SCIENTIST AND CITIZEN

SEPTEMBER-OCTOBER, 1964

Formerly **NUCLEAR INFORMATION**

TEST BAN TREATY ANNIVERSARY ISSUE

OCTOBER, 1963

OCTOBER, 1964

SCIENTIST AND CITIZEN

September-October, 1964 Vol. VI, Nos. 9-10

THE TEST BAN

Is THE TEST BAN TREATY in the best interests of the United States? Because candidates in the current presidential campaign are on opposite sides of this question, it has once more become an important public issue.

As the citizen evaluates the candidates and their views, he will want to consider the political and military benefits the treaty may have, or the political and military benefits that might be gained from a resumption of testing. These are not scientific questions, but *the price tag on nuclear weapons tests in terms of possible risks to human life and health is a scientific question.*

We return, therefore, to the subject of fallout, on which *Scientist and Citizen* has focused so often in the past. What have scientists learned about fallout in the nineteen years since it was first created? To what extent did past testing contaminate our environment? To what degree would this radioactive contamination have been intensified if atmospheric testing had continued? What effect is this radioactivity having on us and our children?

In this issue we address ourselves to these questions.

A TECHNICAL SUPPLEMENT has been prepared explaining how predictions were made in "Human Inheritance" and "Radioactivity in Arctic Peoples." It is available from *Scientist and Citizen* on request. (Methods used in making predictions in other articles will be found in the publications referenced for each article.)

Dr. Herman Kalckar Introduces the Issue

THE GREATER SAINT LOUIS CITIZENS' COMMITTEE FOR NUCLEAR INFORMATION is publishing a special issue of its monthly bulletin, reviewing some of the most important results of the Committee's unique community project on the effects of radioactive fallout.

The appearance of this issue will mark the one-year anniversary of the nuclear test ban ratified on a non-partisan basis by the United States Senate and signed by the late President Kennedy. In a telling way, the publication will commemorate this historic event.

I am honored to respond to the request of the Committee by writing a brief introduction to this special issue. I feel that the Greater Saint Louis Citizens' Committee has pioneered a community project of unique importance in our time. Among its many creative ventures, the success of the baby tooth survey for radioactive strontium is particularly noteworthy. When in 1958 I suggested the idea of a large scale radiation census of baby teeth, I intended to stress the broad aspects of such a proposition. Such a census, I thought, would provide useful information not available in any other way and would encourage the orientation and education of the public to problems of the nuclear age. It would represent a simple and active type of mutual cooperation between a family unit and the scientists. At the same time, such a project would have a social touch and an aspect of cheerfulness despite the serious background of growing nuclear power.

The main question which arose was, of course, the availability of a group who would be willing and able to do the pioneering job of coordinating community education with development of the necessary research and technology.

This entirely novel venture was initiated in the fall of 1958 by a little group of competent, enlightened, and spirited Saint Louisans. The Greater Saint Louis Citizens' Committee for Nuclear Information (CNI) is a non-profit organization of public-minded citizens, founded in April, 1958, dedicated to a sober education of the public towards the problems of radioactive fallout and related concerns. Already by the fall of 1958 the Committee had become aware of the importance of a baby tooth survey for its joint educational and scientific task. The dental schools of Washington University and St. Louis University threw their full support behind the project. A subcommittee for the tooth collection program was created and a director appointed. The first director made this community project a singular success by her sober and tactful approach. Every school superintendent of the Greater St. Louis area collaborated 100 per cent. The Washington University of Dentistry created special facilities to conduct the analyses. The enthusiastic work and support from the entire community could well be a model for the future. At the same time, the monthly bulletin of CNI, "Nuclear Information", kept the public oriented, with emphasis on facts, and restrained interpretations and conclusions. This spirit of work and direction has been kept under the present leadership of the CNI.

THE BABY TOOTH SURVEY largely portrays the exposure of the infant, just before and after birth, to the fallout contaminant strontium 90. This is the well-known radioactive element that contaminates all of our food, including milk which supplies the main food source of children. The mother of the infant absorbs strontium 90, together with highly needed calcium, from her food into her bloodstream. The infant receives both elements either directly from the mother before birth, or from mother's milk — or cow's milk — after birth.

Strontium 90 is not an innocent contaminant; prolonged exposure can give rise to bone cancer and leukemia. This is the reason why the bone sampling of dead infants (stillborn or newborn) organized by the Biology Division of the Atomic Energy Commission and the U.S. Public Health Service is of the utmost importance. Fortunately enough, however, this country has a very low infant mortality. In order to study some of the problems of radioactive fallout on infants in various localities of the country, scientists long thought it would be advantageous to have a biological source of strontium deposition more readily available than bone. Here is where the baby teeth come in — as soon as they come out! The enamel of the baby teeth is deposited during the later part of pregnancy and during the first months after birth; after deposition it remains amazingly static. Any radioactive strontium deposited by the time around birth remains largely in the enamel at the time the tooth is shed, put under the pillow, given to the tooth fairy or to CNI. The young developing bones probably receive about the same degree of radioactive exposure, the factor which in some cases may bring about fatal damage.

The recent CNI baby tooth survey shows an intense rise in the amount of radioactive strontium present in baby teeth over the last five years, corresponding to an increased number of atomic explosions. The first anniversary of the test ban cannot be registered in terms of a fall of radioactivity in baby teeth shed during 1963 to 1964 for two reasons. The first is the great delay between the time of explosion and fallout, and the time necessary to process and distribute the contaminated food. The other factor, characteristic only of baby teeth, is that their strontium 90 content manifests a situation existing seven to ten years earlier, at the time they were formed in the newborn infant. Since the calcium in the bones is renewed relatively rapidly, a test ban on atmospheric nuclear explosions should soon relieve the radioactive burden on the bones of children who have received strontium 90 previously.

If the test ban continues, about a decade from now baby teeth may once more approach their previous non-radioactive state. More important, the ban would limit the tragic damage already done by strontium and other elements, such as the long-lived radioactive carbon 14, generated by the hydrogen bomb, which constitutes a particular menace to the future of man. Each additional anniversary of the late President Kennedy's nuclear test ban is a token of restraint which might give our civilization time to solve successfully the question: Are we strong enough to live in peace — with the nuclear forces unleashed?

The Beginning of the Baby Tooth Survey

from "An International Milk Teeth Radiation Census"
by Dr. Herman M. Kalckar in *Nature,* August 2, 1958

WITHOUT EXPRESSING HERE any opinion concerning atomic weapons test programmes, I wish to suggest a scientific study which would at the same time have educational values in its practical demonstration of the peaceful applications of atomic research. The suggestion arises from the belief that any family, regardless of whether or not its country has ambitions in the development of atomic weapons, would be sympathetic to and support an international study involving atomic radiation and ultimately concerned with the health of its own children.

• • •

The proposed milk teeth census is, of course, a long-range programme. If a continued general trend toward a rise in radioactivity in children's teeth were ascertained, it might well have important bearings on national and international policy. The results should be conveyed to the public without interpretations which might give rise to either complacency or fear, but rather in a spirit that would encourage sober, continued, active concern. It should be emphasized that the data would portray the situation as it existed about seven years previous to the study. In spite of this, the fact that these data would give a general estimate of the exposure of newborn children to radioactivity should be stressed.

By H. T. BLUMENTHAL

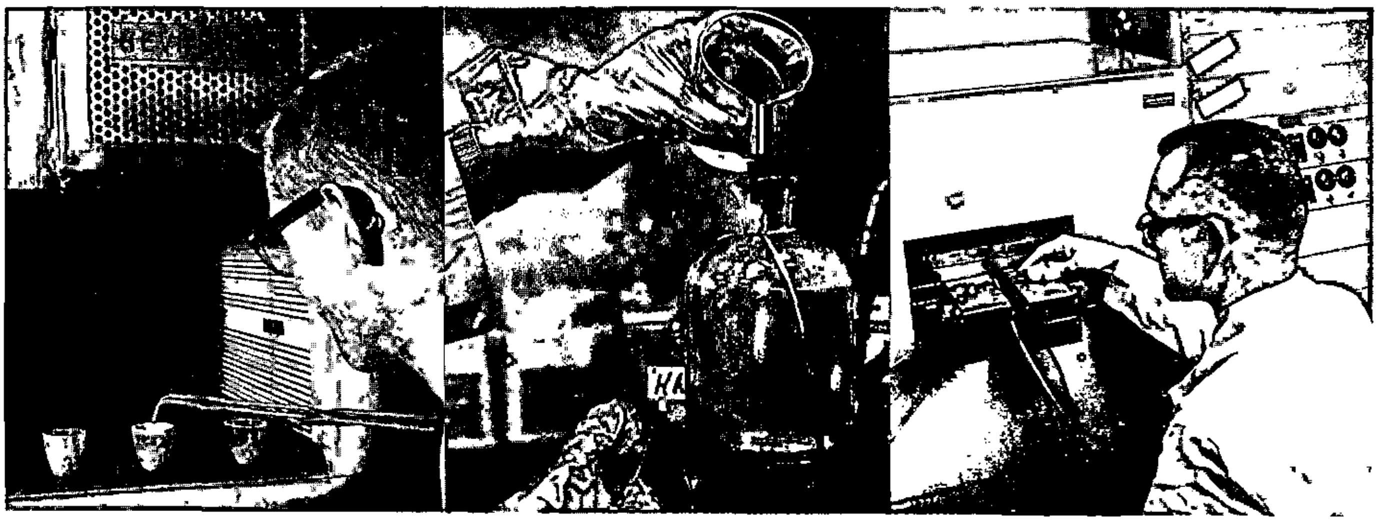
STRONTIUM 90 IN CHILDREN

If the baby tooth survey had not been conceived and set in operation, the only accurate information on the accumulation of strontium 90 in bone would have had to come from an analysis of bone samples obtained either during surgery or at postmortem examination. This would have seriously limited the availability of material for the analysis of strontium 90 levels in the bones of children because of the low mortality rate in infancy and childhood. Information on the content of radioactive materials in children's bones is particularly important because they accumulate bone-seeking radioactive substances more readily than adults and are more sensitive to the effects of such radioactivity, particularly in respect to the development of leukemia and bone cancer.

The birth and organization of the Baby Tooth Survey is related elsewhere in this issue and has also been detailed in two previous issues of *Nuclear Information*.[1,2] It should be emphasized here, however, that the information which has been accumulated since its inception in 1958 provides the most accurate information on the progressive accumulation of strontium 90 in bone dating from about 1951. It has been possible to "back-date" strontium 90 levels in teeth, because, after calcification, tooth enamel — a non-living structure — can be altered only by mechanical means, and to a small extent by an interchange of molecules at the surface. For all practical purposes the tooth can be considered a stable structure which retains the mineral composition acquired at the time of its formation. The calcification of baby teeth begins after the twelfth week of pregnancy and becomes complete during the first year of life. Analyses of the deciduous teeth, therefore, provide information concerning the amount of calcium and of strontium 90 taken up during the year of birth, some 5-12 years before the time of shedding.

By comparing the amount of strontium 90 in the deciduous teeth and bones of stillborn infants, Reiss[3] has been able to establish the fact that the teeth and bones of infants accumulate strontium 90 and calcium in the same proportion. Therefore, the information provided by an analysis of calcium and strontium 90 of deciduous teeth accurately reflects the amounts of these elements in bone at the time of tooth formation. After the first year of life the teeth accumulate little or no additional calcium or strontium 90, but the bones continue to do so particularly during the period of growth. The strontium 90 contents in the bones of individuals over one year of age can therefore be expected to be higher than in the teeth.

This article is based in part on "Incorporation of Fallout Sr-90 in Deciduous Incisors and Foetal Bone," by Harold L. Rosenthal, Shirley Austin, Sheila O'Neill, Kunisuke Tahouchi, John T. Bird and John E. Gilster in *Nature*, 203:615, 1964.



Analysis of deciduous teeth (baby teeth) is done in a laboratory at Washington University School of Dentistry. The study is supported by a grant from the U. S. Public Health Service. In the first picture on the left, the teeth are being incinerated to remove all organic matter, leaving strontium 90. The middle picture shows filtration of strontium 90 and on the right, the strontium 90 in planchet form is placed in a radiation counter.

It is our purpose here to review information now available concerning the changes in the strontium 90 content of deciduous teeth since about 1951, to show how such changes relate to the amount of strontium 90 in the diet, particularly in milk, and to estimate the amount of this radioactive substance in deciduous teeth for those years for which actual data are not yet available; the latter is based on known and projected changes in the content of strontium 90 in the diet. Two types of projection have been made, one based on no further addition to fallout by new nuclear weapons tests in the atmosphere, and the second based on continued testing during 1963, '64, and '65 at the same rate and magnitude as in 1962, the year preceding the test ban treaty.

RELATION OF STRONTIUM 90 IN DIET TO STRONTIUM 90 IN DECIDUOUS TEETH

When an atomic explosion in the atmosphere occurs, the radioactive fallout which results is not only deposited on the surface of plants, but is also absorbed into the soil with the rain water, entering the root system and spreading internally through the remainder of the plant. Because man washes and cooks the plants which he eats, only a minimum of the fallout particles deposited directly on the foliage enters the body. Man takes in more from that which is incorporated into the plant via the root system. Cattle, however, eat the plants directly, and thus take in all of the radioactivity present on the surface as well as in the internal portions of the plant.

In both man and cow some of the ingested radioactive material is excreted. However, in the case of strontium 90 which the body utilizes in the same manner as calcium, much of the absorbed radioactive material is deposited in the bones and teeth. In addition, strontium 90 is also present in the milk of both species, and the milk therefore constitutes the principal source of radioactive material in an infant's diet. Because strontium 90 has a relatively long half-life, approximately 28 years, that portion which reaches the bones can exert its radioactive effects for most of the life-span of the individual. This long half-life is important in another respect. Following an atmospheric test explosion, there is a continuing significant fallout of the relatively long-lived radioactive elements over a period of years, and subsequent explosions add more to that which already exists.

In the first of two reports on the strontium 90 content of deciduous teeth, the investigators at the Baby Tooth Survey laboratory, Rosenthal and co-workers[4] found that during the years 1951 and '52 the strontium 90 content of incisor crowns of breast-fed children was lower, but not significantly different from that found for bottle-fed infants. In succeeding years, between 1953 and '56, when the amount of strontium 90 in teeth was increasing at a rapid rate, the teeth of breast-fed children contained 25 per cent less strontium than comparable bottle-fed children, but how meaningful this difference is, remains to be determined.

In a more recent report, Rosenthal and associates[5] have found that the strontium 90 content of incisor crowns accurately reflects the amount of this radioactive isotope in commercial milk in the St. Louis area at the time the teeth were formed. Because analyses of St. Louis milk were not begun until 1959, they used the values for the Perry, N. Y. milk shed for the period 1954-59. These were provided by the New York Health and Safety Laboratories of the U. S. Atomic Energy Commission. When they compared St. Louis with Perry milk levels for 1959-63, they found that the St. Louis values average 1.4 times greater than those for Perry. This correction factor was then used to estimate the St. Louis milk levels for the period during which figures were not available.

Rosenthal and co-workers have found that the amount of strontium 90 present in incisor crowns is directly proportional to the amount of this radioactive isotope in dietary milk of bottle-fed children at the time the teeth were formed. Furthermore, they have been able to develop an equation with which it is possible to calculate the strontium 90 content of incisor crowns if the amount of this radioactive element in the diet is known. The equation is:

strontium 90 units in teeth = .59 strontium 90 units in diet

When this formula was tested by calculating the content in the teeth from the level in the diet, the result was very close to the actual level obtained by direct analysis of incisor crowns (Fig. 1).

PROJECTION OF FUTURE STRONTIUM 90 LEVELS IN BONES AND TEETH

We have used this equation to make several pertinent estimates:

1. An estimate of the average number of strontium units in teeth of one-year-old bottle-fed children in 1963, '64 and '65 with no further atmospheric testing because of the test ban treaty.

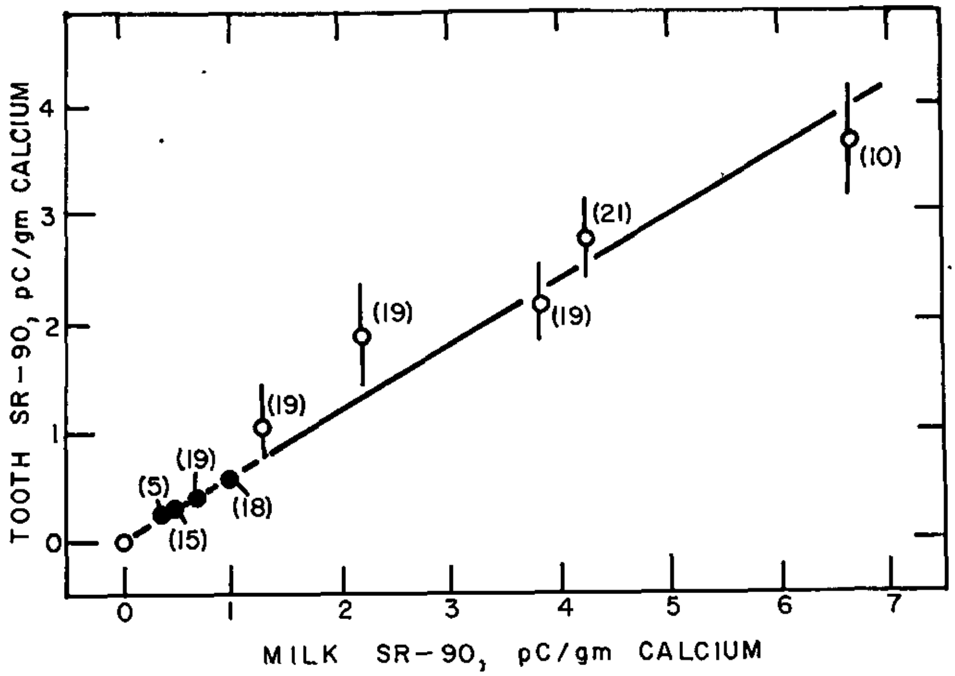
2. An estimate of the average number of strontium 90 units in one-year-old bottle-fed children if further testing had occurred during the period 1963-65 at a rate and magnitude similar to that in 1962; that is, as if there had been no test ban treaty.

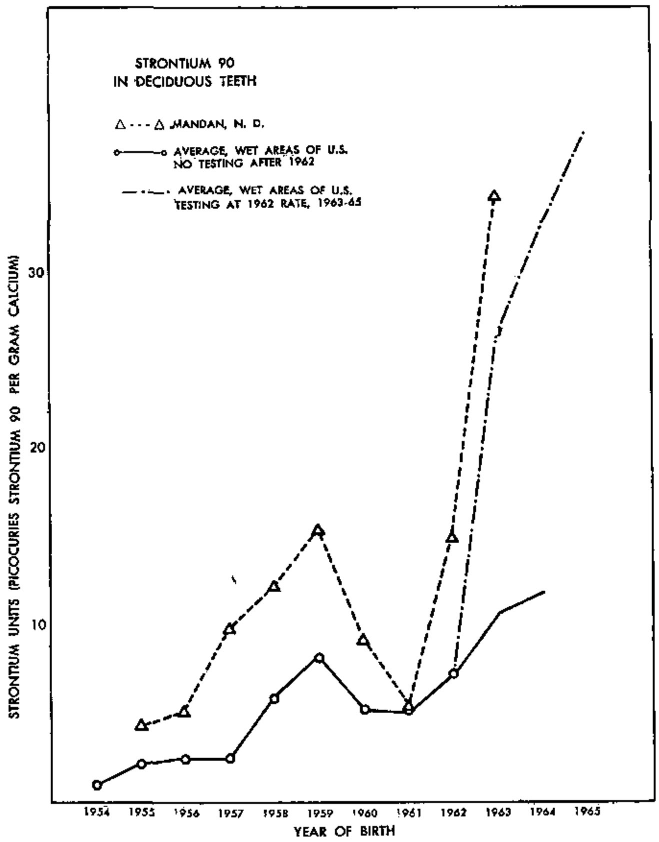
In Table 1 we have listed, for comparative purposes, the published data of Rosenthal and co-workers covering the period 1951-57; these are the results of actual analyses of deciduous incisor crowns. The figures shown under "Average Strontium Units" for the years 1958-63 have been calculated utilizing the Rosenthal equation and the average monthly levels for "wet areas" *provided in the Report of the Federal Radiation Council #4 of May 1963. The estimated milk levels for the period 1963-65 if testing had continued through these years at

*See map on page 13.

Fig. 1. The strontium 90 concentration of deciduous incisor teeth as a function of strontium 90 content of commercial milk. The number of samples analyzed are in parenthesis. The open circles represent values between 1954 and 1958. The closed circles represent values obtained for estimated milk values between 1950-1953. The line was drawn from the equation explained in the text.

Reprinted from Rosenthal, H. L.; S. Austin; S. O'Neill; K. Takeuchi; J. T. Bird and J. E. Gilster "Incorporation of Fallout Strontium 90 in Deciduous Incisors and Foetal Bone." *Nature* 203: 615, 1964.





the same rate and magnitude as in 1962 are also based on data provided by the Federal Radiation Council.

The strontium 90 content of deciduous teeth of infants was zero prior to the beginning of atmospheric testing of atomic weapons. Only stable strontium existed prior to that time. Radioactive strontium first appeared on the earth in 1945 as a result of the first atomic explosion.

The data in Table I indicate that there has already been a progressive rise in the strontium 90 content of incisor crowns, and hence also comparative rise in bones of one-year-old infants to over *30 times* that present in these structures in 1951. The 30-fold increase noted here has taken place over approximately a twelve year period. If testing had continued through the period 1963-65 at the same rate and magnitude as in 1962 there would have been a *100 fold* increase in teeth and bones of one-year-old infants.

This projection is based in part on St. Louis milk levels of strontium 90, and it also applies to other similar "wet areas." It should be pointed out that there are places where the strontium 90 content of milk is lower than those shown in Table I and others where it is considerably higher. The curves shown in Fig. 2 present the changes in the average and in an area of high strontium 90, Mandan, North Dakota (one of the few places where milk data from early years is available). Although the curve for Mandan is not extended

Table I. A PROJECTION ANALYSIS
Strontium 90 Content of Deciduous Incisors of Bottle-Fed Children
(annual averages in strontium units)

Year of birth	Milk	Incisor crowns	Incisor Crowns had testing continued at 1962 rate for three years
1951		.30	
1952		.36	
1953		.54	
1954		1.04	
1955		2.21	
1956		2.26	
1957		2.56	
1958	10	5.90*	
1959	14	8.26*	
1960	9	4.81*	
1961	9	4.81*	
1962	15	8.85*	
1963	18	10.62*	26.00*
1964	20	11.80*	33.00*
1965	17	10.03*	38.00*

* Estimates based on Rosenthal equation.

into the future, it would be expected to remain much higher than the average.

Several points concerning these projections deserve special emphasis:

Had it not been for the Baby Tooth Survey and the data obtained by direct analysis of incisor crowns, it would not have been possible for Rosenthal and coworkers to construct the formula used in these projections and to make current and future estimates of the strontium 90 content of deciduous teeth and bones of one-year-old infants.

Although Dr. Rosenthal has every confidence in the equation used here, he and CNI nevertheless intend to continue with the Baby Tooth Survey and with direct analysis of incisor crowns to check further on the accuracy of these projections.[6]

Since the average strontium 90 content of incisor crowns for the years 1963-65, and for at least several subsequent years, can be expected to remain at approximately ten to twelve strontium units, the resumption of atmospheric testing of atomic weapons at any time in the near future would have the same escalating effect as that shown for continued testing.

BIOLOGICAL IMPLICATIONS

Are these levels of strontium 90 high enough to produce bone cancer in humans? We have no direct evidence that would make it possible to say confidently either "yes" or "no." What little evidence we have comes from animal experiments.

Unless one assumes a linear dose relationship between the incidence of malignant tumors and the level of radioactivity, thereby also assuming that even the smallest increase in radioactivity is capable of producing tumors in some individuals, there is no certain way of translating information from animal experiments to the human situation. Finkel and co-workers[7] have recently reported results of experiments carried out on mice in which strontium 90 was either injected into the veins or introduced into the diet. The dose administered was about one million times greater than human exposure resulting from fallout entering the diet. At the same time, the fact that the human body contains 3500 times as much calcium as does the mouse must also be considered; since almost all of this calcium is represented by bone, the human has almost 3500 times more tissue at risk than does the mouse. Nevertheless, certain observations made by Finkel and co-workers are noteworthy. Female mice exposed in the uterus by feeding the mothers strontium 90 developed more bone cancers after birth than mice fed strontium 90 after they were born. Some doses which were not effective in producing malignant bone tumors in the latter, did produce bone cancers in mice exposed in the uterus.

If one assumes a linear dose relationship as noted above, it can be calculated from some of the data of Finkel and co-workers that at approximately the levels of strontium 90 found in deciduous teeth there would be an increase of about one bone cancer per one million individuals. The best incidence data on bone cancer are provided by the surveys of the National Cancer Institute for 1947-48. They show a crude incidence figure of 1.4-3.3 per 100,000 in various large U. S. cities, with peak incidences in the age groups 11-20 and 61-80 years. This is approximately the equivalent of twenty cases per million people. Thus if strontium 90 caused an increase of one case per million this would represent a five per cent increase in the incidence of bone cancer. The other malignant tumors of concern in respect to exposure to strontium 90 are the so-called malignant lymphatic tumors which include also the leukemias. As a group these have about six times the frequency of malignant bone tumors, but there are no studies from which we can estimate a possible increase of the number of these tumors as a result of strontium 90 in bones.

REFERENCES

1. *Nuclear Information*. Vol. IV, No. 1, November 1961.
2. *Nuclear Information*. Vol. V, No. 5, March-April, 1963.
3. Reiss, L. Z.: "Strontium 90 Absorption in Deciduous Teeth". *Science* 134: 1669, 1961.
4. Rosenthal, H. L.; J. E. Gilster, and J. T. Bird, "Strontium 90 Content of Deciduous Human Incisors." *Science,* 140: 176, 1963.
5. Rosenthal, H. L., S. Austin, S. O'Neill, K. Takeuchi, J. T. Bird, and J. E. Gilster, "Incorporation of Fallout Strontium 90 in Deciduous Incisors and Foetal Bone". *Nature* 203: 615, 1964.
6. Rosenthal, H. L.: Personal communication.
7. Finkel, M. P., P. B. Jinkins, and B. O. Biskis, National Cancer Institute Monograph #14, p. 243, 1964.

By DAN I. BOLEF

BOMB TESTS

what kind of radioactive fallout and how much

ATMOSPHERIC TESTING of nuclear weapons introduces a variety of radioactive elements into man's environment. Some of these elements (or radioisotopes), such as iodine 131, lose their radioactivity very rapidly. Other isotopes, such as strontium 90 and cesium 137, decay in times comparable to a human lifetime. Several, carbon 14 in particular, are very long-lived, and their presence in the atmosphere becomes a permanent alteration of our environment. A measure of the rate at which radioactivity decreases is the half-life, or time it takes for half of the original number of radioactive nuclei of a given isotope to emit their radiation or "decay." For example, the half-life of strontium 90 is 28 years. At the end of one 28 year period half the original number of nuclei will have decayed. At the end of a second 28 year period half the remainder will have decayed, and so on.

These radioactive isotopes differ not only in their decay rates but also with respect to the parts of the body which they affect. After ingestion into the body, iodine 131, for example, is concentrated in the thyroid gland. Strontium 89 and 90, which resemble closely the common element calcium, concentrate in the bone and bone marrow. The radioactive decay of cesium 137 is accompanied by the emission of highly penetrating particles (gamma-rays). As a result, cesium 137 in the human body constitutes a threat to the whole body, in particular to the genes. Like cesium 137, the threat of carbon 14, with a half-life of 5,600 years, is mainly to mankind's heredity. Its role as a genetic hazard is discussed in an accompanying article.

Table I summarizes these characteristics of radioactive isotopes which occur in fallout from nuclear bombs.

The first nuclear weapons tested operated by the fission of uranium or plutonium, and produced large quantities of radioactive fission products. The more recently developed hydrogen bomb releases its energy by a fusion reaction, the fusion, however, being initiated by a fission "trigger." The radioactive fission products of a hydrogen bomb come from this fission trigger (and from the fission of the bomb's jacket.) These, in a large "H-bomb" may release about as much energy, and produce as much fallout as did an early "A-bomb."

Table I. RADIOISOTOPES OF MAJOR BIOLOGICAL IMPORTANCE WHICH OCCUR IN FALLOUT

Isotope	Half-life	Part of Body Affected
Iodine 131	8 days	Thyroid
Strontium 89	53 days	Bone and bone marrow
Strontium 90	28 years	Bone and bone marrow
Cesium 137	30 years	Whole body and reproductive cells
Carbon 14	5,600 years	Whole body and reproductive cells

Fusion creates radioactive fallout in another way. It releases many more neutrons than does fission. The action of neutrons on the nitrogen in the atmosphere produces carbon 14.

Fig. 1 shows the total energy released (the total yield) and the fission yield resulting from nuclear weapons tests in the air and on the surface of the earth to date. A megaton yield is equivalent to the energy released by one million tons of TNT. It shows that the total explosive force was much greater in 1962 than in any previous year. Although the fission yield appears to be dwarfed by the total, it, too, was greater in 1962 than in any previous year.

The same information is given in a different way in Fig. 2. Here, instead of showing the testing year by year,

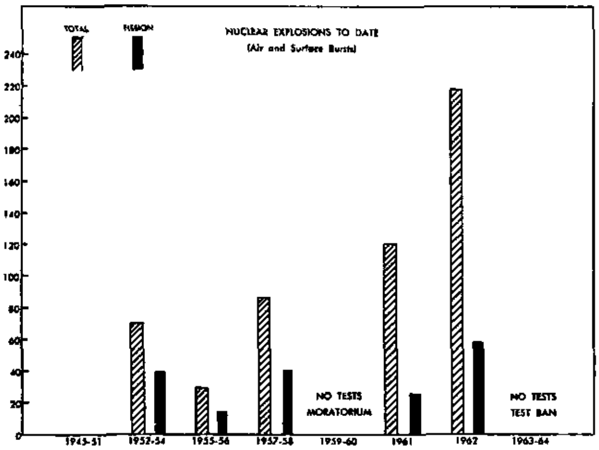


Fig. 1.

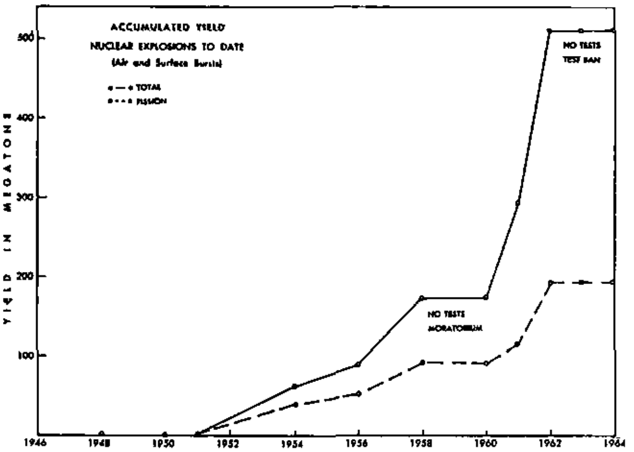


Fig. 2.

it is added up, so that by looking at the year 1958, for instance, one can see that the total explosive force exploded up to that point was approaching 200 megatons.

The quantity of fission products (such as iodine 131 and strontium 90) produced in a nuclear explosion is proportional to the *fission* yield. But the quantity of carbon 14 is dependent on the *total* yield. A fusion reaction producing the same total energy as a fission reaction is estimated to produce six times as much carbon 14. Since, as is evident from Fig. 1, the total yield in nuclear test explosions has gone up relative to the fission yield, carbon 14 has become an increasingly important component in the radioactive fallout from nuclear weapons.

The Federal Radiation Council (FRC), has evaluated the hazard from the quantities of radioisotopes ingested into the body. For each isotope, the Council has established Radiation Protection Guides, (RPG)* for the amount of radiation that may be tolerated upon the various organs in the body. The RPG, according to the Council, "should not be exceeded without careful consideration of the reasons for doing so."

For the three radioisotopes iodine 131, strontium 89 and strontium 90, the FRC has defined three ranges of ingestion rate, representing three degrees of hazard. These are given in Table II in picocuries, a measure of the activity of a radioactive substance. The ranges are defined as follows: *Range I*: The hazard from ingestion rates in this range is considered acceptably small. *Range II*: Ingestion rates within this range are considered a cause for concern, and the FRC recommends control measures to prevent ingestion rates rising above those corresponding to the top of this range. *Range III*: Ingestion rates exceed the RPG set down by the Council. To quote from Report No. 2 of the FRC, dated September, 1961, "Sharply rising trends in Range III would suggest strong and prompt action."

* The RPG's have been said to apply to "normal peace-time uses" only, not to fallout. No limits have been set for fallout, except in the case of iodine 131. See page 36.

Table II. RANGES OF DAILY INTAKE FOR USE IN EVALUATION OF HAZARD. (picocuries per day averaged for one year).

Radioisotope	Range I	Range II	Range III
Iodine 131	0-10	10-100	100-1,000
Strontium 89	0-200	200-2,000	2,000-20,000
Strontium 90	0-20	20-200	200-2,000

In Figs. 3 to 7 are presented the results of measurements obtained by Public Health Service and AEC authorities of the concentrations in milk* and (for strontium 90) in tap water of radioactive isotopes resulting from nuclear bomb tests. The data hold for the "wet" areas of the United States, comprising the eastern half of the United States and parts of the West Coast. About 90 per cent of the nation's people live in the wet areas. Average concentrations for the remainder (or "dry" portion) of the United States may be as much as 50 per cent lower than those given, but in several cases have been known to be higher for iodine 131.

The characteristics of the biologically important radioactive isotopes, listed in Table I, lead to a natural division into three groups: the short-lived isotopes, iodine 131 and strontium 89; the long-lived isotopes, strontium 90 and cesium 137; and carbon 14.

* The raw milk data for St. Louis on which Figures 2 to 5 are based, has given consistently higher concentrations of radioactive isotopes than has the pasteurized milk data. The raw milk data, however, covers a longer span of time and does not differ, in qualitative behaviour, from that for other cities such as Cincinnati and Salt Lake City. Vid. Radiological Health Data, Vol. IV, #10, October, 1963, U. S. Public Health Service.

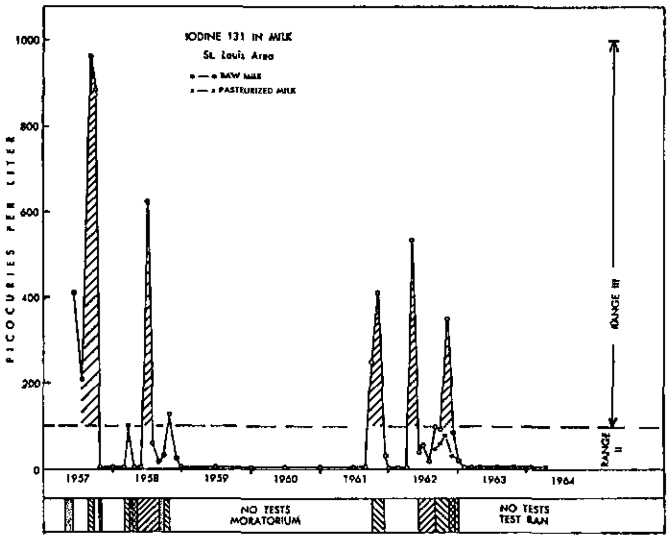


Fig. 3.

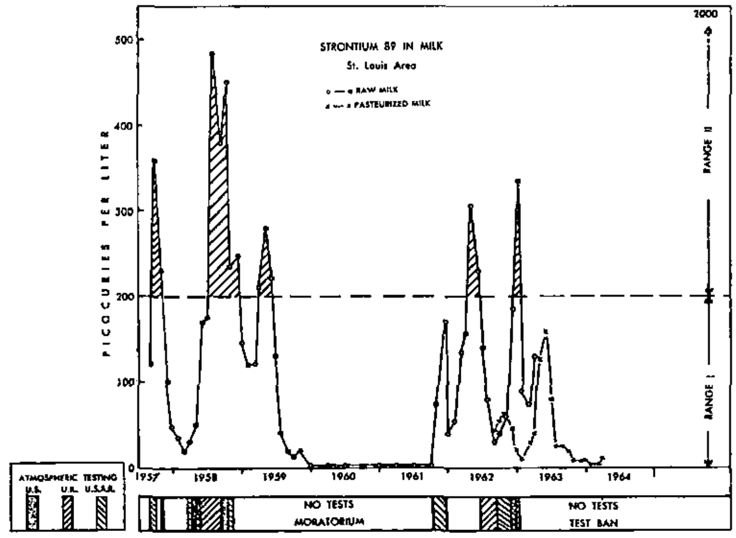


Fig. 4.

Iodine 131 and Strontium 89

The short-lived isotopes have their greatest effect, because of their short half-lives, soon after a nuclear explosion has occurred. This is evident from the close correlation between peak activities of iodine 131 and strontium 89 and dates of nuclear tests, as shown in Figs. 3 and 4. If the tests are widely spaced, there is no build-up of these isotopes. High doses over short periods of time can, however, occur, especially because the geographic distribution of the short-lived isotopes is often extremely uneven. The tests identified on the figures are those made above ground. Underground weapons testing in Nevada was also conducted during the fall of 1957, fall of 1958 and from Oct. 1961 through April, 1964.

Cesium 137 and Strontium 90

The quantities of the long-lived isotopes, cesium 137 and strontium 90, are not only correlated with the occurrence of nuclear testing but will also build up with time. Much of the radioactive material is thrown high up into the stratosphere and "falls out" in rain and snow over a period of months and years. For this

Fig. 5.

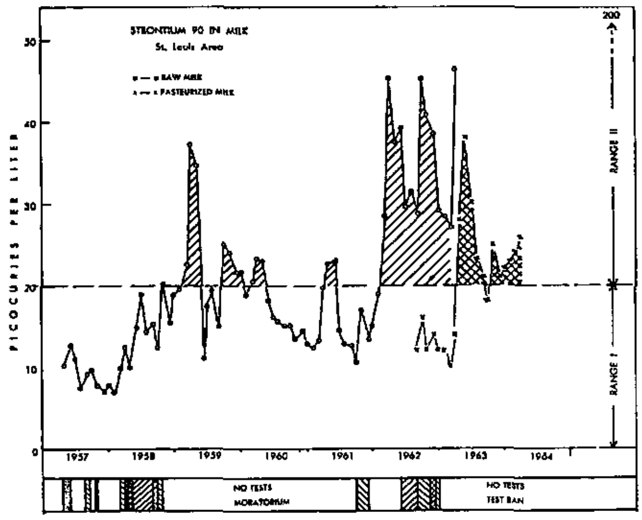


Fig. 6.

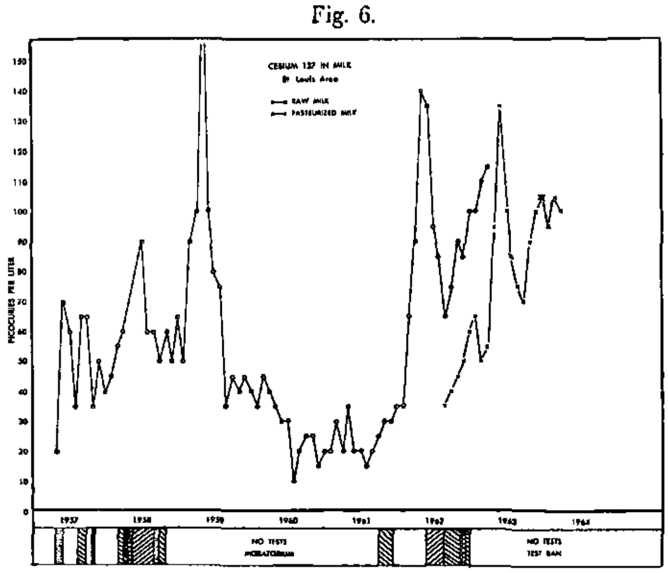
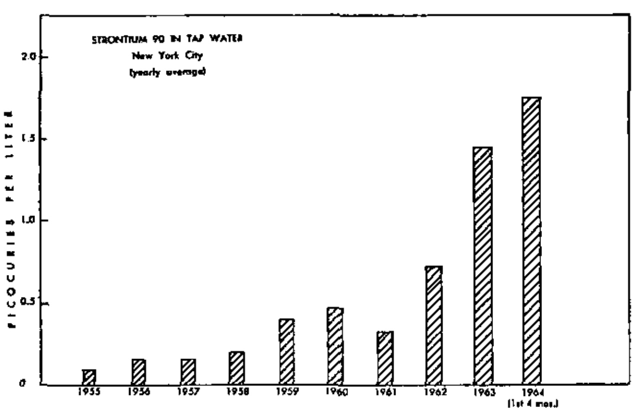


Fig. 7.



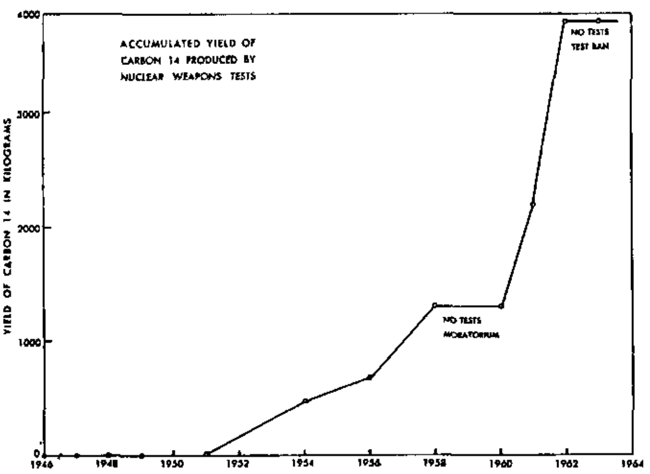


Fig. 8.

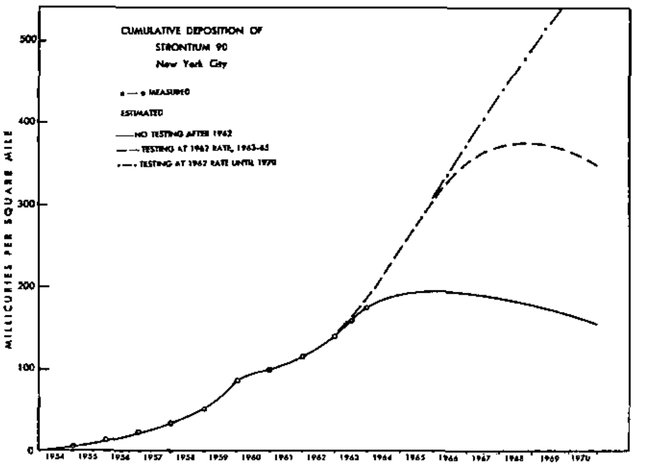
reason, the quantities of cesium 137 and strontium 90 on the earth's surface have continued to increase even since testing stopped. This build up will continue until the total quantity lost each year from the available pool — by a combination of decay and environmental dilution — is equal to the quantity which comes down each year.

Figs. 5 and 6 show the monthly concentration of these isotopes in raw milk for the St. Louis area during the years 1957-64. The progressive build-up of strontium 90 ingested in tap water by New York City residents is shown in Fig. 7.

Carbon 14

In Fig. 8 is shown the accumulated yield of carbon 14 resulting from nuclear weapons testing to date. The graph shown is based on an assumption that a one-megaton total yield in a nuclear explosion produces 7.5 kilograms of carbon 14. Because of the long (5,600 year) half-life of carbon 14, the total amount of carbon 14 corresponds almost exactly to the accumulated total yield from nuclear weapons plus the naturally occurring carbon 14.

Fig. 9.



Much of the total carbon 14 produced never reaches plants, animals or humans. At any given time, what is important to man is the amount of carbon 14 available to living organisms. In Fig. 11, the solid line shows the carbon 14 that has been available to living things each year and is expected to be available in future years. It is shown as a percentage of naturally occurring carbon 14.

Some of the carbon 14 eventually is absorbed into the ocean, and this is not taken into account in Fig. 11. The process is not completely understood; it takes place very slowly — in 33 years half of what is in the lower atmosphere will be absorbed into the ocean.

PROJECTED RADIATION LEVELS DUE TO NUCLEAR TESTING

Knowing what the fallout levels are today, we can estimate what they will be next year, and in succeeding years, if there is no further atmospheric testing.

Suppose the Nuclear Test Ban Treaty had not been consummated. We will estimate the effect of continued testing at the 1962 level through 1965 and also the effect of indefinite testing at the 1962 level.

Short-lived Isotopes

As mentioned above, the effects of iodine 131 and strontium 89 are felt soon after the occurrence of a nuclear weapons test. Were testing not to be renewed, therefore, the presently undetectable levels of these isotopes would not increase. Renewed testing at the 1962 rate, however, would result in further high levels of activity (such as those indicated on Figs. 2 and 3) which would continue as long as testing occurred. Under conditions of prolonged testing, the possibility of extremely high local concentrations of iodine 131, exceeding Range III of the Radiation Protection Guide, cannot be excluded.

Long-lived Isotopes

Cessation of nuclear weapons testing will result in a levelling off of concentrations of strontium 90 and cesium 137. Since the half-lives of these two isotopes are almost the same, their physical behaviour will be similar and we need only discuss strontium 90.

In Fig. 9 is shown graphically (solid line) the cumulative deposition of strontium 90 on the ground in New York City. (A millicurie is one thousandth of a curie, the latter being a standard measure of the activity of a radioactive substance.) As shown by the line into the future, if testing is not renewed, the peak value (200 millicuries per square mile) of strontium 90 deposition will occur about 1965, with a subsequent slow decrease with time.

The long-dashed curve of Fig. 9 shows what would have been expected had testing at the 1962 level been continued through the years 1963, 1964 and 1965. The

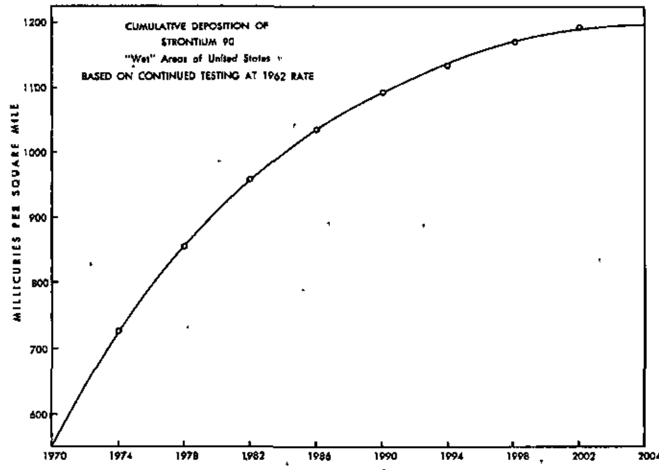


Fig. 10.

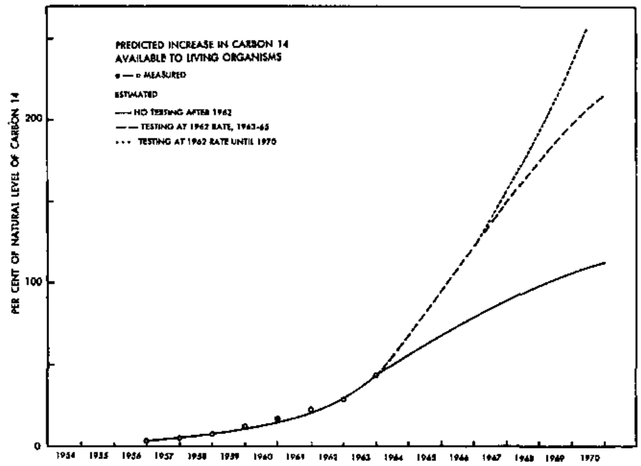


Fig. 11.

peak value (380 millicuries per square mile) would have occurred about 1968, and the levels would have remained consistently higher in ensuing years than in the case of the cessation of testing.

The dash-dot curve of Fig. 9 represents the case of continued testing through 1970, resulting in a practically straight-line increase up to a level, in 1970, of approximately 550 millicuries per square mile. If testing at the 1962 rate were to continue indefinitely, the cumulative deposition of strontium 90 would follow the curve given in Fig. 10, an equilibrium concentration being reached at about the year 2000. After this date, the concentration would remain reasonably constant as long as testing continued.

Carbon 14

Because of its method of production and long half-life, carbon 14 is a special case. Because of its potential effect on the genetic hazard for many generations to come, it is an extremely important case. The availability of carbon 14 concentrations to living organisms for the three models being considered is shown in Fig. 11. If testing is not renewed, the level of bomb-produced carbon 14 will increase slowly up to 1970, reaching a level about equal to that of naturally-occurring carbon 14. To put it another way, the total radiation from carbon 14 will be doubled by 1970.

Had testing at the 1962 rate continued for three years, the 1970 concentration of bomb-produced carbon 14 would be approximately twice that of naturally-occurring carbon 14. Were testing to continue through 1970, the carbon 14 introduced by testing would be about three times that occurring naturally. Were tests at the 1962 rate to continue for the next 100 years, the concentration of carbon 14 available to living things would reach about 20 times the natural level.

REFERENCES

Data used in producing Figures 1-11 were obtained from the following sources:

Figures 1 and 2: Federal Radiation Council Report No. 4, "Estimates and Evaluation of Fallout in the United States from Nuclear Weapons Testing Conducted Through 1962," May, 1963.

Figures 3, 4, 5 and 6: Radiological Health Data, Vol. IV, #10, October, 1963, published by U. S. Department of Health, Education and Welfare, Public Health Service. For data on pasteurized milk, see succeeding 1963 and 1964 issues of this bulletin.

Figure 7: Quarterly Summary Report (HASL-146) "Fallout Program," Health and Safety Laboratory, United States Atomic Energy Commission, New York Operations Office. July 1, 1964.

Figures 8 and 11: Purdom, C. E., "Biological Hazards of Carbon-14," *New Scientist,* August 2, 1962. Also, "Report of the United Nations Scientific Committee on the Effects of Atomic Radiation," New York, 1962.

Figure 9: Rivera, J. and J. H. Harley, "HASL Contributions to the Study of Fallout in Food Chains," (HASL-147) Health and Safety Laboratory, U. S. Atomic Energy Commission. Also Part 1, p. 461 ff, of "Fallout, Radiation Standards, and Countermeasures," Joint Committee on Atomic Energy, August, 1963.

Figure 10: Part 1, p. 461 ff, "Fallout, Radiation Standards, and Countermeasures," Joint Committee on Atomic Energy (U. S. Congress), August, 1963.

By ESTHER K. SLEATOR and RICHARD FERGUSON

FALLOUT IN FOOD AND WATER

On September 17, 1964, under a Washington dateline, an article appeared in the *St. Louis Post-Dispatch* with the headline, "Strontium 90 Increases." "The Public Health Service," the article stated, "reports that large amounts of radioactive strontium 90 continue to fall on the nation." Such information must come as something of a surprise to many people. The test ban treaty has been in effect for over a year and it is now almost two years since the last major nuclear weapon was exploded in the atmosphere. Why has there been no appreciable abatement in the fallout from those old explosions? Why does strontium 90 and other radioactive debris from past nuclear tests continue to appear in our food? Is fallout in food and water a hazard to health?

To answer these questions it is necessary to know the pathway of fallout from its source in the nuclear explosion through the chain of events which finally deposit it within the human body.

When a nuclear bomb explodes, some of the radioactive atoms become associated with relatively large particles in the debris of the explosion and settle to the ground within a few hours or a day after it takes place, spreading only a few hundred miles from its site. Another part of the nuclear debris is injected into the lower atmosphere, from which it descends after a period of several months. The lightest fallout particles thrown high into the stratosphere require months to years to come back to earth. Fallout which does not come down to the earth within a few hours after the explosion is carried around the world and comes down gradually in rain and snow.

Most of the fallout is found in a band which circles the globe in the Temperate Zone at about 30-60 degrees north latitude. The major cities of the world lie in this band; New York, London, Berlin, Moscow, Peking and Tokyo. It includes 80 per cent of the people that live on the earth.

Since fallout comes to earth by rain or snow, regions with heavy rain or snowfalls tend to get most fallout radioactivity. For the same reason there is seasonal variation in the descent of fallout to the ground, with maximum deposition in the spring. 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 the greatest annual precipitation), to 40 to 50 millicuries per square mile in the "dry" regions. These "wet" and "dry" regions are shown in the map (Fig. 1). The half-life of strontium 90 is 28 years. If there is no further testing, the rate of radioactive decay of the accumulated strontium 90 will exceed the rate of deposition of fallout on the earth, probably sometime in 1965, as can be seen in Fig 9, p. 11.

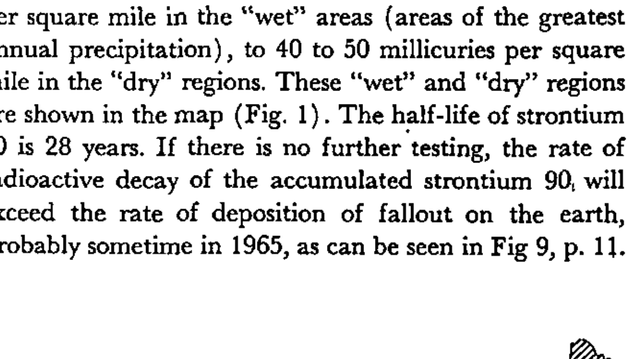
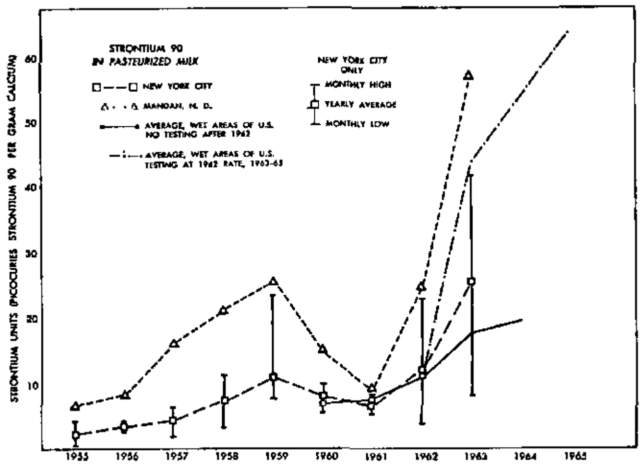


Fig. 1. The "wet" and "dry" areas of the United States. Wet areas, with more rain, generally have higher fallout levels. Only about 19 million people live in the dry areas, while 171 million live in the wet areas. (Map reprinted from Federal Radiation Council Staff Report No. 4.)



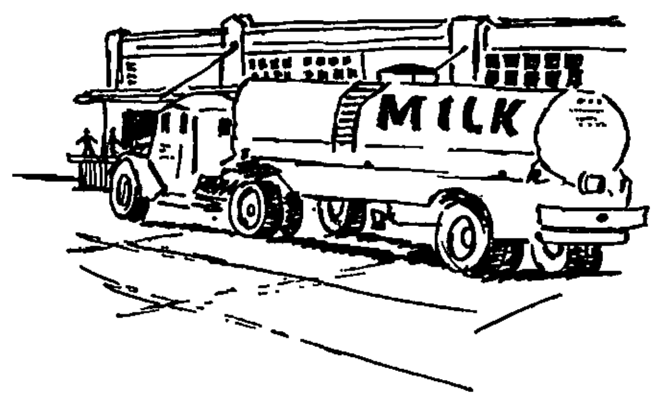


Fig. 2

resulting in a gradual lowering of the amount of strontium 90 on the ground in succeeding years.[1]

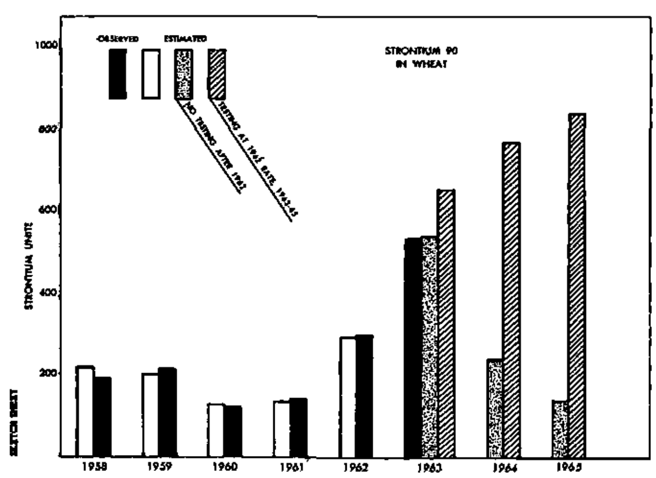
Every nuclear explosion produces a great variety of radioactive elements. Some of these elements are chemically similar to nonradioactive elements which are normal constituents of living things. Strontium 90 and strontium 89 which are radioactive fallout constituents closely resemble normal calcium, which is an important component of all living cells and which in animals appears especially in milk and bone. Radioactive cesium 137 is chemically similar to potassium, a common constituent of all living cells. Radioactive iodine 131 has the same chemical behavior as ordinary nonradioactive iodine, and like the normal element becomes concentrated in the thyroid, where it is incorporated into the iodine-containing hormone, thyroxin, that is the special product of the thyroid gland. Carbon 14, which is produced when neutrons emitted by exploding nuclear bombs collide with nitrogen atoms in the air, is chemically identical to ordinary carbon; carbon is common to all living things, carbon 14 becomes incorporated into them.

Thus, the radioactive atoms—strontium 90, cesium 137, iodine 131 and carbon 14—which are produced by nuclear testing and are chemically similar to important life constituents can become integral parts of all forms of life and, once absorbed, subject them to *internal* radiation.

Calcium nutrition is a useful illustration of the relationship between the normal and fallout constituents. Calcium is absorbed from the soil by plants, and animals obtain the calcium that they need by feeding on the plants. Animals require calcium mainly for the growth of bones and teeth; in cows much of the calcium appears in the milk. Human beings obtain their required calcium by drinking milk, and by eating vegetables and cereals.

Wherever calcium occurs we now find strontium 90 as well. Being chemically similar to calcium, strontium 90 follows calcium from the soil into plants, into animals and through milk and other foods into human beings.

Fig. 3



City	May 1963	May 1964
Albuquerque, N. M.	10	12
Boston, Mass.	23	39
Chicago, Ill.	19	17
Des Moines, Iowa	41	34
Helena, Mont.	20	34
Jackson, Miss.	38	54
Little Rock, Ark.	51	69
Minot, N. D.	56	77
New Orleans, La.	40	59
New York, N. Y.	22	28
Palmer, Alaska	14	28
Phoenix, Ariz.	6	5
Pittsburgh, Pa.	22	34
Rapid City, S. D.	27	52
San Francisco, Cal.	25	11
Seattle, Wash.	35	44
St. Louis, Mo.	28	30
Washington, D. C.	25	25

Table I. STRONTIUM 90 IN MILK
Selected Cities
(in strontium units)

As the soil accumulates an increasing burden of strontium 90, the amount in plants goes up and with it the amount that we find in the milk of cows that feed on these plants. Each of the fallout radioisotopes that resembles a normal element of importance to animals and plants will, like strontium 90, follow the path taken by the normal constituents and find its way into our bodies.

Because of the variations in weather conditions, in rates of fallout absorption by different kinds of plants, in the affinities of various parts of the body for certain radioisotopes, and because the dietary habits of various groups are different, no simple generalizations can be made about the amount of radioactivity being incorporated into our bodies through these complex pathways. The extraordinarily high body burdens of radioisotopes now present in certain Arctic people, discussed in another article in this issue, is a striking example of how special conditions can lead to unexpected concentrations of fallout radioactivity.

However, it is possible to measure this radioactivity on our immediate sources — food and water. Such measurements of fallout radioactivity are now quite extensive.

MEASUREMENT OF RADIOACTIVITY IN THE DIET

In 1959, the Atomic Energy Commission's Health and Safety Laboratory (HASL) began a quarterly survey of radioactivity in food purchased in New York City, San Francisco, and Chicago. *Consumer's Union* has collected and analyzed complete two-week diets of teenagers in 24 cities starting in November, 1959; such collections have continued at regular intervals up to the present. The United States Public Health Service institutional diet sampling program began monthly measurements in March, 1961 and now includes institutions in 22 states and covers the eight to twenty age group. The Food and Drug Administration initiated a total diet sampling program in May, 1961, and has continued sampling of major food items from various regions. The United States Public Health Service program of surveillance of radioactive substances in pasteurized milk began in 1957 and now has 63 stations with a sampling frequency of once a week.

In order to provide a picture of the present status of fallout in food, some of the chief results of these surveys that are available at this time are summarized in the accompanying tables and graphs.

When both calcium and strontium are taken into the body, the body discriminates in favor of calcium — if more calcium is present, less strontium 90 will reach the bones. The important thing to know about strontium 90 in food, then, is how much is there in relation to calcium. For this reason, the levels are given in picocuries of strontium 90 per gram of calcium (called strontium units).

Fig. 2 shows yearly national averages of the amounts of strontium 90 in commercially available milk during the last ten years.[2] It shows the levels measured through 1963, and the levels that can be expected in succeeding years if there is no more testing.[3] Such predictions are possible because of the known relationship between strontium 90 on the ground and the amount appearing in milk. Although testing ended in the fall of 1962, strontium 90 levels in milk continued to rise in 1963 and 1964. If the test ban continues, strontium 90 levels will decline gradually thereafter. In contrast, if the test ban had not been enacted, strontium 90 levels would now be nearly three times higher than they are and would continue to rise for some years to come.

These averaged values show the overall trends from year to year; but it should be remembered that in some places strontium 90 will be considerably higher than this average. For example, milk from Mandan, North Dakota has more than twice the strontium 90 levels of "average" milk. In May, 1963, the highest level yet observed in milk was found in Mandan — 105 strontium units. In relatively dry areas of the nation, strontium in milk is below the national average.

The Federal Radiation Council's protection guideline for strontium 90 sets a daily intake of 200 picocuries per day from all sources as the beginning of Range III, the range calling for "appropriate positive control

Table II. STRONTIUM 90 IN THE DIET (New York City)
Annual intake in picocuries per year

	1960	1961	1962	1963
Wheat foods	927	637	907	2386
Milk	1967	1796	2456	6728
Vegetables	923	801	474	1435
Fruit	318	404	489	813
Meat	89	70	134	126
Eggs	84	21	18	80
Total	4398	3729	4478	11,568

measures." Translating strontium units to the amount of strontium 90 in a child's average daily consumption of milk, the high level in Mandan is about half way to Range III. (Further discussion of FRC radiation protection guides will be found in the article on Radioiodine, p. 34).

The most recent available measurements of strontium 90 in milk — those for May, 1964 — are shown in Table I for eighteen U. S. cities.[4] This shows how the level varies from one city to another. Strontium 90 in milk in the same cities one year ago is also shown here; illustrating how, in most cases, it is still increasing.

Fig. 3 shows trends in the strontium 90 content of United States wheat crops from 1958 to 1963.[2] Here, too, it is possible to calculate strontium 90 contents of wheat from the amount of fallout in the soil and thereby predict the contamination of future wheat crops. It can be seen from Fig. 3 that because of the test ban, strontium 90 in wheat this year declined to about one-half its 1963 value, and will decline further in 1965. On the other hand, if testing had continued, wheat in 1965 would contain more than six times the amount expected under no-test conditions.

The average American gets more than half of his calcium in milk; from two-thirds to three-fourths of his total strontium 90 intake comes from milk and wheat. Although there is no practical way to remove strontium 90 from wheat products, this can be done in the case of milk. Processing to remove most of the strontium 90 from milk would add about two cents to the price of a quart.[5] An attempt to substitute other foods for milk would decrease calcium intake more sharply than strontium 90 intake, and, in fact, *increase* the strontium to calcium ratio in the diet.

The distribution of strontium 90 in various parts of the diet (in New York City), and changes during 1960-63 are shown in Table II. Clearly, because of intensive testing in 1962, there was a sharp rise in dietary strontium 90 in 1963. If the test ban continues, this value will begin to decline after 1965.

Although data on the cesium 137 content of the U. S. diet are less detailed than for strontium 90, they follow similar trends. For example, the cesium 137 level in flour in San Francisco in December, 1962, was 23.6 picocuries per kilogram. One year later, in December, 1963, it was 303 picocuries per kilogram, a twelve-fold increase. This sharp increase has been attributed to the arrival on the market of flour from the relatively heavily contaminated 1963 wheat crop. According to a report from the AEC's Health and Safety Laboratory, "it is expected that the cesium 137 contribution from this source will be of increased importance during 1964.[3]

The problem of analysing the iodine 131 content of the diet is a rather special one. A separate article in this issue discusses how this behavior influences the appearance of iodine 131 in the diet.

These results, taken together, show that because of the rapid rate of nuclear testing in 1962, we are now eating foods which contain record levels of radioisotopes from fallout; however, these levels will begin to decline gradually about a year from now. The data also show that if the test ban had not been put into effect, these levels would now still be rising rapidly. Had testing continued, in 1965 our dietary intake of radioisotopes from fallout would be roughly three times higher than what is expected with the test ban treaty in effect.

RADIOACTIVITY IN WATER

Water plays such an important role in our lives that one is bound to wonder if radioactive fallout has contaminated our water supplies. Fortunately for humans, water undergoes considerable natural purification before entering man's processing plants, so that in almost all circumstances, the levels of radioactivity are substantially below the FRC guidelines for drinking water. For example, the strontium 90 levels in New York City tapwater shown in Fig. 6, p. 10, are well below the intake limit of 10 picocuries per liter.[6] The national average for surface water (river or lake water) is 3 picocuries per liter.

While water might now be generally assumed to be safe, there are causes for concern. There is always the possibility of a local "hot spot." For example, the Red River at Grand Forks, North Dakota, had an average strontium 90 concentration of 11.3 picocuries per liter for the third quarter of 1963, as compared with 1.9 for New York City tapwater.

Natural purification of surface water comes mainly through its contact with the soil as strontium 90 ions are captured by the soil particles. Rainwater which is stored in cisterns and used as drinking water never has a chance to lose its strontium 90 to the soil and radioactivity in this water can reach unusually high levels.

Recent measurements of cistern water in North Carolina show that *total radioactivity* there (which includes strontium 90) is 6.75 times the total radioactivity in the river water of the area. Although the strontium 90 content of this water was not measured separately, it would be expected to be 6.75 times the strontium 90 of the surface water. If this is typical, then cistern water in other areas may generally be six times as high as surface water in the same area. (Another way of estimating it, from the levels of strontium 90 on the ground and the total precipitation, suggests that it is at least four times as high.)

There is no figure for strontium 90 in North Carolina surface water, but we can estimate what the level in cistern water is this way: The *total* radioactivity of the North Carolina cistern water is 3.6 times that of the national average for surface water. We can assume, then, that the strontium 90 levels in North Carolina cistern water are also 3.6 times the national average. That means that people in North Carolina who drink cistern water are now getting about 10.2 picocuries of strontium 90 per liter, just over the intake limit.

In an area where the surface water has a high level of radioactivity, it seems reasonable to suppose that the cistern water will have a still higher level. Thus cistern water in North Dakota might have a concentration of 40 picocuries of strontium 90 per liter or more — four times the intake limit.

The effects of the test ban treaty on radioactivity in water are difficult to estimate, since there is no established formula relating fallout rates and accumulated fallout to the levels in water. A crude estimate made from predicted fallout rates indicates that in 1965 levels all over the country might be double what they are at present had there been no treaty. In such a case, the radioactivity levels in a "hot spot" like Grand Forks might be more than double the intake limit, while New York City water would still be less than half the limit.

What do these increased levels of radioactivity in our food and water mean in terms of health risk? This is discussed elsewhere in this issue, in connection with an evaluation of the effects of radioactivity from nuclear tests on the incidence of hereditary defects, in the article on radioiodine and in connection with the results of the Baby Tooth Survey.

REFERENCES

1. Federal Radiation Council, Staff Report No. 4, May, 1963.
2. "HASL Contributions to the Study of Fallout in Food Chains." Health and Safety Laboratory, United States Atomic Energy Commission. HASL-147. July 1, 1964.
3. Dunning, Gordon M. and Paul C. Tompkins, "Fallout Estimates for Continuous Testing at the 1962 Testing Rate," Hearings before a subcommittee of the Joint Committee on Atomic Energy, Part I, Appendix 11, 1963.
4. Radiological Health Data, U. S. Dept. of Health, Education and Welfare, IV: 9, Sept. 1963, and Dept. of HEW data release, Sept. 18, 1964.
5. Wilson, David J. "Cost of Removing Radiostrontium from Milk," *Scientist and Citizen*, Aug. 1964.
6. Radiological Health Data, U. S. Dept. of Health, Education and Welfare, V: 8, Aug. 1964.
7. Ibid., V: 9, Sept. 1964.