, 1964, and 1965 are 12, 8, and 5 SU respectively, whereas the values estimated in bone for the 0-4 age group are about 5, 7, and 7 SU respectively in the "wet" areas of the United States and 3, 5, and 5 SU respectively in the "dry" areas.

Cesium-137

4.19 Cesium-137, another long-lived radionuclide (half-life 30 years), distributes itself throughout soft tissue and has a relatively short residence time in the body. Its gamma radiation allows direct measurement in the living body with a whole-body counter.

4.20 The distribution of cesium-137 in the diet is not well defined, but milk, meat, and vegetables are the main contributors. Trends in dietary cesium-137 have been similar to those for strontium-90, in that both tend to fluctuate with fallout rate. Because of this dependence on fallout rate and the rapid turnover rate of cesium in the body, cesium-137 levels in foods and in the body increase and decrease more rapidly than levels of strontium-90. Peak concentrations of cesium-137 in milk have appeared about one month after peak fallout rates, and peaks in the balance of the diet have appeared about one year after peak fallout rates. Peak levels in people have been observed about seven months after peaks in fallout rates.

4.21 Because of the differences in the mechanisms by which cesium-137 moves through the environment, predictions for cesium-137 cannot be made on the same basis as those for strontium-90. About all that can be done is to make comparisons with previous test patterns and the corresponding observations for milk and man, and noting that a year by year comparison is not direct inasmuch as there are different time lags in the responses. Table 10 gives the observations on cesium-137 measured in pasteurized milk samples by the U.S. Public Health Service from 1959 through the first quarter of 1963. Table 11 gives measured and predicted concentrations of cesium-137 in milk and man.

4.22 Table 10 shows that the concentration of cesium-137 in milk in picocuries per liter, was about 4 to 5 times the corresponding strontium-90 concentration in 1959; it was essentially the same as strontium-90 in 1960 and 1961; it rose to 3 to 4 times the strontium-90 concentration in 1962 as the result of fresh fallout in that year. Although there is no uniform relationship between cesium-137 and strontium-90 concentrations in milk, estimates based on fallout rate lead to the conclusion that the average "wet" area concentrations of cesium-137 in milk may be about 140, 70, and 30 picocuries per liter respectively in 1963, 1964, and 1965. The anticipated concentration in man is expected to be about 150 picocuries per gram of potassium 1/ in 1963 and then drop to a value below 100 by the end of 1965.

Iodine-131

4.23 Iodine-131 is a short-lived radionuclide (half-life 8 days) which concentrates in the thyroid gland. Its gamma radiation allows direct measurement in the body. The residence time in the body and the half-life are both short. Therefore iodine-131 disappears in a few weeks. The significant diet contributor is milk because the time lag between production, and distribution is only a few days.

4.24 The U.S. Public Health Service measurements of iodine-131 in milk are summarized in Table 10. Iodine-131 levels from past testing are based on values observed from 1959 through March 1963. Radioactive decay has reduced the iodine-131 resulting from tests conducted in 1962 to insignificant levels. The presentation of iodine-131 levels by "wet" and "dry" areas is included only to keep the form of the information comparable. The deposition of iodine-131 is largely associated with material initially injected into the troposphere and hence is not systematically related to the mean annual rainfall.

4.25 Since November 1961, the Public Health Service with the cooperation of selected medical centers throughout the continental United States has collected and analyzed several hundred thyroid autopsy specimens. The thyroids were primarily from adults experiencing a traumatic death. Iodine-131 values ranged from 0-20 picocuries per gram of thyroid with a probable mean in the range of 5-7 picocuries per gram. Iodine-131 in the thyroid was found only where appreciable levels of iodine-131 were observed in the pasteurized milk network samples in the area from which the thyroid specimen was obtained.

4.26 The highest station for iodine-131 in milk in the continental U.S. in 1962 was in Utah. A large percentage of the observed iodine-131 occurred as the result of atmospheric tests in Nevada. Although the Utah State Health Department reported iodine-131 concentrations in excess of 1000 picocuries iodine-131 per liter of milk for about a week, the equivalent daily intake for a year for the population in the milkshed would have been 103 picocuries iodine-131 per liter. Milk from individual farms or from individual cows could, of course, be higher or lower than the measured average for the station.

Strontium-89

4.27 Strontium-89 has a half-life of 50 days, and is similar chemically to strontium-90. It deposits preferentially in bone, and remains there until it is reduced to a negligible level through radioactive decay. Like strontium-90 it is a beta emitter and is measured in humans by the radiochemical analyses of bone samples obtained at autopsy. Milk is the important dietary contributor since time lags between deposition and the production and distribution of most other foods result in the radioactive decay of strontium-89. Strontium-89 appears in other foods attached to their surfaces.

4.28 The observed values for strontium-89 in milk since 1959 are given in Table 10. It can be seen that the annual average concentration for most stations was three to four times the corresponding concentration of strontium-90 for that station. Based on the apparent age of the fission debris in the stratosphere, the strontium-89/strontium-90 ratio in milk in 1963 may reach a maximum value of about 8 during the first part of the year, but due to the short half-life of strontium-89, the annual averages in 1963 should be comparable to those observed in 1962.

Carbon-14

4.29 Carbon-14 is a very long-lived radionuclide (half-life 5,760 years) produced by the interaction between neutrons and nitrogen in the atmosphere. It is produced naturally by cosmic radiation, and artificially by nuclear weapons. It follows non-radioactive carbon chemically and metabolically, and is part of all living matter. Carbon-14 in the body is essentially in equilibrium with carbon-14 in the environment. The environmental level tends to decrease slowly as carbon-14 enters the carbonates of the deep ocean waters and sediments. Carbon-14 emits only beta particles and cannot be measured directly in the body. All items of the diet contribute in proportion to their carbon content so that measurements made on atmospheric carbon dioxide, which is the source of plant carbon, can be substituted for measurements in the body.

1/ Potassium is essential to life and its naturally occurring radionuclide contributes a whole-body dose of about 20 millirems per year. It is chemically similar to cesium and is distributed through the soft tissues of the body. Therefore, cesium concentrations in people are usually reported as the cesium-137/potassium ratio.

4.30 As a result of nuclear weapons tests conducted through 1958 the tropospheric level of carbon-14 was about 30 percent above the equilibrium inventory of naturally produced carbon-14 in the atmosphere due to its normal production by cosmic radiation.

4.31 The testing conducted in 1961 and 1962 probably produced about 100 times more carbon-14 than was produced naturally by cosmic rays during the same period. This should raise the artificially produced carbon-14 in the atmosphere to twice the natural levels over the next several years. This excess carbon-14 is expected to be removed from the atmosphere by exchange with the ocean with a rate corresponding to a half-time (See Glossary) of about 33 years. Ultimately, about 96 percent will be removed, leaving an atmospheric level about 4 percent higher than the natural level. This conclusion is consistent with preliminary data from the stratospheric sampling program.

TABLE 5

Average Strontium-90 Content of U.S. Total Diet

(pc Sr^{90}/g Ca)

	"Wet" Area	"Dry" Area
	Observed	
1959	13-18	9
1960	11	4
1961	4-8	3-6
1962	8-13	4-8
1963 (Through March)	10	8
	Predicted	
1963	50	35
1964	30	20
1965	20	10

TABLE 6

Average Percent Contributions of Diet Categories

	Diet Weight 1/	Diet Calcium	Approximate Percent of Annual Strontium-90 Intake N.Y.	Chicago	S. F. 2/
Milk Products	33 6	61	51	39	37
Grain Products	14	15	16	26	24
Fruits and Vegetables	36	13	30	30	32
Others	17	11	3	5	7
	100	100	100	100	100

1/ The diet weights do not include water, coffee, tea and other nonmilk beverages.

2/ S.F. - San Francisco

TABLE 7

Average Strontium-90 Content in Milk in the U.S.

(pc Sr^{90}/1. of milk)

	New York	"Wet" Areas	San Francisco	"Dry" Areas
		Observed (PHS values)		
1959 1/	9	14	---	9
1960	9	9	4	5
1961	8	9	4	6
1962	14	15	5	10
1963 (1st Quarter)	16	18	8	11
		Predicted		
1963	31	-	11	-
1964	20	-	6	-
1965	17	-	4	-

1/ Based on raw milk data; dash (-) indicates no raw milk station.

TABLE 8

Strontium-90 Content of Wheat and Flour in the U.S.

(pc/kg)

	Average from 9-15 States Weighted for Production (HASL) 1/			Average of Pared Samples (FDA) 2/		FDA Sampling Program
Year of Harvest	Wheat	Flour		Wheat	Flour	Wheat
			Observed			
1959	48	9		--	--	--
1960	26	4		13	4	17
1961	23	7		19	4	18
1962	--	--		--	--	56 3/
			Predicted			
1962 3/	130	22				
1963	250	40				
1964	100	16				
1965	50	8				

1/ (HASL) Health and Safety Laboratory, USAEC, New York

2/ (FDA) Food and Drug Administration, Department of Health, Education and Welfare. The "Paired Samples" indicates that the same sample of wheat was analyzed when made into flour.

3/ Incomplete - includes less than 50% of production. The 1962 predicted value is presented pending the availability of more complete data.

TABLE 9

Average Strontium-90 Content of Human Bone in the U.S.

(pc Sr^{90}/g Ca)

	"Wet" Areas	"Dry" Areas
	Observed (0-4 years old)	
1958 1/	2.0	2.0
1959	2.7	2.2
1960	2.4	1.8
1961	2.6	0.9
1962 (6 months)	2.9	1.0
	Predicted (New Bone) 2/	
1963	12	9
1964	8	5
1965	5	3

1/ Data for 1958-60 are from Lamont Geological Observatory, 1961-62 are from HASL.

2/ One-fourth the predicted total diet values in Table 5.

TABLE 10

Radionuclide Concentrations in Pasteurized Milk

(pc/1. of milk)

Year	Strontium-90				Strontium-89				Cesium-137				Iodine-131			
	"Wet"	"Dry"	A.2/	H.3/	"Wet"	"Dry"	A.2/	H.3/	"Wet"	"Dry"	A.2/	H.3/	"Wet"	"Dry"	A.2/	H.3/
1959 1/ Annual average level	14	9	-	-	30	20	-	-	65	55	-	-	<10	<10	-	-
1960 Annual average level	9	5	7	4	<5	<5	<5	<5	10	10	10	20	<10	<10	<10	<10
1961 Annual average level	9	6	8	5	15	5	15	<5	10	10	10	20	20	20	60	<10
1962 Annual average level	15	10	10	5	55	38	51	27	49	36	37	27	29	36	104	12
1st Quarter 1963 3-month average level	18	11	11	8	40	30	20	55	75	65	65	55	<10	<10	10	20

1/ Based on raw milk data; dash (-) indicates no raw milk station. (Table prepared from USPHS data)

2/ Alaska

3/ Hawaii

TABLE 11

Average Cesium-137 Measured and Predicted Concentrations in Man and Milk

	Measured			
	In Man 2/			In Milk "Wet" Areas 3/
	Washington D. C.	Los Alamos	Average	
1957	-	51	-	
1958	69 1/	62	-	
1959	67	74	70	65
1960	51	67	60	10
1961	31	-	30	10
1962	-	-	-	49
			Predicted	Predicted
1963			150	140
1964			120	70
1965			80	30

1/ July-December only.

2/ Units, picocuries per gram of potassium.

3/ Units, picocuries per liter of milk. (USPHS Data)

SECTION V

RADIATION DOSE ESTIMATES

Exposure from Testing Conducted in 1962

5.1 Radiation doses that could affect present and future generations as the result of nuclear weapons testing conducted through 1961 were reported in FRC Report No. 3, "Health Implications of Fallout from Nuclear Weapons Testing through 1961." The present report considers doses attributable to the tests conducted in 1962 separately from the cumulative doses attributable to all tests conducted through 1962. The major interest is to isolate as much as possible the effects of the fallout rates expected from 1962 through 1965. Results from tests conducted in 1962 are shown in Table 12. Estimates of doses from short-lived nuclides, cesium-137, strontium-89, and strontium-90 were based on measurements made through March 1963 plus the predicted fallout deposition through 1965 in order to emphasize the information which is important in the immediate future. This procedure leaves a small percentage of the debris unaccounted for since it will still be in the stratosphere in 1965. However, the short-term carbon-14 estimates and the bone and bone marrow estimates would not be changed substantially. Estimates of radiation doses incurred in 1962 from tropospheric fallout were based on surveillance data as shown in Table 10.

5.2 Predictions shown in Table 12 of future doses from external radiation from debris yet to be deposited are based on projected deposition rates for "wet" areas of the U.S. as given in Table 4. The levels of cesium-137 were taken to be 1.7 times the level of strontium-90. Estimates of the possible contributions from short-lived nuclides were based on an apparent age of fission debris in the stratosphere corresponding to a mean production time of mid-September 1962, and the estimated levels of these nuclides relative to strontium-90 at the time of deposition. The estimated doses were then calculated, making corrections for weathering, shielding, and the movement of different radionuclides through the environment to man.

5.3 The period of the test moratorium from 1959 to 1961 was sufficient for a peak level of radionuclides such as strontium-90 and cesium-137 to occur and for subsequent downward trends in levels of these radionuclides to be established. The period was not sufficient to define the effective rates of removal of these radionuclides from the biosphere in the absence of deposition of additional fallout. The effective half-times in the environment for these radionuclides and their biological availability are, therefore, subject to uncertainty, and dose estimates in this report should be considered in that light.

5.4 Whole body and reproductive cell doses from both short-lived and long-lived radionuclides from 1962 tests were considered to begin during 1962. External exposures from cesium-137 were assumed to diminish with an effective halftime of ten years. Exposures to external short-lived radionuclides and short-lived internal emitters such as strontium-89 and barium-140 --- lanthanum-140 were considered to be completed within about one year following the 1962 tests.

5.5 Strontium-90 is expected to be effectively removed from that part of the biosphere which is important to man with an effective half-time of ten years. Therefore, doses for bone and bone marrow from 1962 tests were predicted for infants born in 1963 since this is the most sensitive age group and is expected to have the maximum concentration of strontium-90 per gram of calcium as discussed in Section IV of this report. Similarly, this is the age group expected to receive the highest lifetime bone dose from tests conducted in 1962.

5.6 The whole-body and bone doses to people deriving their foodstuffs from "dry" areas of the U.S. are estimated to be somewhat less (possibly as much as one-third to one-half) than those deriving their food from "wet" areas. Individuals and population groups subsisting on diets differing greatly from the diet typical of the majority of the population in "wet" and "dry" areas of the U.S. are expected to receive doses both higher and lower than the average dose for the "wet" area presented in Table 12. Although some individuals in the U.S. will receive doses higher than for "wet" areas and some will receive doses lower than for "dry" areas, it is expected that doses differing from these average values by more than a factor of 10 will not occur.

5.7 For calculations of 30-year and 70-year doses, exposure to carbon-14 from 1962 tests of 217 MT total yield (Table 2) was assumed to be reduced with a mean time of 48 years (see Glossary), or a half-time of 33 years. Since the total yields of tests conducted in 1962 are about two-thirds of the total yield from tests conducted through 1961, the long-term doses from carbon-14 from 1962 tests will be almost the same as the long-term doses from carbon-14 discussed in FRC Report No. 3.

Doses from all Tests through 1962

5.8 Estimates of doses to people in the U.S. in "wet" areas from exposure to fallout radioactivity produced by all nuclear tests conducted through 1962 are presented in Table 13. These estimates are based upon observed levels of deposited radioactivity and observed levels of radioactivity in people for "wet" areas through 1962 and upon annual deposition levels of radioactivity expected to occur in "wet" areas through 1965.

5.9 Whole-body and reproductive cell doses from both short-lived and long-lived radionuclides produced by all tests were estimated for population in the U.S. born prior to beginning of nuclear testing. These doses are assumed to be independent of age groups within the population. Based primarily upon measurements of radioactivity in 1961 and 1962, 30-year and 70-year doses related to tests through 1961 are now estimated to closely approximate the lower number of the range of estimated values for whole-body and reproductive cells presented in Table I of FRC Report No. 3 (30-year, whole body and reproductive cells both 60 millirems; 70-year, whole-body and reproductive cells both 70 millirems;) The estimates of whole-body and reproductive cell doses for all tests through 1962 in Table 13 of the current report will be found to be the sum of whole-body doses from all tests through 1961 (shown in Col. 1 of Table 13), plus the estimated whole-body and reproductive cell doses from 1962 tests presented in Table 12, and repeated as Col. 2 in Table 13.

5.10 The doses to bone and bone marrow from all tests through 1962, presented in Table 13, will not be the sum of estimated bone doses in FRC Report No. 3 (Col. 1 of Table 13) plus doses from 1962 tests in Table 12 of this report. The doses to bone and bone marrow were estimated for the age group in the population expected to receive the highest doses from all tests through 1962. The age group considered was infants born in 1963. This determination was based upon a review of measured values of strontium-90 in human bone samples obtained from the beginning of testing through the first six months in 1962, predicted levels in new bone and bone being re-formed or exchanged metabolically from 1963 through 1965, and whole body doses for infants born during various years since testing began.

5.11 Doses to bone and bone marrow in Table 13 are very little higher than those estimated for tests through 1961 and presented in Table I of FRC Report No. 3. The reason for such results is that measured levels of strontium-90 deposition were less in 1962 than had been predicted.

5.12 Doses to bone and bone marrow for the adult population in the U.S. are expected to be smaller than the doses to the most sensitive age group of children.

5.13 Doses to people in "dry" areas of the U.S. from all tests through 1962 are estimated to be about one-third to one-half those for people in "wet" areas. The lower deposition levels in the "dry" areas reduce the exposure from sources external to the body, and lower the concentrations of radionuclides in locally produced food.

5.14 Thirty-year and 70-year carbon-14 doses from tests through 1962 were estimated using a total yield of 459 MT 1/ a production rate of 2×10^{26} atoms carbon-14 per MT total yield, and a dose rate of 1 millirem per year for naturally occurring carbon-14. The exposure from carbon-14 was assumed to be reduced with a mean time of 48 years, the time calculated for exchange between the atmosphere and the vast carbon reservoir in the oceans.

5.15 It was estimated in FRC Report No. 3 that carbon-14 from weapons testing conducted through 1961 would lead to an average per capita whole-body and reproductive cell dose of 10 to 15 millirems in the first thirty years. This was estimated to equilibrate eventually at a level of about 0.75 millirem per generation, and this would continue for hundreds of generations. Since testing conducted in 1962 contributed almost an equal amount of carbon-14, the above values may be doubled to arrive at the long-term doses that are now predicted.

Thyroid Doses from Iodine-131

5.16 Doses to the thyroid due to iodine-131 in fallout have occurred during and immediately following periods of nuclear testing. The Public Health Service's Pasteurized Milk Network reported no iodine-131 at detectable levels in the interval from 1959 through August 1961. Table 10 shows that following resumption of nuclear testing in September 1961, iodine-131 was found generally throughout the nation in zones of both high and low

1/ Based on the sum of the total yields for air detonations and one-half the total yields of surface detonations from Table 1 of this report.

precipitation. Limited in vivo measurements in the fall of 1961 and in 1962 support a conclusion that fresh milk is the principal source of iodine-131 exposure to the thyroid gland in a large proportion of the population.

5.17 The relationship between iodine-131 intake and thyroid dose is based on the biological model derived in FRC Report No. 2. An estimated annual average daily intake of 80 1/ picocuries of iodine-131 would result in an average dose of 500 millirems in one year to a suitable sample of exposed infants in which the thyroid weight is taken as two grams. This condition applies approximately to the age group from 6 to 18 months. With children above approximately 18 months of age the dose to the thyroid would become progressively smaller with the increase in size of the thyroid to a value in the adult of approximately one-tenth the value in infants.

5.18 Estimates of iodine-131 dose to the thyroid developed for infants 6 to 18 months of age on the basis of the above relationship between intake and dose, assuming one liter of fresh milk consumption per day, ranged from 30 to 440 millirems in 1961 and from 30 to 650 millirems in 1962. These values are estimates of thyroid dose for high and low individual stations in the pasteurized milk network for the years indicated. It has been estimated that a small number of infants in localized areas conceivably could receive doses from 10 to 30 times the average.

1/ "Using the known factors and the assumptions enumerated above, it can be calculated that an average daily intake of 80 micromicrocuries of iodine-131 per day would meet the RPG for the thyroid for averages of suitable samples of an exposed population group of 0.5 rem per year. As stated in Section I, it is appropriate to specify three ranges of transient rates of daily intake in order to provide guidance for the Federal agencies in the extablishment of operating criteria. For this purpose, the value of 80 micromicrocuries per day has been rounded off to 100 micromicrocuries per day as being more in keeping with the precision of the data." (Paragraph 2.14, FRC Report No. 2).

TABLE 12

Estimated Radiation Doses in the "Wet" Areas from Testing Conducted in 1962

(Doses expressed in millirem)

Tissue or Organ	Radiation Doses 30-year	70-year
Whole body and reproductive cells		
Cesium-137 external	9	10
Cesium-137 internal	9	10
Short-lived nuclides	18	18
Carbon-14	11	18
TOTAL	47	56
Bone		
Strontium-90		180
Strontium-89		39
Whole body		56
TOTAL		275
Bone Marrow		
Strontium-90		60
Strontium-89		13
Whole body		56
TOTAL		129

TABLE 13

Estimated Radiation Doses in the "Wet" Areas of the U.S. from all Nuclear Weapons Testing Conducted Through 1962

(Doses expressed in millirem)

Tissue or Organ	From Tests Conducted Through 1961 1/	From Tests Conducted in 1962	From all Tests Conducted Through 1962	From Natural Background
Whole Body and Reproductive Cells				
1 year	10-25	24		
30 years	60-130	47	110 2/	3,000
70 years	70-150	56	130 2/	7,000
Bone				
1 year	30-80	83		
70 years	400-900	275	465 3/ 4/	9,100
Bone Marrow				
1 year	20-40	44		
70 years	150-350	130	215 3/ 4/	7,000

1/ Taken from Table 1, FRC No. 3. Based on surveillance measurements made in 1962, the actual exposures are expected to correspond to the low end of the reported range. Actual exposures to bone and bone marrow are now expected to be even lower than the reported range.

2/ The whole body dose is based on the average person receiving the highest exposure assuming that the person was born prior to the beginning of testing. Current estimates indicate that from tests conducted through 1961, the whole body and reproductive cell doses for 30 and 70 years will be 63 and 74 millirems respectively.

3/ The bone and bone marrow doses are caluclated for the average person born in 1963 since it is believed that this person might receive the highest bone dose of any age group.

4/ Doses in previous columns are not additive; see paragraph 5.10.

SECTION VI

EVALUATION

6.1 The Federal Radiation Council reported on the health implications of fallout from nuclear weapons testing through 1961 in FRC Report No. 3, issued in May 1962. (Copy attached) The doses were evaluated by comparison with the doses due to naturally occurring sources of radiation following the procedures developed over the past several years through studies conducted by the National Academy of Sciences, the United Nations Scientific Committee on the Effects of Atomic Radiation, the National Committee on Radiation Protection and Measurements, the International Commission on Radiological Protection, and the fallout prediction panels convened by the Joint Committee on Atomic Energy in 1957, 1959, and 1962. Two types of biological effects are of concern; effects induced by exposure of the reproductive cells (genetic effects), and possible effects on persons now living (somatic effects) resulting from the exposure. Both types of effects have been considered and evaluated by the National Academy of Sciences Committee on the Biological Effects of Atomic Radiation and the conclusions of this committee have been accepted by the Federal Radiation Council as the basis for the scientific aspects of the present evaluation.

6.2 The genetics subcommittee of the National Academy of Sciences Committee on the Biological Effects of Atomic Radiation has recommended that the genetically effective per capita dose during the first thirty years of life be limited to 10 Roentgens (equivalent to 10,000 millirems as used in this report) from all man-made sources, including medical exposures.

6.3 The revised estimates of the short-term per capita effective dose to the reproductive cells show that weapons tests conducted during 1962 will be about 47 millirems. All tests conducted through December 1962 will result in a per capita 30-year dose of about 110 millirems. This is about one-hundredth of the amount recommended by the National Academy of Sciences. These values are considerably less than the corresponding 30-year dose of 3,000 millirems from naturally occurring sources during the same period. Similarly, the variations in dose-rate from worldwide fallout in different parts of the country are less than the variations in dose-rate from naturally occurring sources in the inhabited parts of the world. Further, comparison with the 5,000 millirems per generation proposed previously by the Federal Radiation Council as a level of genetic risk that would be acceptable to gain the benefits of nuclear energy from normal peacetime operations and the 10,000 millirems per generation recommended by the NAS Subcommittee on Genetics as a "reasonable quota" for man-made radiation exposure of the general public indicates that present and anticipated levels of fallout do not constitute an undue risk to the genetic future of the nation.

6.4 The genetically significant dose per generation attributable to tests conducted through 1962 will be greatly reduced in later generations. The total dose which may come eventually from material still in the stratosphere in 1966 plus the long-term effects from carbon-14 may be somewhat larger than the estimates reported. Thus, the ultimate genetic effects attributable to weapons tests conducted in 1962 are expected to be nearly as much as that from all tests conducted prior to 1962.

6.5 In addition to the possible influence of weapons testing on heredity, the possibility of adverse health effects on persons now living is of concern to the Council. The estimates in Table 13 show that testing conducted through 1962 is expected to result in cumulative whole-body doses over a 70-year period from radionuclides external to the body and radionuclides in the body of about 130 millirems. The biological effect of concern is the induction of serious diseases such as cancer that might result from irradiation of the whole body.

6.6 The Subcommittee on Pathological Effects of the National Academy of Sciences Committees on the Biological Effects of Atomic Radiation (1960) concluded that as long as the criteria for the effective genetic exposure were met, any possible effects on the health of the persons exposed would be much too small to be perceptible. However, the special cases of iodine-131 and strontium-90 which deposit preferentially in the thyroid and bone respectively were pointed out as possible exceptions to the evaluation. The Council, therefore, concludes that except for iodine-131 and strontium-90, the estimated whole-body doses from present and anticipated levels of fallout do not constitute an undue risk in terms of direct effects on the individuals exposed.

Evaluation of Iodine-131

6.7 The special case of iodine-131 has been recognized by the Federal Radiation Council. The known experience in the U.S. related to iodine-131 in milk from 1959 to the present is summarized in Table 10. The data are reported in terms of the average daily intake of iodine-131 over a 12-month period assuming a consumption of 1 liter of milk per day to correspond to the cumulative levels of iodine-131 actually observed at the regular milk sampling stations. The corresponding radiation dose for the average infant thyroid in the highest region has a calculated value of 620 millirems. In the special case where nearly all of the annual intake could come from exposure to abnormally high concentrations in a local area, resulting from a single nuclear explosion of low yield, the Council recognized that some small number of individual infants could conceivably receive doses 10 to 30 times the average for the area as a whole.

6.8 Based on the advice of a special panel convened by the Council in the summer of 1962, it was concluded that radiation doses to the thyroid many times higher than those provided in FRC Report No. 2 would not result in a detectable increase in diseases such as thyroid cancer. No case of thyroid cancer in man ascribable to radioactive iodine used in the medical diagnosis and treatment of thyroid disease has yet been established. The radiation doses administered for diagnosis and treatment of thyroid disorders have ranged up to thousands of times higher than the 1.5 rems per year recommended as a Radiation Protection Guide in FRC Report No. 2 for exposure to individuals due to iodine-131 released to the environment from normal peacetime operations.

6.9 The Council concluded in September 1962 that iodine-131 exposures at the levels existing then, involve health risks so slight that countermeasures applied to the food industries might have an adverse, rather than favorable effect on public well-being. It is similarly concluded in this report that iodine-131 doses from weapons testing conducted through 1962 have not caused an undue risk to health.

Evaluation of Strontium-90

6.10 The health risk from strontium-90 arises from the fact that it is taken into the body with calcium and is deposited in the skeleton. Once incorporated into the skeleton, it causes radiation doses to the skeleton at a continuously decreasing rate during the entire life of the individual. The lifetime doses to the age group receiving the highest doses from radionuclides in fallout are expected to be about 465 millirems for bone and 215 millirems for bone marrow. Of this exposure, it is estimated that the average concentration of strontium-90 in new bone at its maximum value from fallout associated with all weapons testing conducted through 1962 may reach about 12 picocuries strontium-90 per gram of calcium, although by metabolic activity this would soon drop to an average concentration in the whole skeleton of about 7 picocuries per gram of calcium. This would give an initial dose rate to new bone of 36 millirems per year and to bone marrow of 12 millirems per year. When redistributed, the dose rates would be 21 millirems per year to bone, and 7 millirems per year to bone marrow.

6.11 The Council has evaluated the possible need and desirability of instituting national programs for modifying the diet, removing strontium-90 from food supplies such as milk, or otherwise limiting the annual intake of strontium-90. A general appreciation of the contribution of strontium-90 to health risks can be gained by comparing the lifetime radiation dose of 465 millirems to bone with the corresponding dose of 9,100 millirems from natural sources; the radiation dose of 215 millirems to bone marrow with the corresponding dose of 7,000 millirems from natural sources.

6.12 With specific reference to strontium-90, the Council has re-examined its recommendations for skeletal burdens of strontium-90 which have been judged to be an acceptable risk to gain the benefits of normal peacetime operations. The selection of these skeletal burdens reflect the simultaneous judgment that the corresponding risks to health are too small to warrant actions that would interfere with or disrupt the normal utilization of food. The skeletal burden of strontium-90 corresponding to the Radiation Protection Guide recommended in FRC Report No. 2 for limiting the exposure of the skeleton is 150 picocuries of strontium-90 per gram of calcium. However, since no operating need for exposures this high was foreseen, the recommended level was reduced to 50 picocuries of strontium-90 per gram of calcium, corresponding to a sustained dietary intake of 200 picocuries of strontium-90 per day. The skeletal burdens of strontium-90 from present and anticipated levels of fallout are well below these values.

6.13 On the basis of the preceding considerations, it is concluded that the health risks from present and anticipated levels of strontium-90 from fallout due to testing through 1962 are too small to justify measures to limit the intake by modification of the diet or altering the normal distribution and use of food. It is further concluded that since milk and dairy products are the major sources of calcium in the U.S. diet and since these products have a lower concentration of strontium-90 in relation to calcium than the total diet, restriction or reduction in the normal use of these food products would be unwise.

Future Indications

6.14 Looking into the future, the Council notes that the highest .annual dose rates have been associated with the short-lived radionuclides and tropospheric fallout. How much these annual transients contribute to the cumulative lifetime exposures depends, of course, on the frequency with which test programs occur. This review has shown that the testing programs of 1961 and 1962 reached higher levels of fission and total yields than any previous comparable period, and the radionuclides associated with tropospheric fallout were correspondingly evident.

6.15 Renewed attention has been directed to the special case of iodine-131, and the pathways by which it passes through the environment to man. Studies conducted by the Department of Agriculture and the U.S. Public Health Service in 1962 have demonstrated the effectiveness of reducing the iodine-131 levels in milk by adjusting the source of feed used by the dairy cattle if such action is needed. Also, the Atomic Energy Commission has recently initiated a program at the Livermore Radiation Laboratory to gain a better understanding of the processes affecting the distribution of fallout and its movement through the environment. Iodine-131 is included among the nuclides of interest to this program.

6.16 As to long-lived radionuclides such as strontium-90 the Council notes that processes for the removal of radionuclides from milk developed jointly by the Department of Agriculture, the Public Health Service, and the Atomic Energy Commission are now being evaluated for the feasibility of full-scale production for possible use in an emergency.

6.17 However, in the Council's judgment, major national programs directed at tremoving strontium-90 from food supplies would not contribute to the national welfare at present or projected levels of strontium-90. Even if the strontium-90 levels in human bone reached those corresponding to the Radiation Protection Guide established for the control of normal peacetime operations, the removal of strontium-90 from foods would not necessarily be in the best interests of the nation. The Council would have to consider whether the health risk would be great enough to justify the total impact of such a program on the economy and the necessary allocation of national resources in relation to the health benefits that might be achieved through feasible reduction in strontium-90 intake.

Absorbed Dose The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest.

Activity The number of disintegrations of a quantity of radionuclide per unit time.

Average Dose The arthmetic mean radiation dose. The average may be taken with respect to time, number of people, location, or the dose distribution in tissue.

Beta Radiation Swiftly moving electrons emitted by radioactive substances. Strontium-90, strontium-89, and carbon-14 all emit beta particles.

Biological Half-life The time taken for the body burden of a radionuclide to be reduced by biological removal processes to one-half its initial value. Radioactive decay is not involved.

Body Burden The amount of a specified radioactive material or the summation of the amounts of various radioactive materials in a person's body at the time of interest.

Critical Organ An organ or tissue most affected by ionizing radiations from the deposition of a specified internal emitter or from external sources. The reproductive cells are considered the critical tissue for genetic effects. The thyroid is considered the critical organ for the effects from radioactive iodine. Bone and bone marrow are considered the critical organs for the effects from strontium-90.

Curie A measure of the activity (rate of disintegration or decay) of a radioactive substance. One curie equals 3.7×10^{10} nuclear disintegrations per second, or 2.2×10^{12} per minute.

Megacurie (MC) One million curies. A fission yield of 10 megatons creates approximately 1 megacurie of strontium-90.

Millicurie (mc) One-thousandth of a curie. Also one thousand microcuries.

Microcurie (μc) One-millionth of a curie.

Picocurie (pc) One micromicrocurie ($\mu\mu$c). This is one-millionth of a microcurie or one-millionth-millionth of a curie. It corresponds to a rate of radioactive decay equivalent to 2.2 disintegrations per minute.

Dose A measure of the energy absorbed in tissue by the action of ionizing radiation on tissue. As used in radiation protection, definitive practice requires that the term be used in such combining forms as radiation dose, absorbed dose, whole-body dose, and partial-body dose.

Dose-effect Relationship The magnitude of a specific biological effect, expressed as a function of the radiation dose producing it. It is frequently represented as a curve described as a dose-effect curve, dose-effect response curve, or dose response curve.

Dose Equivalent A concept used in radiation-protection work to permit the summation of doses from radiations having varying linear energy transfers, distributions of dose, etc. It is equal numerically to the product of absorbed dose in rads and arbitrarily defined quality factors, dose distribution factors and other necessary modifying factors. In the case of mixed radiations, the dose equivalent is assumed to be equal to the sum of the products of the absorbed dose of each radiation and its factors.

Effective Half-life or Half-time The time taken for the total number of atoms of a radioactive nuclide to be reduced to one-half of its initial value by combined radioactive decay and biological removal processes.

Environment The physical environment of the world we live in consisting of the atmosphere, the hydrosphere, and the lithosphere. The biosphere is that part of the environment supporting life and which is important to man.

Exposure A measure of x and gamma radiation at a point. However, it is often used in the sense of being made subject to the action of radiation.

External Exposure The exposure of body tissues to ionizing radiation originating from sources outside the body.

Fallout The process or phenomenon of the fallback to the earth's surface of particles contaminated with radioactive material from the radioactive cloud. The term is also applied in a collective sense to the contaminated particulate matter itself. The early (or local) fallout is defined, somewhat arbitrarily, as those particles which reach the earth within 24 hours after a nuclear explosion. The delayed (or worldwide) fallout consists of the smaller particles which ascend into the upper troposphere and into the stratosphere and are carried by the winds to all parts of the earth. The delayed fallout is brought to earth, mainly by rain and snow, over extended periods ranging from months to years.

Internal Exposure The exposure of body tissue to ionizing radiations originating from radionuclides contained within the body.

Whole-bodyExposure Literally, the exposure of the whole body.

Fission The process whereby the nucleus of the particular heavy element splits into (generally) 2 nuclei of lighter elements, with the release of substantial amounts of energy. The most important fissionable materials are uranium-235 and plutonium-239.

Fission Products A general term for the complex mixture of substances produced as the result of nuclear fission. Something like 80 different fission fragments result from approximately 40 different modes of fission of a given nuclear species. The fission fragments, being radioactive, immediately begin to decay, forming additional radioactive products with the result that the complex mixture of fission products so formed contains about 200 different isotopes of 36 elements. For example, iodine-131, being a daughter element with several preceding radioactive parents, reaches its maximum production approximately 7 hours after the detonation of a fission device.

Fission Yield The equivalent energy released as the result of nuclear fission. The production of fission products is proportional to the fission yield,

Fusion The process whereby the nuclei of light elements, especially those of the isotopes of hydrogen, combine to form the nucleus of a heavier element with the release of substantial amounts of energy. These are so called thermonuclear reactions because very high temperatures are used to bring about the fusion of the light nuclei. Neutrons, leading to the production of carbon-14, are produced by this reaction; however, fission products are not.

GammaRays Electromagneticwavesof very short wave lengths produced during the disintegration of radioactive elements. Like x-rays, they readily penetrate body tissues.

Genetic Effect A change in a reproductive cell which would alter the characteristics of an individual produced from the affected cell or which causes a mutation that may be inheritable by subsequent generations.

Half-life The time required for the activity (the disintegration rate) of a radioactive nuclide to decay to one-half of the initial value.

Internal Emitters Radionuclides contained within the human body.

Isotopes Atoms of the same element, i.e., having the same atomic number, but of differing atomic weights. The isotopes of an element have closely similar chemical and physical properties, but differ in atomic mass (due to different numbers of neutrons in the atomic nuclei) and in their nuclear properties (e.g., stable, radioactive, fissionable, etc.). Nearly all elements found in nature are mixtures of several isotopes. (See nuclide)

Mean or Average-lifetime A particular radioactive atom can decay now, later, or never. However, the average or mean-life expectancy of a number of the same radionuclides is a definite quantity and is equal to 1.4 times the half-life. Analogous terms are often used to express changes in radionuclide concentrations in different compartments of the environment as a function of time. For example, the rate of disappearance of carbon-14 from the atmosphere as the result of diffusion into the ocean, the biosphere, and other environmental compartments has been expressed in terms of a half-time of 33 years and a mean-time of 48 years.

Megaton Yield A nuclear detonation which releases a total energy equivalent to one million tons of TNT.

Natural Background Radiation Ionizing radiations from naturally occurring radionuclides as they exist in nature plus cosmic radiation.

Normal Peacetime Operations The peaceful applications of nuclear technology where the primary radiation protection control is placed on the design and use of the source.

Nuclide An atom of a particular species or element; that is, characterized by an atomic number and an atomic weight. Carbon-14 is a nuclide. Carbon as it occurs naturally consists of 3 nuclides; carbon-12, carbon-13, and carbon-14, which together bear the relationship of isotopes.

Organ or Tissue Dose The radiation dose received by a particular body organ or tissue. The radiation may be from an external or an internal source.

Population Dose The radiation dose received by members of a population. It is usually estimated as that dose which would be received by the average member of the population under consideration.

Radiation Effect A response or change induced by exposure to ionizing radiation.

Radiation (Ionizing) Radiation capable of producing ions in a medium, particularly tissues of the human body. Examples are x-radiationand gamma radiation, beta radiation, and cosmic radiation.

Radiation Protection Guide (RPG) The radiation dose which should not be exceeded without careful consideration of the reasons for doing so; every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable.

Radioactivity The property or Process whereby certain isotopes or nuclides spontaneously disintegrate emitting particles and/or gamma rays by the disintegration of the atomic nuclei. (See activity)

Radionuclide A radioactive nuclide.

Rem A special unit of dose equivalent. It is that quantity of any type of ionizing radiation which, when absorbed in the human body, produces an effect equivalent to the absorption of 1 roentgen of x or gamma radiation at a given energy.

Seventy-year Somatic Dose That whole-body dose received by tissues other than the reproductive cells over a period of 70 years. When calculated for exposures from fallout this dose includes contributions from whole-body radiation from external sources, cesium-137 taken internally, and carbon-14.

Somatic Effect A change (other than genetic) produced in any tissue which alters the normal body processes of the irradiated individual.

Stratosphere A relatively stable layer of the atmosphere lying above the tropopause. For the purpose of this document, the lower stratosphere is defined as the first few tens of thousands of feet above the tropopause and the upper stratosphere as the layer to about 150,000 feet.

Stratospheric Fallout Fallout associated with weapon debris which was initially injected above the troposphere into the stratosphere. This is the component that results in world-wide distribution of fallout from the testing of nuclear weapons.

Strontium Unit (SU) One picocurie of strontium-90 per gram of calcium, usually in bone but now extended to items of food and milk.

Thirty-year Genetic Dose The dose estimated to be received from all sources by the reproductive tissues for a period of 30 years. When computed for fallout exposures this includes whole-body doses from external sources, gamma radiation from cesium-137 in the body, and carbon-14. Recent reports indicate that strontium-90 may also be a minor contributor.

Tropopause The boundary between the troposphere and the stratosphere. It normally occurs at an altitude of about 30,000 to 40,000 feet in polar and temperature regions and about 55,000 feet in the tropical and equatorial regions.

Troposphere That portion of the atmosphere below the stratosphere. It is that portion in which temperature generally decreases rapidly with altitude, clouds form, and which is associated with all of what we generally know as "weather." The altitude of the troposphere varies from the equator to the poles and from winter to summer.

Tropospheric Fallout The deposition of radioactive weapons debris which was initially injected into the troposphere and not deposited as local fallout.

Yield The total effective energy released in the nuclear explosion. It is usually expressed in terms of the equivalent tonnage of TNT required to produce the same energy release in an explosion.