POPULATION EXPOSURE TO RADIATION: NATURAL AND MAN-MADE

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1. Radiation in the environment

Environmental radiation can be detected with great sensitivity. With modern instrumentation and calibration techniques the exposure level can be quantitatively measured to a precision of better than five per cent, even at the extremely low levels of natural background. By proper use of spectroscopic techniques, it is also practical to distinguish between particular natural and man-made sources [27].

Only during the past two decades has the radiation environment of mankind been surveyed extensively [1], [60], [61], primarily to monitor fallout from weapons tests. Considerable data were available more than 40 years ago, but those studies were directed toward an understanding of cosmic rays, rather than environmental exposures [36]. Summaries and bibliography can be found in the annexes of [11], [22].

Numerous studies have been made of the biological effects of radiation. The scope can be appreciated by examining the UNSCEAR reports (for example, see bibliography in [60] pp. 67–83, 108–117, and 183–206). Although laboratory experiments have been limited to plants and animals, several groups of humans, inadvertently exposed, have also been studied. With rare exception, the observations have been based on exposures which were extremely large and at high rates by comparison with environmental levels. No data exist which give dose response curves at such low doses. To be conservative, all standards setting bodies *assume* that the high level, high rate, dose response curves extrapolate linearly to zero dose, that is, that no threshold exists below which radiation is harmless. However, it must be emphasized that the nonthreshold, linear response is an *assumption* and not a scientific fact. A major objective of a statistical study would be to obtain better information on the shape of the low dose response curve.

Despite the sensitivity and precision for measurement of radiation, and despite the extensive knowledge of biological effects, the health hazards associated with environmental radiation are difficult, if not impossible, to evaluate.

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There are several reasons for these difficulties. At such low exposures radiation-induced "afflictions" are rare, and must somehow be discerned from among large populations. This is not straightforward since radiation-induced "afflictions" are not caused uniquely by radiation, but can also be induced by other agents in the environment. Furthermore, since radiation is present everywhere on earth it is impossible to observe a control population with zero exposure.

If we regard natural radiation as *noise*, and man-made radiation "pollution" as the *signal*, then, in normal circumstances, we are working with a very unfavorable signal to noise ratio. Only when the man-made exposure is massive does the signal to noise ratio favor detection of a cause-effect relationship. Incidentally, it should be noted that man-made radiation pollution differs from many other pollutants. Radiation has always been present in the environment and all living things have always been subject to exposure. On the other hand, pollutants such as DDT, Pb, and Hg have been previously either nonexistent or very rare in the biosphere.

2. Population dose distributions from natural radiation

2.1. *Sources of radiation.* Ever since man first walked the surface of the earth, he has been subject to varying amounts of exposure. Ever since he started collecting attractive rocks, selecting building material for dwellings, mining ores from the ground, he has unwittingly modified his exposure. There are two primary sources of natural radiation: cosmic rays and radioactive isotopes. Both fluctuate with time and geographical location. Typical doses from natural sources are shown in Table I.

TABLE I

TYPICAL WHOLE BODY DOSES TO STANDARD MAN FROM NATURAL SOURCES

Values listed for cosmic rays omit neutron component which lies in range of approximately 0.7 to 7 mrem at sea level.

Source	Dose (mrem/year)
Internal	
Potassium 40 in human body	20
Other radionuclides in body (carbon 14, radon 222, radium 222, 228 and so on)	3
External out of doors	
γ-rays from soil and rocks	50
Cosmic rays (sea level, 50° geomagnetic lat.)	28
Cosmic rays (Denver)	67

The "standard man" (the characteristics of "Standard Man" can be found in Appendix III, p. 408 and following, of H. Cember [9]) contains 140 grams of potassium in equilibrium which has a specific activity of approximately 32 disintegrations per second per gram due to the presence of the radioisotope

potassium 40 (0.0118 per cent isotopic abundance). The annual whole body dose from potassium contained in the body is about 20 mrem. Other natural radioactive materials in the body contribute three mrem/year. (The unit of radiation dosage used here is the millirem (mrem) which is 1/1000 of one rem. For most purposes one rem (roentgen equivalent man) is equal to one rad which is defined as the dose which deposits 100 ergs of energy in 1 gram of tissue. The dose in rems equals the dose in rads multiplied by the relative biological effectiveness (RBE); that is, rems = rads $\times$ RBE where the RBE for electrons is taken as unity. Other forms of radiations can have larger RBE depending on the details of their interaction with tissue.)

Rocks and soil contain varying amounts of natural radioactivity (potassium 40, members of the thorium 232, uranium 235 and uranium 238 decay series, products of cosmic ray interactions, and miscellaneous long lived natural radioisotopes). A typical annual dose from rocks and soil is 50 mrem. This is due mostly to the γ-ray components of the decays, since β- and α-particles are absorbed by relatively small thicknesses of material and have only short range in air.

Cosmic rays originate from outer space and the sun. The primary rays consist of extremely energetic charged particles, mostly protons and α-particles. As the primaries enter the atmosphere they interact with nuclei to produce a variety of secondary radiation consisting of muons, electrons, γ-rays, protons and neutrons. The intensity of the primaries and secondaries are attenuated as they pass downward through the atmosphere, the energy being gradually dissipated by particle production, nuclear reactions, and ionizing events. Thus the composition and intensity is a strong function of altitude. The magnetic field which surrounds the earth, deflects and traps some of the less energetic components producing a variation with geomagnetic latitude.

At sea level, in middle latitudes the dose due to the ionizing component is about 28 mrem/year. The neutron component contributes an additional 0.7 to 7 mrem/year, the uncertainty being associated in assessing the RBE of this component (see [61] pp. 14–18). As the altitude is increased there is less protection from the atmosphere, hence the dose increases, for example, at the elevation of Denver being more than double that of sea level.

2.2. *Geographical and temporal variations.* Except for the internal dose from the body burden of potassium, the natural radiation dose varies widely with location and time.

Many regions of the earth are rich in radioactive ores and in such regions the rocks and soil contribute higher than average external doses. In addition, the radioactive content of vegetation and animal life depend on the soil and water, consequently the human body burden depends on the source of foodstuffs and drinking water. For example, approximately 1,000,000 people in Illinois and Iowa consume drinking water containing unusually high content of lead 210 (RaD), polonium 210 (RaF), radium 226, and so forth [18], [51]. The bones of these people contain as much as four times the normal amounts of radium

and daughter products. Other areas in the United States having relatively high radioactive content in rock are regions of Vermont and New Hampshire [29], parts of Connecticut [35], Manhattan Island [28], areas in the Rocky Mountain states [47], and a section of North Carolina [27]. A few "hot spots" have even been located along coastal beaches [31]. Other inhabited areas of the world have even higher natural radiation levels, for example, the Black Forest of Germany, the states of Espirito Santo and Rio de Janeiro, Brazil and Kerala, India. (These anomalies are discussed in [1], [60], [61].)

Several radioisotopes are present in the atmosphere as gases or attached to dust particles. Among these are the isotopes produced by cosmic rays, and the noble gases radon and thoron which are formed as daughter products in the thorium and uranium decay series. Radon and thoron diffuse from the soil at rates which depend on such factors as snow cover, moisture content of the soil and vegetation cover. The radioactive content of a local volume of air varies with meteorological conditions, being enhanced during periods of inversion (particularly in valleys), and at a minimum after heavy rainfall.

Cosmic ray dose rates at sea level fluctuate with time by as much as ten per cent during the course of the solar cycle [33]. This variation increases at higher altitudes, becoming approximately 20 per cent at 20 km. As mentioned earlier, the cosmic ray dose increases with elevation. Near sea level the dose approximately doubles for each 1400 meters increase in elevation. Table II compares the cosmic ray dose for several locations in the U.S.

TABLE II

APPROXIMATE COSMIC RAY DOSES FOR SEVERAL AMERICAN CITIES
The doses listed were obtained from graphs in [43].

Location	Nominal elevation (feet)	Dose rate (mrem/year)	Difference from sea level (mrem/year)
Albuquerque	4958	60	32
Atlanta	1050	33	5
Baltimore	20	28	0
Chicago	579	31	3
Denver	5280	67	39
Kansas City	750	32	4
Oklahoma City	1207	34	6
Phoenix	1090	33	5
Salt Lake City	4260	54	26
San Francisco	65	28.5	0.5

A broad maximum in the dose rate occurs at 20–25 km altitude as a consequence of the various mechanisms for converting the primaries [43]. At flight altitudes for commercial jet aircraft the dose rate is in the range 0.3–0.7 mrem per hour. During a transcontinental round trip flight the average passenger receives an approximate five mrem dose.

2.3. *The effect of shelter.* The average American spends much of his time indoors where the walls and the roof of the building reduce exposure to external radiation. Often this reduction is partially offset or overwhelmed by exposure from the natural radioactivity in the structural materials. A typical wooden house will reduce exposure to about 70 per cent of the outdoor level [29]. Brick, concrete and stone buildings typically contribute exposures 50 to 100 mrem/year greater than outdoor values at the same site; however, much larger indoor exposures have been observed (see Table III), and might be more common than generally suspected.

TABLE III

GAMMA EXPOSURE RATES INSIDE VARIOUS BUILDINGS

Cosmic ray component included.

Location	Structure	Exposure rate Typical (mrem/year)	Exposure rate Extreme (mrem/year)	Ref.
East Germany		106	1200	[44]
New York City	brick	79–118		[54]
Grand Central Station	Millstone Point granite	25– 75	525	[34], [39], [50]
United States	wood	60		[42]
" "	concrete	130		[42]
Aberdeen, Scotland		81	110	[55]
Cornwall, U.K.	granite	145		[63]
Sweden	wood	48– 57		[19]
"	brick	99–112		[19]
"	concrete	158–202		[19]

Within a building exposure rates can vary dramatically, for example, in a multistory building the lower floors are better shielded against cosmic γ-rays. In rooms with poor ventilation radon and thoron content of the air can build up to very high levels. Finishing details of walls such as tiles can produce significant changes—increases or decreases.

At the present time, there is no systematic effort to select building material on the basis of low radioactivity.

2.4. *Population distribution of dose (natural sources).* As the average person moves about during the course of his activities, he is subject to a wide range of exposure from natural sources. The doses to average man are not monitored. Only a few studies have been made in which individuals were monitored over a relatively long period of time [29], [49], [52].

There are enough data to obtain a rough estimate of the population dose distribution. Figure 1 is a histogram constructed from the product of the population and the mean outdoor dose for various localities. (Most of the data for constructing the histogram were measured by the USAEC Health and Safety Laboratory (HASL). The author is indebted to H. L. Beck and J. E. McLaughlin

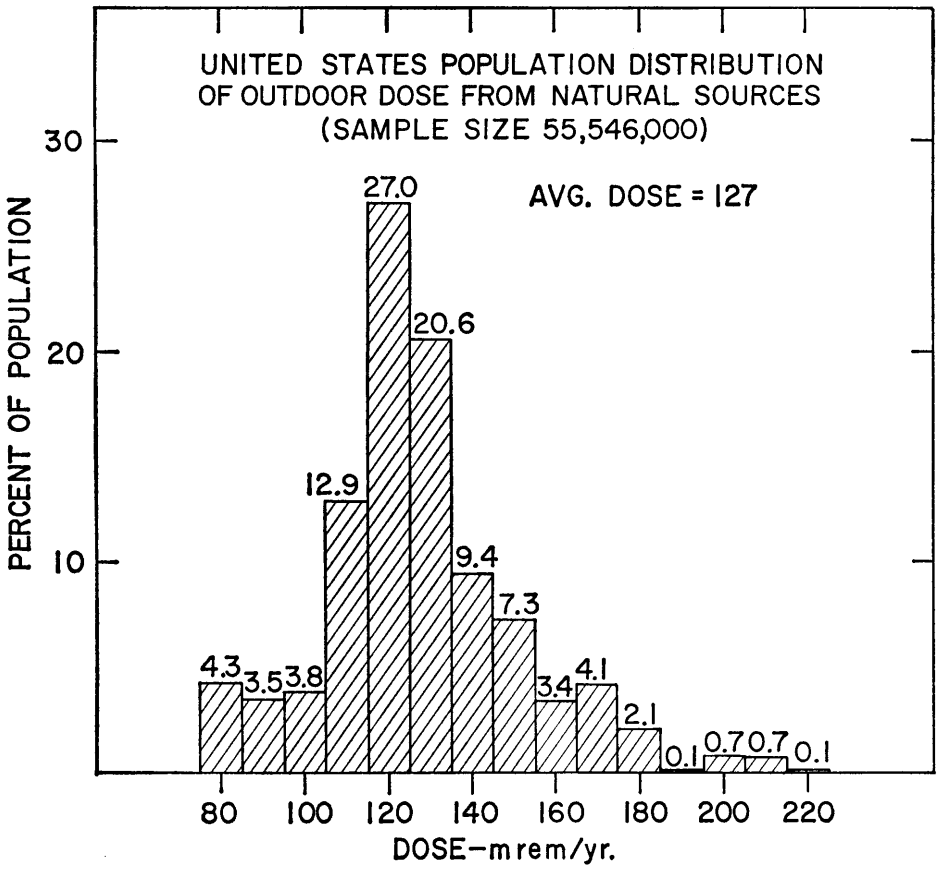

FIGURE 1

Population dose distribution. The histogram was prepared by multiplying the observed dose at each locality by the population of that same locality. The data include 23 mrem from natural radioactivity in the body. Effects of fallout from weapons testing are excluded.

for making such data available.) No corrections were made to account for time spent indoors. The measured exposure rates include natural radiation from the earth and cosmic rays, and internal radiation from potassium, and so forth, of "standard man," but discriminate against radiation from weapons fallout. The weighted average is 127 mrem/year, the full width at half maximum is about 15 mrem/year. The minimum exposure is of the order of 75 mrem/year for beach locations and exceeds 215 mrem/year in the Rocky Mountains.

Since Americans tend to be mobile, and have varying tastes in housing, an estimate of the annual dose to a given individual will have considerable uncertainty, but the value will probably lie inside the distribution curve shown

in Figure 1. Any statistical study which attempts to relate radiation dose with biological effect must recognize the "fuzziness" of the base line.

3. Exposures to man-made radiation

3.1. *Medical X-rays.* By far the largest population exposure to man-made radiation comes from medical X-rays. Techniques and condition of equipment show wide variation, consequently the doses received from a given procedure spread over a wide range. The dose delivered to a patient is usually not calculated, measured, nor recorded. In general, no systematic records are kept on the lifetime accumulated doses to individuals.

Because of the lack of systematic records, the task of compiling statistical data on population doses is very complex. Many laborious surveys have been made [2], [5], [6], [13], [17], [21], [45], [60], [64] which provide estimates of average population doses, as well as age and sex distributions for various procedures. I have not been able to locate data which can be used to construct dose distribution among individuals. A Public Health Service analysis [5] concluded that the genetically significant U.S. population dose for the year 1964 was 55 mrad per person per year. There is evidence that this has increased to approximately 95 mrad/person/year as of 1970 [62]. These doses should be about doubled to be comparable to the *whole body doses* cited in Tables I to III.

Compared with other advanced countries of the world, the average U.S. X-ray dose from diagnostic procedures is quite large as shown in Table IV which was compiled by Dr. Karl Z. Morgan of ORNL [38].

TABLE IV

GENETICALLY SIGNIFICANT DOSE (mrem/year) FROM MEDICAL DIAGNOSIS IN VARIOUS ADVANCED COUNTRIES

Table borrowed from [38].

United States	95
Japan	39
Sweden	38
Switzerland	22
United Kingdom	14
New Zealand	12
Norway	10

It is obvious that the history of medical X-ray exposures differs widely among individuals. Many persons in the United States live their entire life without any exposures while others receive massive doses. Since individual records are not generally maintained (indeed the ICRP and ICRU recommended against the maintenance of such records [21], we must regard this contribution of human exposure as additional "noise" which any statistical study of radiation pollution must duly take into account.

3.2. *Fallout from weapons testing.* For more than a decade the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has complied and evaluated data on world wide fallout of radioactivity from weapons testing [60], [61]. The latest evaluation of the population dose commitment up to the year 2000 from all tests to date gives a value of approximately 200 mrem or about five mrem/year [16].

Several cases of localized fallout have been recorded which have been subjected to intensive special studies [24]. I will not attempt to discuss this complex subject.

3.3. *Commercial nuclear power.* At the present time more than 20 large commercial nuclear power stations and one fuel reprocessing plant are in operation in the United States. These emit radioactive isotopes into the atmosphere and waterways. The operation of each of these installations has been subjected to close surveillance by a variety of agencies including the U.S. Public Health Service, the AEC Division of Compliance, state health departments and private contractors. Off site doses are generally too small to measure in comparison to natural background, and hence, must be calculated from known emission rates, meteorological conditions, population distributions, and so on. The surveillance studies include sampling of agricultural products, foliage, wild life, water supplies, waterways and marine biota to detect any possible buildup of activity in foodchains (for example, see [11] and [22]).

The calculated off site radiation doses have been extremely small, for example, at the Dresden I Nuclear Power Station, Illinois, during 1968 they were less than 14 mrem/year ([22], p. 53). In a later report, the same authors state: "The radiation exposure from discharged radionuclides was computed to be 1 per cent of the annual average concentration limit for air at the site boundary; and 0.1 per cent of the annual average concentration limit in Illinois River water at the point of discharge" [23]. Probably the largest off site doses which have been detected were at the Humboldt Bay Power Plant (Unit No. 3) near Eureka, California, where the maximum observed values were approximately 50 mrem in 1965 and approximately 35 mrem in 1966 [3].

The newer Boiling Water Reactors (BWR), descendants of the Humboldt Bay and Dresden I reactors, have improved facilities for handling radioactive wastes. In particular, provisions are made for longer delays in discharging gases which further reduces off site doses because a larger fraction of the radioisotopes decay before release. Emissions from Pressurized Water Reactors (PWR) and the only High Temperature Gas Cooled Reactor (HTGR) (Peach Bottom I) have been generally lower than BWR [32] since even longer delays in release of gases is practical. This is a consequence of the fact that the BWR must handle far greater quantities of gas because the pressure of the primary steam loop drops below atmospheric at the condenser encouraging air leakage into the condensate via pump seals, and so on. This air mixes with the radioactive gases and thus greatly increases the volume of gas to be processed. Systems are being

designed which will deal with this situation, introducing delays of several days by various absorber beds.

Recently the Atomic Energy Commission has proposed new regulations which will limit off site doses to five mrem per year [12]. This limit is the sum of the contributions of all light water reactors located at a given site if more than one is in operation. If these new rules are adopted, existing plants which fail to meet the new limits must be modified to comply within three years. In view of the actual operating record and the new rules, it appears reasonable to assume that nuclear power plants will be limited to off site doses which do not exceed five mrem/year. Let us consider what we can expect the *real* dose to the population to be. The five mrem/year limit applies to *any location* off site. Under normal meteorological and geographical circumstances the maximum off site dose occurs at some point on the site boundary, and is due primarily to noble gases of long half life. Beyond the site boundary, the dose will decrease as a result of dilution of the effluents. J. B. Knox has considered the dose distribution for a variety of situations [25]. It is possible, of course, to assess the geographical distribution of the off site dose in great detail by taking into account the observed meteorological conditions and recorded plant emissions.

In order to gain some understanding of the dose distribution let us consider an extremely simplified model, but retain the notation used by Knox. We shall assume that the population density is constant and that the dose $D(r, \theta)$ is a function of direction θ, and distance r from point of emission. If $D_0(\theta_{\max})$ is the limiting dose at the site boundary in the direction $\theta_{\max}$ which gives the maximum dose average over the year, then the boundary dose in every other direction will be $D_0(\theta) < D_0(\theta_{\max}) < 5$ mrem. Assuming that the wind direction is uniform in the area under consideration, we can write $D(r, \theta) = D_0(\theta)R(r)$, where $R(r)$ will depend on the amount of vertical diffusion. It is plausible that $R(r)$ will have a dependence between the extremes of (r_0/r) and $(r_0/r)^2$ where r_0 is the distance to the site boundary. The mean dose within any annulus of width Δr_i is given by

$$\bar{D}_i = \int_{r_i}^{r_i+\Delta r_i} D_0 R(r) p r dr \Big/ \int_{r_i}^{r_i+\Delta r_i} p r dr \tag{3.1}$$

where p is the population density. As a practical example take $r_0 = \frac{1}{4}$ mile. When the integrals are evaluated out to a 50 mile distance for the two extremes of $R(r)$, the histograms shown in Figures 2 and 3 are obtained. For $R \propto (r_0/r)$ the mean dose to the population within the 50 mile radius is 0.05 mrem/year (see Figure 2) with two-thirds of the people receiving less than 0.05 mrem/year and less than five per cent receive doses greater than 0.1 mrem. For the inverse square case (Figure 3), the mean dose is 1.3×10^{-3} mrem/year and three-quarters of the population receives less than 5×10^{-4} mrem/year.

Knox gives a more realistic function $R(r)$ which lies between the two extremes of Figures 2 and 3. The three cases are compared in Figure 4.

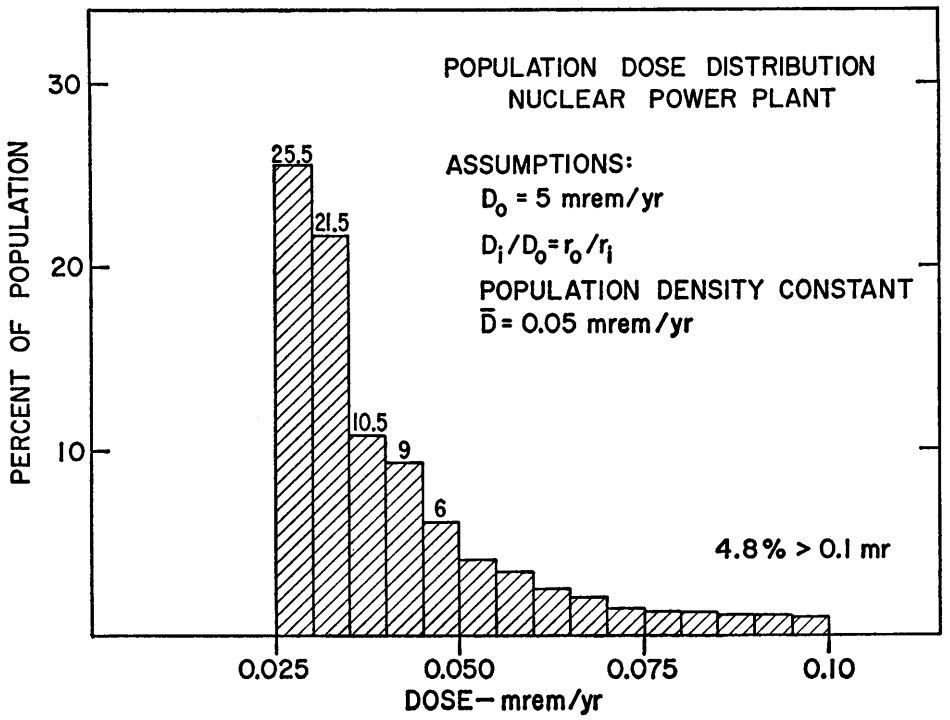

FIGURE 2

Population dose distribution in 50 mile radius about a Nuclear Power Plant. Model assumes a uniform population distribution and a 5 mrem/year maximum fence post dose. This plot assumes that the dose decreases as the inverse of the distance.

Knox considers the effect of multiple facilities surrounding a city such as might be expected in future years. For a case involving 16 plants equally spaced on a 50 *km* radius, his calculations give a maximum annual dose of approximately 0.27 mrem provided the 5 mrem fence post limit is observed [25].

It appears that commercial nuclear power, even taking into account a large anticipated growth, will not contribute a significant increment to the radiation environment of the population.

4. Special biological hazards

The biological effect of radiation depends on the nature of the radiation and location of the source (internal or external). The manifestations from radioisotopes incorporated in the body depend on the biochemistry of the element and on its chemical compound when ingested. Some elements concentrate in particular organs. An obvious example is the case of radioiodine which con-

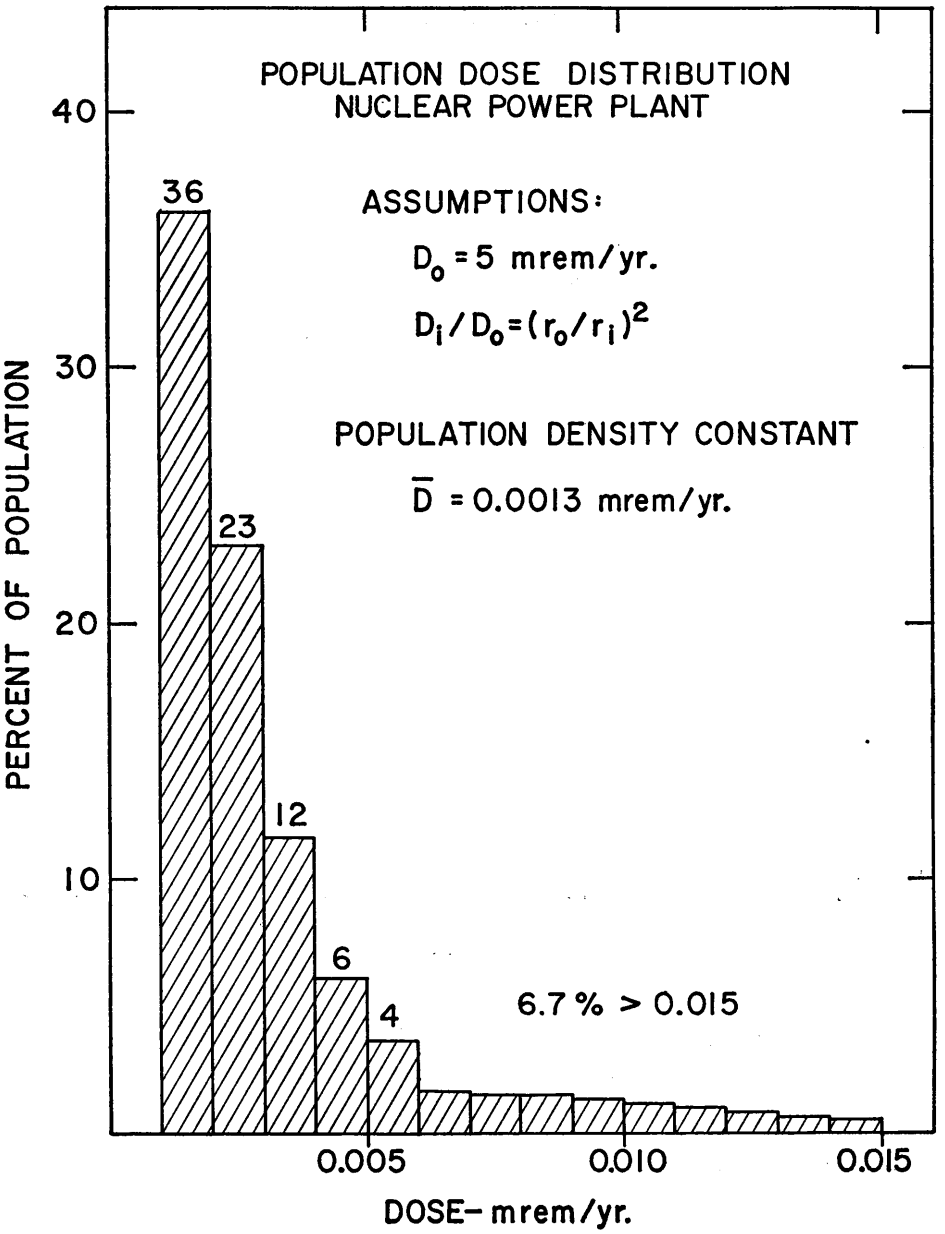

FIGURE 3

Population dose distribution in 50 mile radius about a Nuclear Power Plant. The same assumptions apply as for Figure 2, except this plot assumes that the dose decreases as the inverse square of the distance.

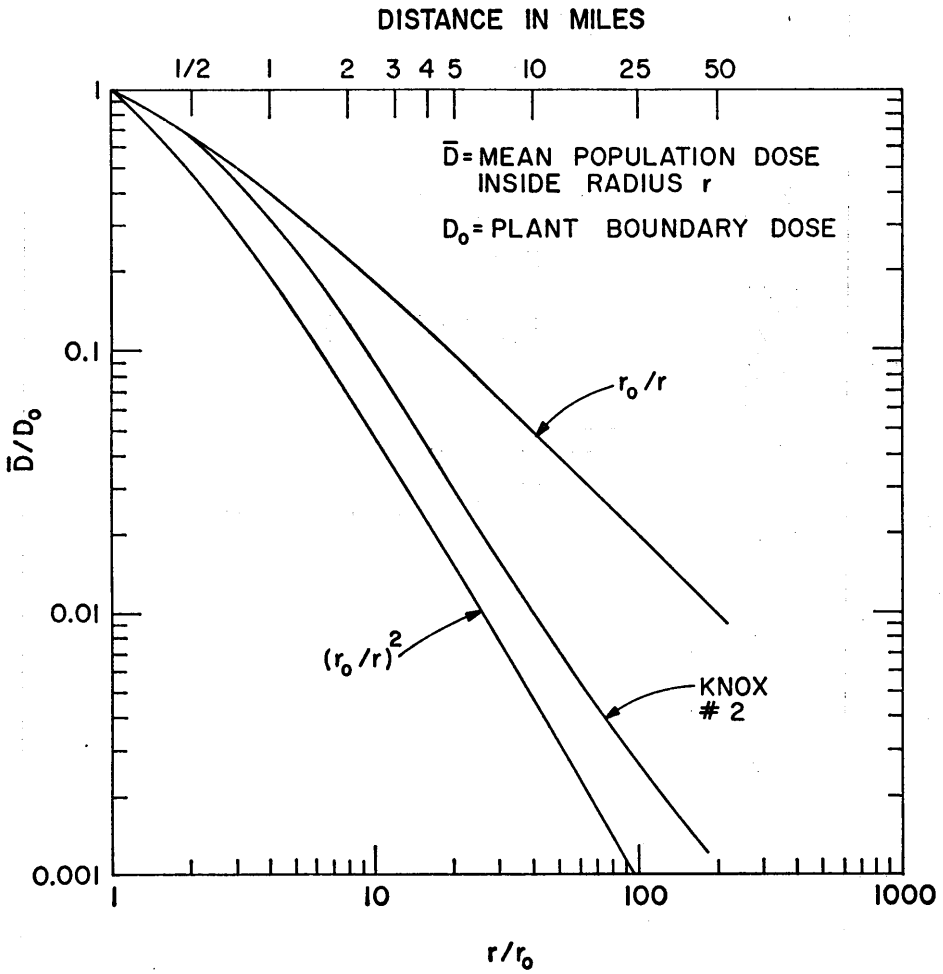

FIGURE 4

Mean doses to population inside circle of radius r from Nuclear Power Plant. The models used to construct Figures 2 and 3 are compared with the more realistic model of Knox [25].

centrates in the thyroid. The dose calculations take such factors into account (for example, see [9], pp. 204–208). In order to make realistic dose calculations, the effects of individual isotopes have been extensively studied and evaluated by ICRP and NCRP [41]. The process of evaluating the special hazards of individual isotopes is a continuing one and revisions to the "standards" are issued as necessary (for example, Subcommittee #24 of the National Council on Radiation Protection and Measurements is currently reappraising the hazards of radioactive nucleic acid precursors). After the maximum body burden

has been established, practical working limits are set by studying the pathways to man [7], [8], [10], [48].

In recent times popular articles on environmental topics frequently give the impression that our understanding of biological effects and pathways is very limited (for example, see [46]). Obviously, such complex evaluations cannot be perfect in every respect, and it is prudent to continue to improve our understanding. Cember expressed the situation quite eloquently ([9], p. 177), "Radiation ranks among the most thoroughly investigated etiologic agents associated with disease. Although much still remains to be learned about the interaction between ionizing radiation and living matter, more is known about the mechanism of radiation damage on molecular, cellular, and organ system levels than is known for most other environmental stressing agents. Indeed, it is precisely this vast accumulation of quantitative dose-response data that is available to the health physicist that enables him to specify environmental radiation levels for occupational exposure, thus permitting the continuing industrial, scientific, and medical exploitation of nuclear energy in safety."

Tritium is often cited as an example of an unusual hazard [20], [30], one that reactor operators are unaware of or ignoring [46]. Lyon implies that tritium undergoes concentration in biological chains [30] (this would require *isotopic* separation in the biological processes with an incredibly high separation factor). C. W. Huver has discussed "the abundant evidence illustrating the serious biological effects of tritium" [20] and advocates that routine release of tritium effluents be prohibited. These views are not shared by most authorities. Particularly it is important to distinguish between the hazards associated with tritium in various chemical compounds. The usual environmental effluent is in the form of tritiated water, which behaves quite differently in biological systems than for example would tritiated precursors of nucleic acids (bicarbonate, formate, glycine, hypoxanthine zanthine, orotic acid, and so on). V. P. Bond has recently reviewed the hazards associated with tritiated water effluents [4] and concludes that, "A given dose (for example, an MPD) of radiation from the beta rays of tritium (from either inhalation or ingestion) has the same radiobiological and radiation protection meaning as the given dose from X-rays or gamma rays (same dose rate pattern), and no added significance or potential hazard is to be attached by virtue of the fact that the dose may have been derived from tritium."

E. J. Sternglass has postulated a special toxicity associated with radiostrontium for which the existing ICRP-NCRP recommendations do not provide. According to the Sternglass hypothesis when the skeletal burden of Sr 90 decays the daughter product, yttrium 90, "concentrates in such vital glands as the pituitary, the liver, the pancreas and the male and female reproduction glands" [57]. This contributes to increased infant mortality and congenital defects, and "it also appears to act indirectly so as to produce small decreases in maturity, at birth that in turn can increase the chance of early death from various causes such as respiratory and infectious diseases" [58]. Sternglass elaborated

on this postulated sequence as follows: "But what happens apparently is now this: A young woman who drinks the milk over a period of years accumulates strontium 90 in her body, which is known. It is shown in the UN report that it builds up for a period of some years. It reaches a peak and then at the same time the yttrium which is created all the time by the decay of the strontium will now be circulating in her blood. Now the key element that seems to be happening is that the mother in effect is a source of yttrium herself because she has stored up strontium 90 which unfortunately stays bound in the bone for a long time. Now she is pregnant. What will happen is that in the early critical phases of organ development and maturation, the process of maturation of the embryo could be ever so slightly arrested or slowed down with the result that one has babies which are quite normal in every apparent respect but slightly underweight. And such underweight babies have a much greater chance of dying of all the normal causes like respiratory disease, hyaline membrane disease, all the types of infections that affect young babies" [58].

In support of this thesis, he cites the data of Muller [40], Spode [56], and Graul and Hundeshagen [15]. He also cites his own analysis which purports to show correlations of infant mortality with Sr 90 from fallout, and with the emission of short lived noble gas daughter products Sr 89 and Cs 138 from the Peach Bottom Reactor in Pennsylvania.

The Sternglass hypothesis has some flaws. The experiments of Muller, which showed slower decrease of Y 90 in the testes than expected through normal secretion, were done by intraperitoneally injections of Sr 90 and hence the body distribution of Sr 90 and its daughter product Y 90 were not the usual equilibrium distribution that would occur from ingestion through ordinary pathways. Similar comments apply to the other two references cited. More recent work by Mole and Ward [37] showed no concentration of Y 90 in monkey gonads. M. Goldman has strongly refuted the Sternglass hypothesis citing a variety of data including very detailed results of his own group obtained from many years of research with beagle hounds [14]. He emphasizes that Sr 90 is tightly bound in the bone structure, and upon decay the newly formed Y 90 remains trapped in the bones until it has decayed.

The alleged Sr 90 infant mortality correlations have been examined by many investigators and rejected as spurious. A detailed discussion appears in a Public Health Service report by Tompkins and Brown [59]. Shaw and Smith [53] using Sternglass' methodology obtained a negative regression coefficient for Canada which had larger Sr 90 fallout than the U.S. The "Peach Bottom" situation cited by Sternglass is erroneous because the gaseous waste system does not emit the short lived Kr 89 and Xe 138 precursors of Sr 89 and Cs 138 due to the extremely long holdup of the gases before release. Apparently Sternglass misinterpreted the data on pages 57–61 of the Public Health Service report which he cites [26]. The short lived activities cited refer to the main coolant loop and not to the gaseous release.

For these reasons it appears unlikely that Sternglass has identified a hazard from radiostrontium that has gone unrecognized by ICRP or NCRP.

5. Conclusions

Statistical studies which might be capable of demonstrating relationships between health effects and low level radiation pollutants in the environment will be difficult to design, because:

(1) the "pollutants" are small by comparison with natural background radiation and with variations in natural backgrounds;

(2) the radiation burden of medical X-rays are about as large as natural background and thus large compared with the "pollutants," and medical X-ray exposures for which no precise records are kept vary widely among individuals; and,

(3) the biological manifestations of radiation are not uniquely induced by radiation.

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Discussion

Question: J. Neyman, Statistical Laboratory, University of California, Berkeley

Is the radiation from effluents of a nuclear power facility qualitatively similar to or different from what might be called "natural" radiation, that is, approximately the same proportion of α-, β-, γ-radiation, and so forth?

Reply: V. L. Sailor

They are qualitatively similar, although it is necessary, of course, to take into account each individual source of radiation in calculating the dose. The calculation must account for the location of the source (whether internal or external), the energy and type of the radiation, and the duration of the exposure (the half-life for decay, and the residence time in the body). Very voluminous work has been done on dosimetry calculations, and this has been discussed in several of my references (for example, see [7], [8], [9], [10], [41], [60], and [61]). When two different doses have been reduced to units of *rems* they should be directly comparable, within the limits of perfection of the procedure. Note that doses are calculated for *whole body* as well as for *specific organs* of the body.

The detailed procedures for dose calculations were outlined in a publication which is not included in my references (International Commission on Radiological Protection, *Radiation Protection*, ICRP Publication No. 2, New York, Pergamon Press, 1960). Although some of the numbers and recommendations contained in this report have been revised in recent years, the basic procedures are still considered valid, and it gives a good discussion of the calculations.

Question: E. J. Sternglass, School of Medicine, University of Pittsburgh

It is misleading to compare external sources of gamma and X-ray radiation with the internal beta emitters that are inhaled or ingested in the case of nuclear fallout and radioactive isotopes emitted by nuclear facilities for the following reasons.

(1) A given amount of radioactive material on the ground giving rise to gamma rays is far less hazardous or toxic than an equal amount of beta emitters inhaled or ingested, since all the energy from the beta emitters is deposited in a very thin layer of tissue, giving it a much higher amount of damage per unit volume than a gamma emitter. The existing permissible levels of concentration for beta emitters recommended by the International Commission for Radiation Protection recognize differences in toxicity for beta emitters and gamma emitters by many thousands of times.

(2) Unlike all sources of external gamma or X-ray radiation such as cosmic rays or medical X-rays, internal emitters concentrate chemically in certain critical organs of the body. This is especially serious in the case of the early fetus and infant, where the most critical glandular organs are much smaller than in the adult. Measurements have shown that, for instance, iodine 131 gives a dose to a three months fetal thyroid gland some ten times larger than for the full term fetus or young infant, which in turn is known to receive a dose ten times greater than the adult. As a result, the fetal dose for a given amount of iodine intake is typically 100 times greater than for the adult thyroid, which in turn concentrates iodine 100 times more than ordinary muscle tissue!

(3) Medical X-rays are very rarely given to a developing early embryo or fetus during its most critical stage of organ development, while fallout radiation is present throughout the most critical phases of embryonic and fetal life.

Reply: V. L. Sailor

I disagree that there is any misrepresentation. The dose calculations do, in fact, take account of the concentration factor and the beta component, mentioned by Dr. Sternglass. They also set special limits on exposure to particular population groups such as infants, pregnant females, and so forth. One might want to argue about some of the specific details or numbers, since such complex calculations can never be perfect, and this is recognized by ICRP and NCRP who continually strive for more perfect methods. However, allowing for such imperfections, the final doses expressed in units of the rem are directly comparable whether the source was an X-ray machine, a cosmic ray muon, or an ingested radioactive fission product.

Question: A. B. Makhijani, Electrical Engineering and Computer Sciences, University of California, Berkeley

The dose rates from fuel processing and reprocessing plants for nuclear reactors were not discussed, even though the major releases of radioactivity to the environment from nuclear power plant operation occur at these points—and consequently the major radiation exposures will be due to these sources. The radiation released at these points have substantial amounts of high LET components, the carcinogenic effects of which are known to be more severe than those of gamma and beta radiation.

Reply: V. L. Sailor

This is a point of considerable public interest at the present time. Plants for reprocessing nuclear fuel must handle the great bulk of the fission products produced in reactors. These plants are required to meet the same off site dose limitations as any other nuclear facility. So far our experience with such plants is limited because only one commercial reprocessing plant is in operation and that only for a few years. Surveys have shown that the off site effluents from this plant have been only a few per cent of the applicable standards. (For example, see B. Shleien, *An Estimate of Radiation Doses Received by Individuals Living in the Vicinity of a Nuclear Fuel Reprocessing Plant*, U.S. Dept. of Health, Education and Welfare, Report No. BRH/NERHL 70–1, May 1970.)

I assume that when you mention "high LET components" you refer to alpha emitters, particularly transuranic isotopes (Pu, Am, and so forth). I have seen no data which indicate that such isotopes are detectable in the off site effluent.

Question: H. L. Rosenthal, School of Dentistry, Washington University

I think it is necessary to comment about equating the dosage for the medical use of radiation with the permissible dosage in the general population. These two usages are entirely different and must be kept separate. The doses of X-radiation or isotope therapy and diagnosis are prefaced on an entirely different basis for risk benefit. I hope Dr. Sailor is not recommending that doses used for medical purposes are also satisfactory for the general population. These two systems should also be kept separate for statistical and epidemiological purposes.

Reply: V. L. Sailor

I hope that my paper does not give the impression that I *recommend* any dose. Its purpose was to report as accurately as possible what exposures people receive, how these exposures vary and from whence they come. The facts show that medical X-rays are unquestionably the largest man-made radiation burden by a big margin.

Question: Alfred C. Hexter, California Department of Public Health

You and some of the previous speakers have indicated some of the average population exposures. But these are only means. Do not some exposures follow, approximately, a log-normal distribution? If so, this would indicate that a

significant portion of the population is receiving substantially greater exposures than these average figures indicate.

Reply: V. L. Sailor

To the best of my knowledge, dose distribution curves have not been constructed with any great precision, but your suggested distribution seems plausible. There is no question that many individuals within the population receive five or ten times the mean dose.

Question: Emanuel Hoffer, California Department of Public Health

You avoided discussing "biological concentration mechanisms." An illustration of this is the "low level waste radiation dumping" in the Columbia River in Washington. This low level radiation went through a number of hosts: plant, fish, bird, and animal, concentrating the initial low level dose 500–1000 times. Man at the end of this food chain could eat the animal. In addition, there is the illustration of clams in the San Francisco Bay concentrating radioactive cobalt from bomb tests.

Reply: V. L. Sailor

In principle, biological concentration of radioisotopes in food chains can enhance the dose individuals receive. We need to exercise care that such situations are not allowed to happen. Some of the measures which have been taken to monitor various facilities are described in [10], [11], [22], and [48]. At the present time, it appears that the contribution of such effects to population exposure is completely negligible.