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MAXIMUM PERMISSIBLE LEVELS OF INTERNALLY-DEPOSITED
RADIOISOTOPES IN RELATION TO WORLD-WIDE FALLOUT

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INTRODUCTION

During the past year public attention has been increasingly focused on the potential hazard to the general population of widespread, low-level radioactive fallout from nuclear weapons testing (1-5). Although a number of radioisotopes are present in the fission mixture, the principal concern is Sr^{90} . Sr^{90} is believed to be the most important isotope because of its similarity to calcium, its long physical and biological half-life^{lives},* and high relative fission yield. These factors lead to high incorporation in ^{biological materials} the biosphere, and a long residence time ^{animal} in bone. General contamination will result in the bones of the population eventually reaching an equilibrium state with Sr^{90} in the biosphere. The predominance of Sr^{90} over other long-lived radioelements as a potential hazard can be deduced in part from data in Table 1,

which show that it is the only isotope that combines high fission yield, long half-life, high absorption rate and a low maximum permissible level.

These data suggest Cs^{137} as the second most important fission product ^{with respect} for the long-term hazard, and its presence in people and foodstuffs has been reported (6, 7).

However, for reasons not discussed here, its potential hazard to the population is believed to be less than Sr^{90} by at least an order of magnitude.

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*Physical half-life is the time required for a given amount of a radioisotope to be reduced to one-half by radioactive decay. The biological half-life is the time required for an organism to reduce its burden of a material to one-half by excretion.

*Should put
biological half life back
in this table*

Table 1

RADIOELEMENTS OF IMPORTANCE TO LONG-TERM FALLOUT PROBLEM

Radio-element	Type Radiation	Fission Abundance (per cent)	Radiological Half-Life	Abs. on Ingestion (per cent)	MPL (μ c)
Pu ²³⁹	α	--	24,000 yr	3×10^{-3}	0.04
Cs ¹³⁷	β, γ	6.2	28 yr	100	98
Sr ⁹⁰	β	5.1	28 yr	35	1
Pm ¹⁴⁷	β	2.6	3.7 yr	3×10^{-2}	25
Ru-Rh ¹⁰⁶	β, γ	0.5	1.0 yr	5×10^{-2}	4
Ce-Pr ¹⁴⁴	β, γ	5.3	275 days	3×10^{-2}	1

Appraisal of the potential hazard from world-wide fallout requires consideration of the present basis for the maximum permissible levels of internally-deposited isotopes, the rate and extent of fallout, and the method of incorporation of radionuclides into the biosphere and the human body. Information on all of these factors is somewhat inadequate at the present time. This paper is an attempt to present a general summary of the present thinking with regard to the above factors.

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BASIS FOR MAXIMUM PERMISSIBLE LEVELS OF INTERNALLY-DEPOSITED
RADIOISOTOPES

Human experience through the diagnostic and therapeutic use of X- and gamma rays and extensive animal experimentation with all types of radiation have demonstrated that ionizing radiations may produce deleterious biological effects. ^{Damage} ~~These effects~~ are manifest in the production of early physiologic aging resulting in life shortening, mutations, irregularities in hematopoietic function (some of which result in increased incidence of leukemia) and specific organ or tissue changes such as cataract of the lens of the eye and tumors of the bone.

Damage from ionizing radiations may occur from radioactive isotopes deposited in the tissues and organs, as well as from radiations originating from an external source.

Maximum permissible amounts of radioisotopes deposited in the body are calculated on the premise that no critical organ or tissue will receive an average dose rate greater than 300 mrem per week (the maximum permissible dose rate for external whole body radiation), assuming uniform distribution of the isotope throughout the tissue or organ. It is recognized that calculations based on average dose or uniform distribution in a critical organ or tissue may lead to considerable error since some radioisotopes are unevenly deposited. Although the average dose

rate to a critical organ may be 300 mrem per week, some portions of the organ may receive considerably less than the average and others correspondingly more. This error, however, is believed to be offset at least in part by the fact that 300 mrem is considered the acceptable weekly exposure to the entire body or the blood-forming organs and not a permissible exposure to a small element of tissue.

The Maximum Permissible Body Burden q (μc) of a radioisotope, based on the weekly dose rate of 300 mrem for external radiation, is calculated according to the following expression (8):

$$q = \frac{100 \text{ m W}}{3.7 \times 10^4 \times 1.6 \times 10^{-6} \times 6.05 \times 10^5 \times f_2 \times \sum E(\text{RBE})N} = \frac{8.4 \times 10^{-4} \text{ m}}{f_2 \sum E(\text{RBE})N}$$

in which $100 = \text{ergs/g/rad}$

$m = \text{mass of critical organ in grams}$

$W = \text{permissible dose of external radiation (0.3 rem/wk)}$

$3.7 \times 10^4 = \text{d/sec}/\mu\text{c}$

$1.6 \times 10^{-6} = \text{ergs/mev}$

$6.05 \times 10^5 = \text{sec/wk}$

$f_2 = \text{fraction in critical organ of that in total body}$

$\sum E(\text{RBE})N = \text{weighted energy of absorbed radiation, weighted for summation of energies of all decays, for their relative biological effectiveness (RBE) and for nonhomogeneous distribution (N).}$

For some isotopes that localize in bone the maximum permissible body

When could be omitted from
 a bone population left

burdens are determined by direct comparison with the 0.1 μ c maximum permissible burden for radium (an ~~internal emitter~~ ^{internally deposited nuclide} with which there has been considerable human experience) and not with the 300 mrem per week level for whole body external radiation. In these cases, a factor of safety of 5 is introduced to take into account the uneven distribution of the radioactive material within the bone. Comparison with 0.1 μ c of radium is made in the following manner (8):

Jargon

$$q = \frac{q(\text{Ra}) f_2(\text{Ra}) \left[\sum E(\text{RBE})N \right] (\text{Ra})}{f_2 \sum E(\text{RBE})N} = \frac{16}{f_2 \sum E(\text{RBE})N}$$

in which the various symbols have the same definitions given above.

Derivations of the above formulas, their parameters, pertinent information on individual nuclides and values for q are given in the Handbooks of the International (8) and the National (9) Commissions on Radiological Protection. These handbooks provide the only official sources of such information for the various radionuclides, ~~from the standpoint of internal absorbed dose.~~ All of the MPC values presently published in the handbooks refer to continuous occupational exposure.

Was there an official report from S. Taylor on this?

BASIS FOR MAXIMUM PERMISSIBLE LEVELS APPLIED TO THE GENERAL POPULATION

Maximum permissible levels for non-occupational exposure or exposure of a large segment of the general population were established by taking arbitrarily 1/10th of the value for working personnel (8-10). The

Ref. 10.

could this

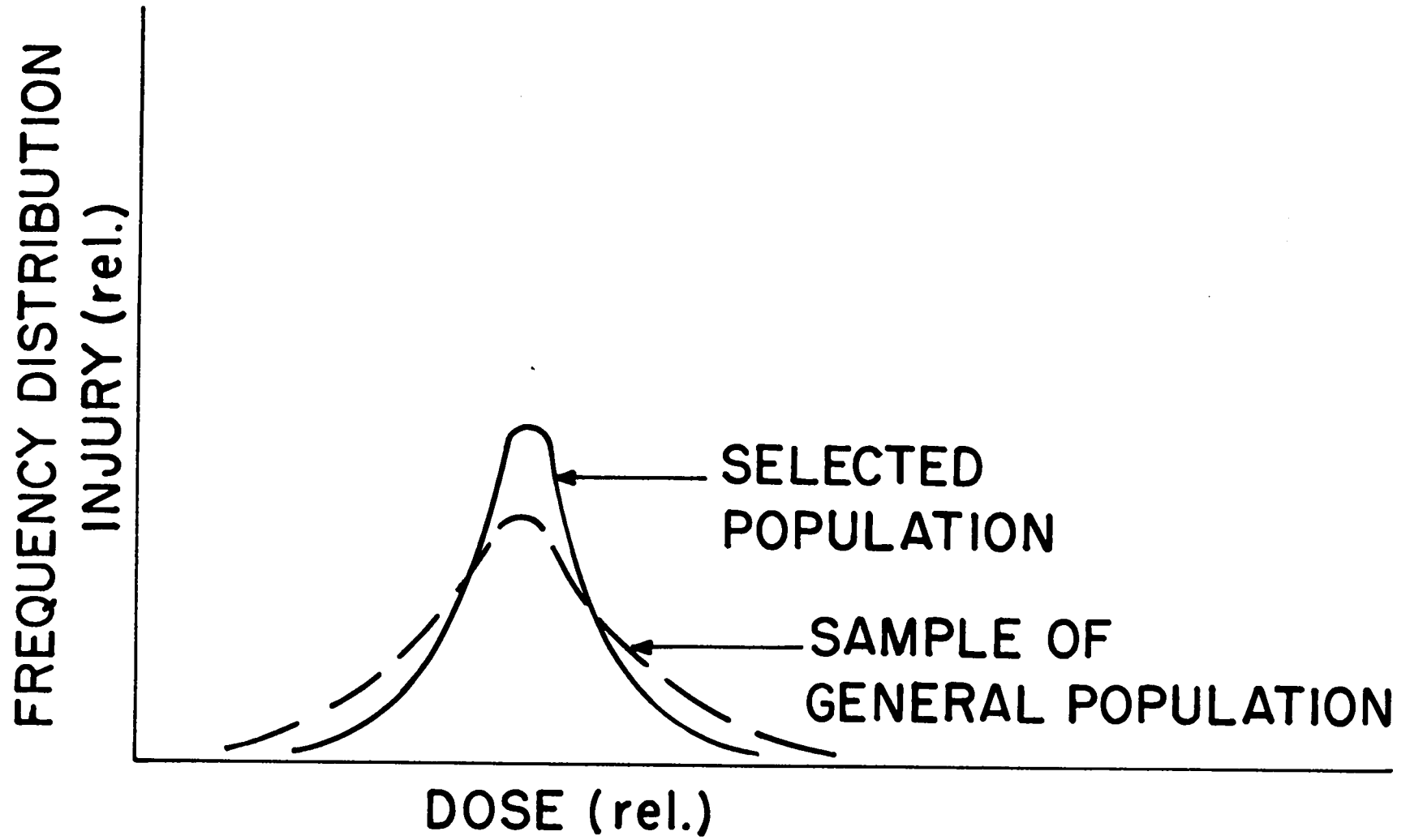
rationale behind a lower value for the general population is based on the numbers involved in the two groups at risk and the increased heterogeneity of the general population over that of the select working group. The latter group is composed of supposedly healthy workers (over 20 years of age), while the general population group ~~may~~ contain children, pregnant women, the undernourished, the sick and the old. On the assumption that frequency of response to radiation stress follows a Gaussian distribution (Fig. 1), the probability of injury of a few individuals from a specified dose increases with increase in size and heterogeneity of the group at risk.

The maximum permissible level of Sr^{90} for workers is set at $1 \mu\text{c}$ on the basis of comparison with radium, while the recommended level for the general population is set at $0.1 \mu\text{c}^*$ (11-13). The permissible level of Sr^{90} is predicated on the assumption that chronic and/or delayed effects of radiation are threshold phenomena (Fig. 2). That is to say, there is a threshold dose below which ^{any} effect rapidly becomes insignificant and above which ^{the} effect increases exponentially over a limited dose range. If this is indeed the case, $100 \text{ m}\mu\text{c} \text{ Sr}^{90} / \text{kg Ca}$ must be looked upon as a true maximum permissible level and not an average ^{permissible} level.

* There is about 1 kg of calcium in the adult human skeleton; therefore, the MPL of Sr^{90} in the general population is equivalent to $0.1 \mu\text{c} / \text{kg Ca} = 100 \text{ m}\mu\text{c} / \text{kg Ca} = 100 \mu\text{c} / \text{g Ca} = 100 \text{ Sunshine Units (Libby)}$.

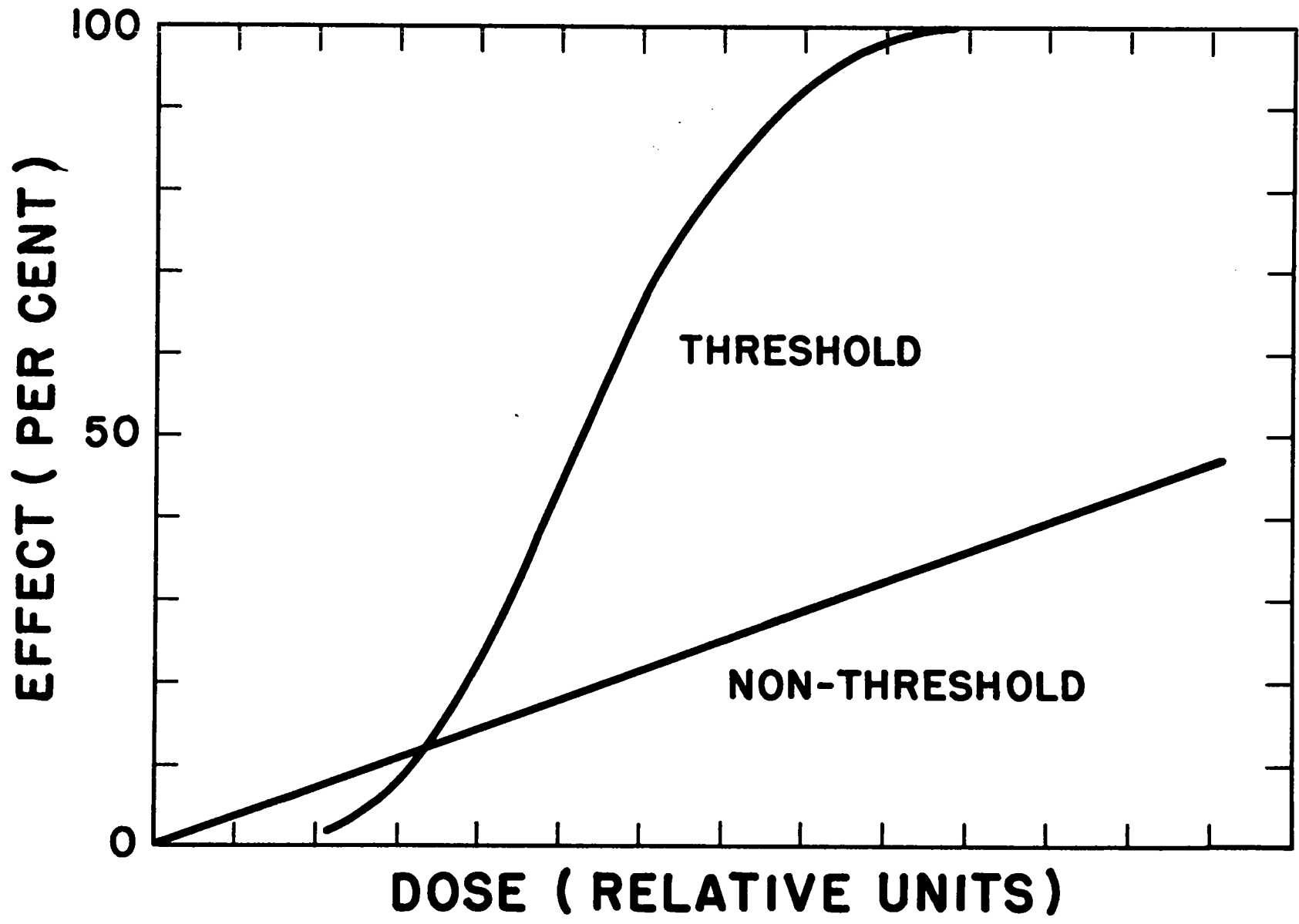
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Fig. 1. Frequency distribution response as a function of dose.



As yet, there is not conclusive evidence of a threshold dose for such chronic effects as leukemia, bone tumors, etc. There is, in fact, some indication that genetic response to external radiation is linear with dose and that a given increment produces a corresponding equal increment of effect, regardless of position on the dosage scale (Fig. 2). If chronic effects of radiation are not threshold phenomena, it would seem more reasonable to establish permissible levels for the general population on the basis of probability of risk averaged over the entire group. Present incidence of bone sarcoma and leukemia averaged over the entire population is about 2 and 6 per 100,000, respectively. About 15% of the natural incidence of leukemia (and presumably of bone sarcoma) may be attributable to natural radiation background (14). If this is true, doubling the natural background dose might be expected to increase the incidence of bone tumors and leukemia to 2.3 and 6.9 per 100,000, respectively. Such a small increase may be undetectable in the general population. On this basis, one might justify a ^{permissible} average Sr⁹⁰ level of 100 $\mu\text{c}/\text{kg Ca}$ in the general population. Dr. Hardin Jones (14), on the basis of vital statistics data, has stated that an average of 50 rads per life-time might reasonably be assumed to be a doubling dose for chronic radiation effects. On the basis of this value, an average strontium burden of 500 $\mu\text{c}/\text{kg Ca}$ in the general population would not be expected to double the incidence of bone sarcoma and leukemia.

Fig. 2. General representation of threshold and nonthreshold effect as a function of dose.

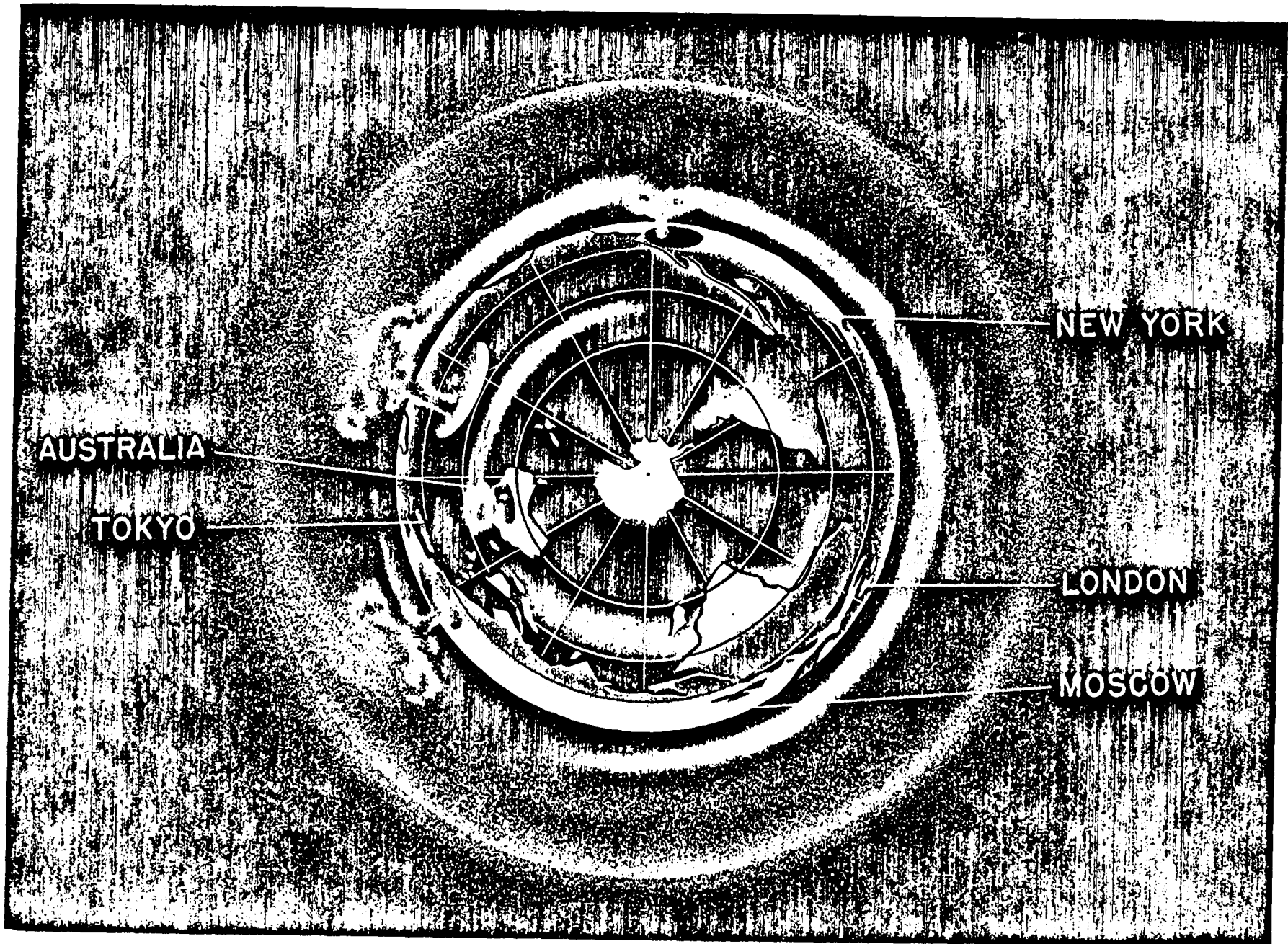


GENERAL WORLD-WIDE FALLOUT FROM BOMB TESTING OPERATIONS

Based on measurements of world-wide fallout, Libby (2, 3) has proposed a mechanism by which atomic debris is disseminated throughout the world. This theory leads to three kinds of fallout, which are ~~presented~~ ^{illustrated} graphically in Fig. 3. First is local fallout which is deposited in the immediate environs of the explosion during the first few hours. This debris consists of the large particles from the fireball and includes residues from the soil and structures which are swept into the cloud in wholly or partially vaporized state. The fraction of the total radioactivity which falls out locally depends very much on those conditions of firing which govern the amount of soil and extraneous debris incorporated in the fireball.

The second type, tropospheric world-wide fallout, is the material, which though not coarse enough to fall out locally, is left suspended in the atmosphere below the tropopause. This material is sufficiently fine that it travels great distances, circling the earth in the general latitude of the explosion, until scrubbed from the atmosphere by rain, fog, contact with vegetation, and other meteorological and/or physical factors. The average tropospheric fallout time is estimated as 20 to 30 days. The fraction of the fallout which is in this category depends

Fig. 3. Types of radioactive fallout from weapons tests (local, tropospheric and stratospheric).



AUSTRALIA

TOKYO

NEW YORK

LONDON

MOSCOW

mainly on the size of the explosion and the conditions of firing. If the weapon is fired close to the ground, a greater percentage of the fission products will deposit as local fallout. If the explosion is large (greater than 1 MT), a large percentage will be carried above the tropopause.

The third type (stratospheric fallout) is composed of fission products that are carried above the tropopause. These are believed to mix throughout the stratosphere and fall out uniformly over the entire surface of the earth with a mean fallout time estimated at from 6 to 10 years.

The above mechanism leads to a general distribution pattern of radioactivity over the surface of the earth as shown in Fig. 4. Dr. Libby's estimates (3) of present levels of Sr^{90} deposition suggest 22 mc/mi^2 for the upper midwestern section of the United States, 15 to 17 mc/mi^2 for the area between about 50°N and 10°S latitude, and 3 to 4 mc/mi^2 for the rest of the world. The higher value for the upper midwestern United States is attributed to greater local and tropospheric fallout because of the proximity of our own continental test site. The 15 to 17 mc/mi^2 deposited between about 50°N and 10°S latitude is due to tropospheric fallout from all tests of less than 1 MT conducted in the northern hemisphere plus stratospheric fallout from all weapons greater than 1 MT. The 3 to 4 mc/mi^2 deposited over the rest of the earth is due entirely to stratospheric fallout from all tests of greater than 1 MT. Actually, the general picture is greatly oversimplified.

Fig. 4. General levels of world-wide fallout deposition.



22

16

3.6

22 mc Sr⁹⁰/mi²

16 mc Sr⁹⁰/mi²

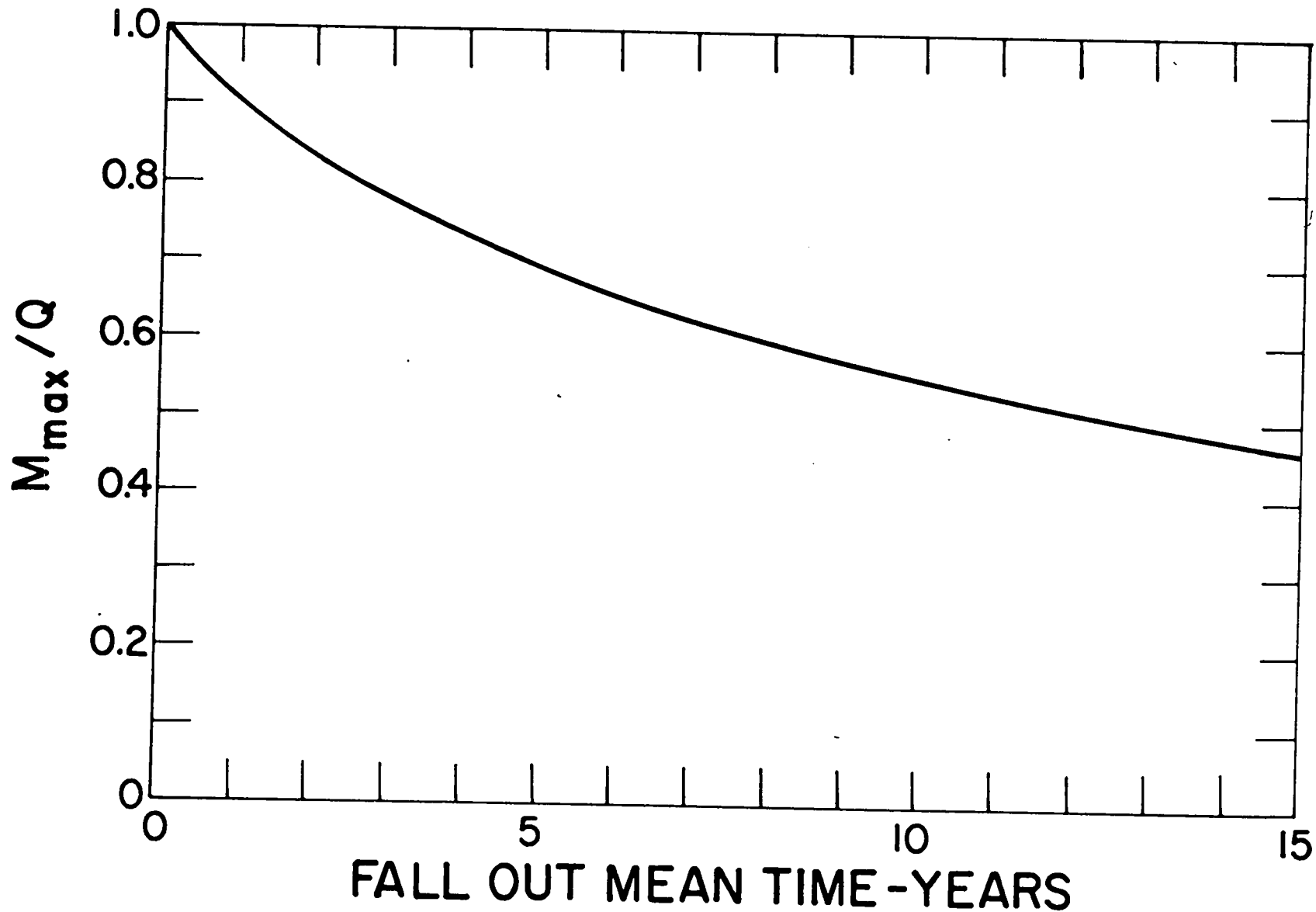
3.6 mc Sr⁹⁰/mi²

Once fission products are suspended in the troposphere (either directly by the detonation or from diffusion back below the tropopause from the stratospheric pool), meteorological conditions play a major role in their deposition. Libby (3) has stressed the importance of rainfall, fog and mist. Within any major fallout area one might expect to find fluctuations in the level of surface deposition which correlate with local meteorological conditions. Higher deposition in a local area may not correlate necessarily with total precipitation but rather with the frequency.

PRESENT AND PREDICTED MAXIMUM LEVELS OF SURFACE DEPOSITION

Libby (3) has estimated that the stratospheric reservoir contains the products of about 24 MT of fission and preliminary direct measurements by means of high altitude balloons suggest that this value is approximately correct. One MT of fission results in the formation of enough Sr^{90} to give a surface deposition of 0.5 mc/mi^2 if uniformly distributed over the entire earth's surface. If all material presently in the stratospheric reservoir were deposited instantaneously and uniformly over the earth, present values would be increased by 12 mc/mi^2 and the maximum surface deposition of Sr^{90} would result. Maximum deposition, however, will not occur because of the relatively long average stratospheric fallout time (6 to 10 years), which will allow some of the strontium to decay before deposition. Figure 5 shows, however, that the predicted maximum level is not highly dependent on the mean time of fallout.

Fig. 5. Dependence of maximum level of deposition on mean time of fallout.



Although meteorologists appear to favor a fallout half-time of about 4 years, Dr. Libby (2) has chosen to use a value of 7, which corresponds to a mean time of about 10 years. With a mean time of 10 years, the maximum predicted level of Sr⁹⁰ surface contamination should occur in about 1975. Table 2 shows the estimated present levels and the maximum predicted levels that might be expected in about 1975.

Table 2

PRESENT AND PREDICTED MAXIMUM LEVELS OF Sr⁹⁰ SURFACE DEPOSITION*

Area	Level October 1956 (mc/mi ²)	Maximum Level 1975 (mc/mi ²)
Midwest United States	22	29
Between 50°N - 10°S Latitude	16	23
Rest of World	3.6	10

* Assuming products of 24 MT fission in the stratosphere January 1, 1957, and a fallout mean time of 10 years.

As stated previously, these figures assume uniform world-wide distribution of the material now in the stratospheric reservoir and no more weapons tests. Under these conditions, the area in the upper midwestern United States would be expected to reach a level of about 29 mc/mi². The area between 50°N and 10°S latitude may reach about 23 mc/mi², and the rest of the world may reach a level of about 10 mc/mi².

INCORPORATION OF Sr⁹⁰ INTO THE BIOSPHERE

When Sr⁹⁰ falls upon the earth's surface, it becomes mixed with calcium and is taken into the biosphere by efficient transmission through ecological chains. That which settles directly on vegetation may remain as surface contamination or it in part may enter the plant through foliate absorption and mix with the plant calcium. The Sr⁹⁰ that falls out on the soil is mixed with the available calcium in the soil, where it is taken in through the root system of the plant, along with calcium. When plants are eaten by animals, Sr⁹⁰ deposited directly on the surface or incorporated in the plant is taken up by the animal and incorporated with the animal calcium. When plant and animal products (i.e., milk) are eaten by man, the Sr⁹⁰ is incorporated into his calcium pool.

It is reasonable to assume that strontium may be discriminated against with respect to calcium in passing up the ecological chain. For example, the Sr⁹⁰/Ca ratio in the bones of people may be expected to be lower than the Sr⁹⁰/Ca ratio in the soil, which is the beginning ultimately of the ecological chain between man and his environment.

One method of obtaining information on the general discrimination between Sr⁹⁰ and calcium in passing up the ecological chain is to consider man's equilibrium level with respect to stable strontium in the

environment (15, 16). Recent comparison of the ratio of stable strontium to available calcium in the soils and rocks of the world suggest an overall discrimination against strontium by a factor of about 10

(i.e., $\frac{(Sr^8/Ca)_b}{(Sr^8/Ca)_s} = \sim \frac{1}{10}$). Recently Comar and others (17-19) have

attempted to determine the discrimination factors between Sr^{90} and calcium corresponding to the various steps in the ecological cycle. They have attempted to determine $\frac{(Sr^{90}/Ca)_{sample}}{(Sr^{90}/Ca)_{precursor}}$ going from soils to plants, from plants to milk, from milk to man, and from plants to man. Assuming 80% of children's dietary calcium comes from milk and 20% comes directly from plants, an overall discrimination ratio in going from soils to human bone via the diet can be estimated. These data are summarized in Fig. 6, which suggest that the $\frac{(Sr^{90}/Ca)_b}{(Sr^{90}/Ca)_{diet}} = \frac{1}{6}$ to $\frac{1}{9}$ (10). Considering the uncertainties involved in the various individual discrimination factors, this is in reasonable agreement with the general value derived from consideration of man's equilibrium with stable strontium in his environment. The uncertainties in the individual discrimination factors at the various steps along the ecological chain suggest a very important field of research for the next several years.

The values shown in Fig. 6 are general only and do not take into consideration a wide variety of variables, including effect of soil and

Fig. 6. Incorporation of Sr⁹⁰ into the biosphere and man.

80% childrens' dietary Ca comes from milk

$$\frac{(Sr^{90}/Ca)_b}{(Sr^{90}/Ca)_m} = \frac{1}{2}$$

$$OR = DF_1 \times DF_2 \times DF_3 = \frac{1}{11} \text{ to } \frac{1}{14}$$

20% dietary Ca comes from plants

$$\frac{(Sr^{90}/Ca)_m}{(Sr^{90}/Ca)_p} = \frac{1}{5.5} \text{ to } \frac{1}{7}$$

$$OR = DF_1 \times DF_4 = \frac{1}{4} \text{ to } \frac{1}{2}$$

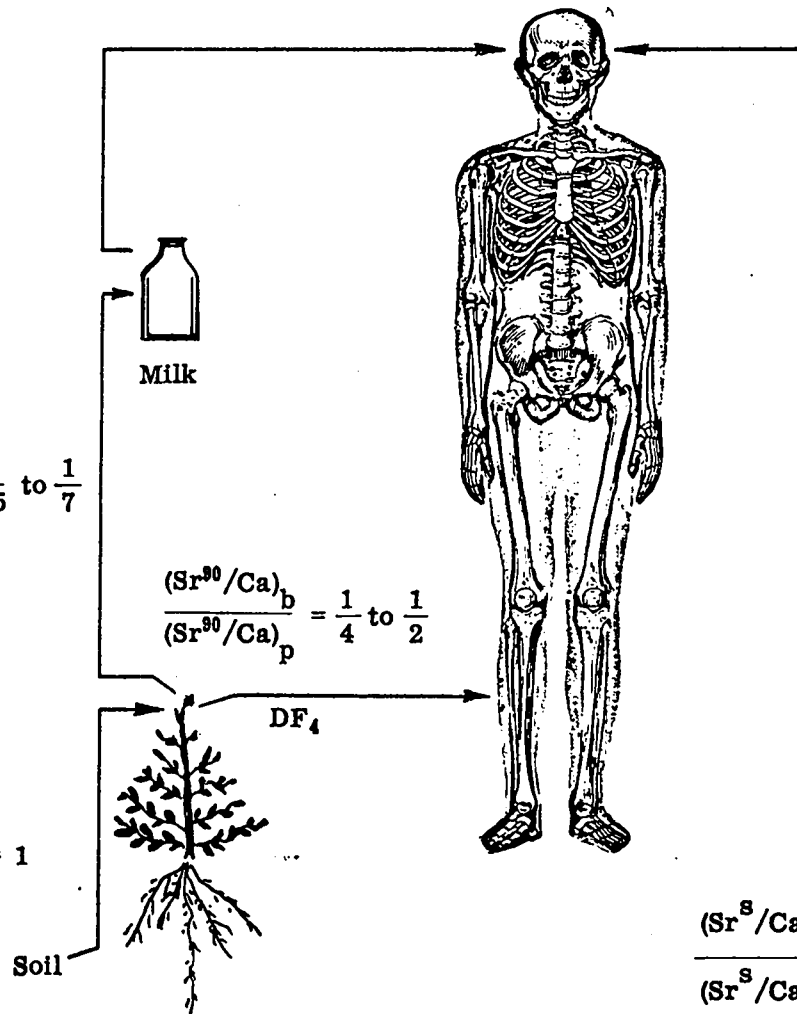
-to-

OR bone A diet

$$(0.8 \times \frac{1}{11} \text{ to } \frac{1}{14}) + (0.2 \times \frac{1}{2} \text{ to } \frac{1}{4}) =$$

$$\frac{(Sr^{90}/Ca)_b}{(Sr^{90}/Ca)_s} = \frac{1}{6} \text{ to } \frac{1}{9}$$

$$\frac{(Sr^{90}/Ca)_p}{(Sr^{90}/Ca)_s} = 1$$



$$\frac{(Sr^S/Ca)_b}{(Sr^S/Ca)_s} = \sim \frac{1}{10}$$

plant type, soil and plant equilibration times, variability of available strontium and calcium in the soil, nature and source of the diet, age and state of nutrition of the individual, etc.

PREDICTED PRESENT AND FUTURE MAXIMUM Sr⁹⁰ LEVELS IN CHILDREN

From the data in Table 2 and the information in Fig. 6, it is possible to make a general prediction of the present and future maximum Sr⁹⁰ levels in the bones of children, who draw their dietary calcium from the three major areas of fallout.

Assuming an average of 20 g available Ca/ft² of soil to a depth of 2-1/2 inches (2), a deposition of 1 mc Sr⁹⁰/mi² is equivalent to 1.8 mc/kg of available soil calcium (1 kg is approximately the amount of calcium in the adult skeleton). Multiplication of the present and predicted maximum levels of Sr⁹⁰ surface deposition (Table 2) by 1.8 gives the corresponding Sr⁹⁰ content of the soils of the various areas in terms of mc/kg available Ca. Assuming steady state conditions and

$\frac{(Sr^{90}/Ca)_b}{(Sr^{90}/Ca)_s} = \frac{1}{10}$, the predicted maximum present and future Sr⁹⁰ levels

in the bones of children expressed as mc/kg bone Ca will be approximately 1/10th of the level in the available soil calcium. Present and future maximum Sr⁹⁰ levels in children calculated in this manner are shown in Table 3. Perhaps the largest uncertainty in these estimations (even greater than the uncertainty in the Sr⁹⁰/Ca discrimination ratio) is due to their dependence on available soil calcium, which may vary

within the United States from about 1 to 100 g/ft² to a depth of 2-1/2 inches. Likewise, the amount of available soil calcium with which the Sr⁹⁰ may be assumed to be in equilibrium is a function of the depth of the feeding zone of various types of plants.

Table 3

PREDICTED PRESENT AND FUTURE MAXIMUM Sr⁹⁰ LEVELS IN CHILDREN*

Area	Predicted Max.** Spring 1957 ($\mu\text{c}/\text{kg Ca}$)	Predicted Max. 1975 ($\mu\text{c}/\text{kg Ca}$)
Midwest United States	4.0	5.2
Between 50°N - 10°S Latitude	2.9	4.1
Rest of World	0.6	1.8

* Assuming steady state conditions, 20 g available Ca/ft² of soil, mean fallout time of 10 years, and $\frac{(\text{Sr}^{90}/\text{Ca})_b}{(\text{Sr}^{90}/\text{Ca})_s} = \frac{1}{10}$.

** Samples of children's bones showed a level of $\sim 1 \mu\text{c}/\text{kg Ca}$ January 1956. MPL Sr⁹⁰ for general population = 100 $\mu\text{c}/\text{kg Ca}$.

The data in Table 3 suggest a present maximum Sr⁹⁰ level in bones from the midwestern United States of 4 $\mu\text{c}/\text{kg Ca}$ and 2.9 $\mu\text{c}/\text{kg Ca}$ for the general area between about 50°N and 10°S latitude. Bone samples collected at various points in the tropospheric band during the first half of 1956 show levels of about 1 $\mu\text{c}/\text{kg Ca}$ in children (3). Extrapolation from earlier results would give a slightly higher value for

December 1956. There are a number of reasons why the measured values might be expected to be lower than the predicted present maximum.

(a) It is quite unlikely that a steady state condition between strontium surface deposition and Sr^{90} in bones has been reached.

(b) The bone samples were from children of various ages and much of their calcium may have come from the soils long before the maximum surface levels given in Table 2 were laid down.

(c) It is possible that the calcium in the bone samples was drawn from soils having greater than 20 g available Ca/ft^2 to the depth of the plant feeding zone.

(d) It is possible also that the average discrimination ratio against strontium with respect to calcium in going from soil to bone is greater than a factor of 10.

A wide variety of milk samples collected from the Chicago (3) and New York (4) areas during 1956 showed an average level of about 3 μc Sr^{90}/kg Ca. Assuming Dr. Comar's discrimination factor $\frac{(\text{Sr}^{90}/\text{Ca})_b}{(\text{Sr}^{90}/\text{Ca})_m} = \frac{1}{2}$, in going from bone to milk, samples of newly formed bone derived from milk calcium from these areas might be expected to show a maximum of about 1.5 $\mu\text{c}/\text{kg}$ Ca. This value is not seriously out of line with the measured values extrapolated to December of 1956.

On the basis of New York milk-shed data, Eisenbud (4) estimated 8 $\mu\text{c}/\text{kg}$ skeletal Ca as the upper limit of the foreseeable Sr^{90} burden of the population in the New York area from bomb detonations that have

already occurred. Admittedly, his estimate was pessimistic since it ignored the possibility that much of the Sr^{90} in milk may be ingested by cows as fresh fallout on the surface of plants and also assumed no discrimination between calcium and strontium during the process of converting milk to human bone. Had he used a discrimination factor of $\frac{1}{2}$, his estimate would have given 4 $\mu\text{c}/\text{kg}$ bone Ca, which is in good agreement with Libby's value (2, 3) and the value shown in Table 3.

The most troublesome feature of the above considerations is that they are based on broad averages and make no allowance for individual variations due to local meteorological effects on fallout, soil properties, and dietary habits. Dr. Eisenbud (4) chose arbitrarily a factor of 3 as ample to define the upper limit of hazard that may be anticipated within the United States. Application of this factor to the predicted future maximum Sr^{90} levels given in Table 3 gives 15, 12 and 6 $\mu\text{c}/\text{kg}$ Ca as the maximum local limit for the upper midwestern United States, the area between about 50°N and 10°S latitude, and the rest of the world, respectively. The probability is high that these numbers are on the conservative side.

SIGNIFICANCE OF PRESENT AND PREDICTED Sr^{90} LEVELS IN THE POPULATION

The significance of present and predicted levels of Sr^{90} in bone can be evaluated only in relation to past human experience, which is indeed inadequate. Experience with a limited number of cases of radium

exposure has indicated conclusively that small amounts of radium fixed in the skeleton will produce osteoporosis, necrosis, and sarcoma (21). Bone changes in radium dial painters and persons who received radium therapeutically provide the basis for the value of 0.1 μc as the maximum permissible level of fixed radium in the skeleton. Bone sarcoma has resulted from a fixed skeletal burden of only 2 to 3 μc of pure Ra^{226} . Nondeleterious bone changes have been observed in persons having only 0.4 μc for a period of 25 years. Necrosis and tumors of the bone have occurred also several years after large doses of X ray (22).

The only other data with which present and predicted levels of Sr^{90} may be compared are natural background radiation levels. Natural background dose to the bone (during a 70-year life-time) may vary from ~ 6 to ~ 35 rads. The major contribution to background variation is differences in the radium levels of soils and minerals. The natural radiation level to bone, estimated by Spiers (23), is shown in Table 4.

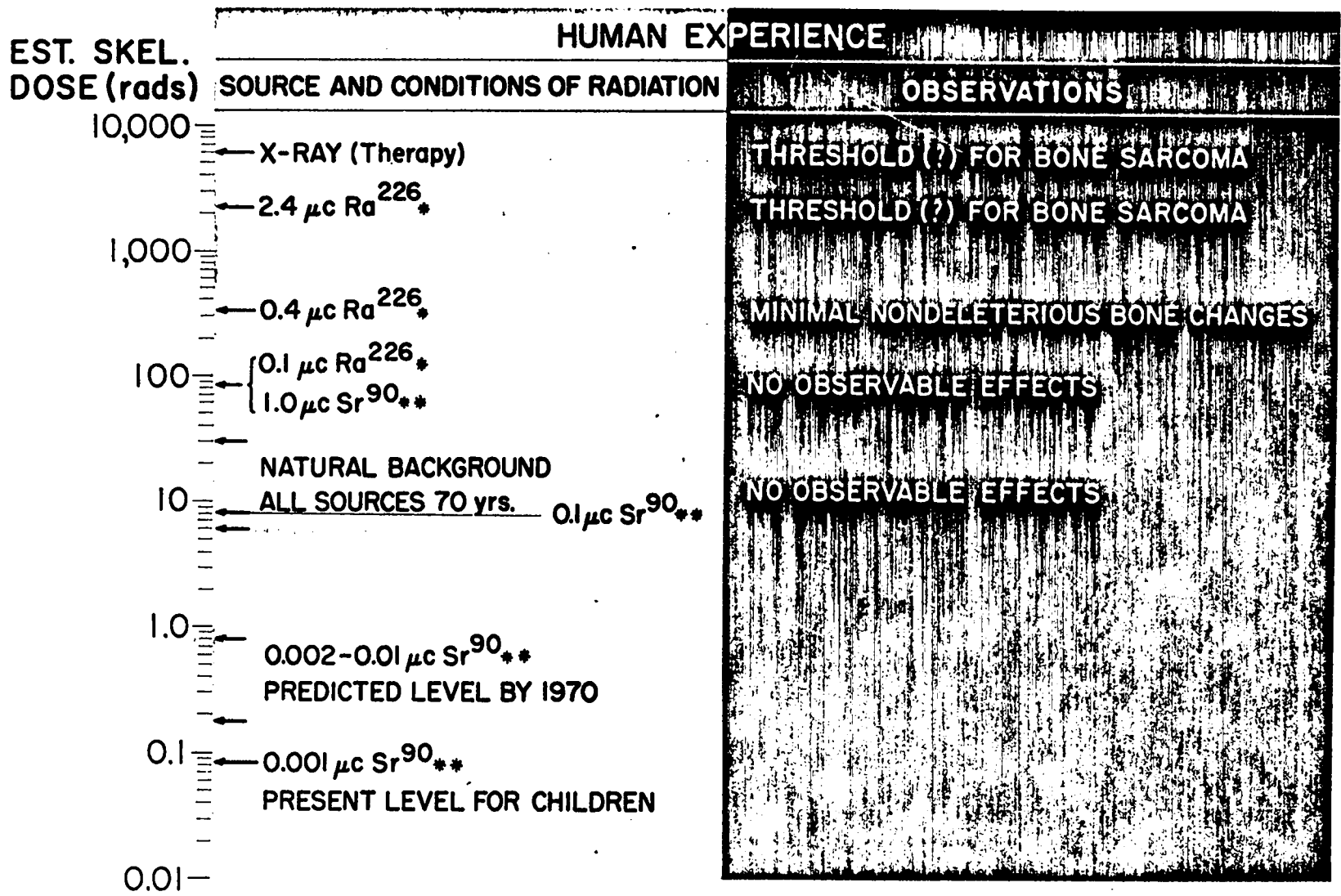
Table 4

NATURAL BACKGROUND RADIATION LEVEL TO BONE (SPIERS)

Conditions	Ra in Skeleton	Dose to Bone			
		External (rem/yr)	Ra (rem/yr)	Total (rem/yr)	Total (rem/70 yrs)
Average	10^{-10} g	0.08	0.037	0.12	8.4
Maximum natural radiation areas	10^{-9} g	0.18	0.37	0.55	38.5

Table 5 gives a general summary of estimated skeletal radiation doses from accepted maximum permissible levels and from present and predicted Sr⁹⁰ burdens in relation to human experience. The maximum permissible level of Sr⁹⁰ is estimated to deliver about 8 rads to the skeleton during a 70-year life-time. This is comparable to the average natural background dose to the bone for the same time period and a factor of ~4 below the maximum natural background dose to which segments of the general population may be exposed as a result of differences in altitude and natural radium content of soils and minerals. It is a factor of 40 below the lowest skeletal dose which has produced minimal nondeleterious bone changes. According to these data, the present measured levels of Sr⁹⁰ in children will result in a life-time radiation dose of approximately 1% of the accepted maximum permissible level for the general population. The predicted average levels of Sr⁹⁰ in about 1975 correspond to a maximum skeletal radiation dose, assuming no further weapons tests, of 2 to 5% of the maximum permissible level. Dependence of Sr⁹⁰ fallout and uptake on meteorological conditions, soil factors, etc., might result in local dose levels of from 1 to 15% of maximum.

Table 5. General Summary of Estimated Skeletal Radiation Doses in
Relation to Human Experience



* FIXED IN BONE ~25 YEARS

* * CONSTANT FOR 20 YEARS, DECAYING WITH 28 YEAR HALF-LIFE TO AGE 70

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