COMPARISON OF RADIATION EXPOSURE OF THE POPULATION FROM MEDICAL DIAGNOSIS AND THE NUCLEAR ENERGY INDUSTRY**

by

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MASTER
NOTICE

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Linear Vs. Threshold Hypothesis

All chronic forms of radiation damage with the possible exception of radiation-induced cataracts appear to increase more or less linearly with the accumulated dose of ionizing radiation. Even in the case of cataracts, the International Commission on Radiological Protection (ICRP)⁽¹⁾ points out, "Possibly no one has sought to see if senile cataract in man is augmented or accelerated by exposure to radiation, and a synergistic interaction of radiation and age must remain a possibility until the investigation is made." Although there is known to be some repair of both genetic and somatic forms of radiation damage (at least in the case of α , γ and β radiation), there appears to be some component of damage which is irreparable and accumulates throughout the life of the individual in proportion to the integrated dose. When radiation passes through a cell of the body, three things are possible: (1) it passes through without any energy loss; (2) sufficient energy is lost to cause the death of a cell or at least to prevent it from further cell division, and (3) the cell is damaged in such a way that it survives and may become the precursor of a malignancy or some other form of chronic damage or may be repaired. We have no concern about the death of a few thousand cells because they are readily replaced. Each somatic cell of our body contains a nucleus which normally has 46 chromosomes, and each of these might be thought to represent an immense library of information, giving instructions to the cell regarding not only all the actions it must take in the future but actions of many successive generations of daughter cells. When ionizing radiation has passed through this nucleus or library of information of a surviving cell, more commonly the damage is so slight that it is repaired or the body is able to tolerate the aberration. It is only

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in the exceptional case that serious damage or disorder is introduced into this library of information in the nucleus of the cell such that it is still able to survive and reproduce but without adequate instructions for future cell division. Thus, we believe radiation tends to increase the entropy of the system, and on this type of reasoning it is difficult to imagine how all radiation damage could be completely reparable. Having examined the vast amount of experimental evidence of the effects of radiation on many forms of living organisms, including man, the International Commission on Radiological Protection and the National Council on Radiation Protection have concluded that the only prudent assumption is that there is a linear relationship between dose and effect, and all exposure to ionizing radiation even at the level of maximum permissible exposure involves some risk. In other words, no dose of ionizing radiation can be so low that the probability of damage--even serious damage such as leukemia--is zero. However, the ICRP⁽²⁾ states that in its best judgment the probability of severe somatic or genetic injuries at recommended permissible exposure levels is negligible, and any effects which ensue more frequently are limited to those of a *minor nature that would not be considered unacceptable by the exposed individual and by competent medical authorities*, and any severe somatic injuries resulting from exposure to individuals at the permissible exposure levels would be limited to an exceedingly small fraction of the exposed group, and effects such as shortening of life-span which might be expected to occur more frequently would be very slight and would be hidden by normal biological variations. Fig. 1 gives the coefficients suggested by ICRP⁽¹⁻³⁾ for chronic forms of damage to man which are assumed to relate linearly to the dose, and, in addition, I have plotted curves for radiation sickness and acute radiation death. These latter two curves become asymptotic to the ordinate at about 20 and 200 rem, respectively. The mid-lethal dose (50% lethality) is thought to occur in man at about 400 rem, and at high doses all the curves reach saturation. The curves for radiation sickness and radiation death apply only to the case where large doses are delivered over a short period of time, whereas the other curves apply to relatively low doses and dose rates. Because of very limited information relative to the effects of ionizing radiation on man, the values of coefficients given in Fig. 1 must be considered only as first approximations. Table 1 summarizes some of the types

FIG. 1

Linear Relations Between Dose and Effect for Chronic Forms of Radiation Damage to Man and the Commonly Assumed Threshold Relationships to Dose in the Cases of Radiation Sickness and Radiation Death.

TABLE I

**TYPES OF DAMAGE RELATING MORE OR LESS
LINEARLY TO THE ACCUMULATED DOSE**

1. Genetic Mutations (1st generation and recessive)
2. Cancer (including leukemia)
3. Life shortening
4. Other Biological Changes
  - (a) Chromosomal aberrations
  - (b) Changes in blood and urine chemistry
  - (c) Areas of increased and decreased bone density
  - (d) Polynucleated cells

TYPES OF DAMAGE REQUIRING A THRESHOLD DOSE

1. Eye Cataracts
2. Radiation Sickness
3. Skin Erythema

of damage which vary more or less linearly with the dose and types of damage which are thought to require a threshold before they make their appearance in man. Early studies of Muller⁽⁴⁾ of *Drosophila* (flies) seem to suggest complete linearity between dose and genetic damage and no dose-rate dependence. The more recent, very fine studies of Russell⁽⁵⁾ (a speaker at this symposium) have shown, however, there is at least a slight kink in the curve (by a factor of 1/6) at very low dose rates. In Fig. 2, I have made a rough plot of some of Russell's data showing that at high dose rates there is no dose-rate dependence, but when the dose rates drop to about 5,000 R/hr, there is a precipitous decrease in the mutation frequency, both for exposure to the oocytes and spermatogonia of the mouse. In case of the oocytes, the curve drops rapidly into the background region where in effect there may be complete repair. In the case of the spermatogonia, however, he found a decrease by a factor of three or four, and the curve leveled out again on another plateau with no evidence of further decrease with reduced dose rate. Thus, since there are the two sexes and a reduction by a factor of three for the male, we use in our estimates of risk a reduction by a factor of 1/6 in the risk estimate from radiation exposure at very low dose rates. However, I do not believe we are justified in assuming any further deviation from linearity other than a slight reduction perhaps by a factor of two because of a low dose-effect. In other words, we might be justified in an over-all reduction in an estimate of the risk by a factor of 1/10 for very low doses and dose rates for the mouse and possibly in the case of man. However, I do not see any possibility of a complete reversal of the law of entropy and the complete repair of all radiation damage to a surviving somatic cell or germ cell at very low levels of exposure. Oddly enough, some persons seem to feel that lack of a "safe" exposure level is an exception to the general rule or a unique situation, and there must certainly be a threshold or safe level of exposure to radiation below which there is no risk. For example, we are accustomed to thinking it is completely safe to take one aspirin per day and that such a dose is below a threshold at which there is any risk whatsoever. I submit, however, that almost all, if not all, insults to which man is subjected probably present some risk even at very low levels of exposure. For example, as we go about our daily tasks, there is some risk of being struck by lightning. For the past number of years, there have been official reports⁽⁶⁾

Rate Dependence of Point Mutations in Mice. (Data from W. R. Russell, *Nucleonics*, 1965)

Figure 2

indicating an average of about 100 deaths/yr in the United States from lightning, so the risk would be about 5×10^{-7} that a person would be struck by lightning in a given year. This figure then can be compared, for example, to the risk of cancer shown in Fig. 1 of 10^{-4} cancers per year if a person were exposed to 1 rem/yr or 0.01% of persons exposed to 1 rem would be expected to develop cancer as a consequence of this exposure.

I am inclined to believe that sometimes the public is misled by the manner in which we present our data. For example, in Figs. 3 and 4, we have given plots indicating the risk of bone sarcomas and carcinomas from various levels of accumulated dose from body burdens of radium. In this case, Rowland et al⁽⁷⁾ have presented their data properly so as not to be misleading. In Fig. 3, they plotted their data on a semi-log graph. Seeing only this, the non-scientific observer might conclude that there is a threshold at about 80 rad for carcinomas and 800 rad for sarcomas for these forms of radium-induced cancer. However, another observer when looking in the same report at the same data which Rowland plotted also in Fig. 4 might conclude at low doses there is a linear relationship and no dose so low that the risk of cancer is zero. I believe a typical example of a case in which the non-scientists were misled occurred following testimony of a number of scientists at the 1967 Congressional hearings regarding deaths which have occurred from lung carcinoma among uranium miners who worked in the Colorado Plateau. At these hearings⁽⁸⁾ in 1967, Dr. Gehring, Acting Surgeon General of the Public Health Service, made an estimate of the risk of lung carcinoma that might be expected among 10,000 exposed underground uranium miners based on the linear hypothesis. Representative Holifield replied, "I think your assumptions relating to the straight-line theory and the threshold theory are subject to the most vigorous opposition . . . I consider (them) to be non-scientific on the basis not that I am a scientist but on the basis of the weight of evidence that has been before this committee for a long time." To the contrary, I believe Gehring would have the support of most of the scientific community in applying the linear hypothesis to his data. Since that time, a more recent report⁽⁹⁾ on cancer among these miners lends stronger support to the linear hypothesis even down to the 120 WLM level of exposure of these miners. I

FIG. 4

believe we must be very careful in presenting our data in order not to mislead the public. I do not believe at the present time we have--or in the foreseeable future we will have--sufficient information to prove whether the linear hypothesis or the threshold hypothesis applies at very low doses and dose rates because as the dose approaches zero the number of animals required to obtain a point on the curve showing a given effect approaches infinity for reasonably low probable errors. I do not believe the question can ever be answered by animal studies, much less from observations on man. In the long run, I believe our answer must be derived from the development of a coherent theory which explains all mechanisms of radiation damage. Since this takes us beyond the foreseeable future, I would like the present to be in conformance with the law of entropy and assume that when a very large disruptive force has been applied to the nucleus of a surviving cell, the end result is most likely a disorganization of the intricate structure and some residual damage.

There are many experiments which seem to lend strong support to the linear hypothesis and to the conclusion that as the dose is increased not only does the probability of serious damage increase, but there is a gradual progression of events pointing to the imminence of impending crises as indicated under item 4 of Table 1. In Table 2, I have simply drawn a wide band diagonally across the table of data prepared by Finkel et al.⁽¹⁰⁾ You will note this includes the summation of most of the numbers in the table suggesting a gradual progression as one increases the body burden of radium from no effects, to minimal, to mild, to moderate, to advanced, and finally to malignancies. You will note, also, the progression toward serious symptoms seems already to have begun even in the range of a permissible body burden of 0.1 μCi of radium-226. In terms of dose rate, the body burden of 0.1 μCi of radium-226 as applied to the occupational worker corresponds approximately to 30 rem/yr when averaged over the entire skeleton and about 15 mrem/yr to the endosteal tissue of the bone. Endosteal tissue is currently considered by ICRP⁽¹¹⁾ to be most critical in terms of radiation-induced bone tumors. The 0.1 μCi of radium-226 is one of the two principal hallmarks or reference standards to which all levels of maximum permissible exposure are referred or from which they are derived. This level of 0.1 μCi of radium-226 was set by the U. S. Advisory Committee on the

Table 2

LONG-TERM EFFECTS OF RADIUM IN MAN

Ra Body Burden (μc)	Average Bone Dose (rem/yr)	Biological Changes (%)					
		None	Minimal	Mild	Moderate	Advanced	Malignant*
0.001-0.03	0.3-9	92	8	0	0	0	0
0.03-0.1	9-30	83	13	0	4	0	0
0.1-0.3	30-90	69	16	3	6	6	3
0.3-1.0	90-300	12	25	25	16	22	16
1.0-3.2		6	6	14	12	62	32
3.2-5.5		0	0	0	9	91	55

*Those with malignancies were listed also under previous columns.

(Data from Finkel, Miller and Hasterlik, ICRP No. 11, 1968)

Safe Handling of Radioactive Luminous Compounds in 1941.⁽¹²⁾ The other reference standard was the early exposure of radiologists who were thought to have averaged in the neighborhood of 15 rem/yr of exposure. Seltser and Sartwell⁽¹³⁾ indicated that radiologists in the period 1935 to 1958 in the age group of 50-64 had seven times the leukemic incidence of members of the medical profession who were not exposed to x-rays and that their average life was shortened approximately five years. If one applies the coefficients of ICRP as plotted in Fig. 1 to these data, it can be shown⁽¹⁴⁾ that this average exposure in terms of leukemic risk or of life shortening was on the order of 15 to 30 rem/yr. Perhaps it is a coincidence that we arrive at these same numbers both in relation to leukemia risk and life shortening of radiologists, but I believe it does provide some evidence that the effective dose to the active bone marrow and other, more important body tissues of early radiologists was not as large as some persons have thought and probably averaged no more than 30 rem/yr, our present dose limit to the bone of the occupational worker.

Although some representatives⁽¹⁵⁾ of the American College of Radiology, the American Medical Association and the American Dental Association seem to go to great pains to indicate that medical exposure to patients is harmless and of no consequence, I believe the record speaks for itself and to the contrary. For example, we recall the follow-up study of Albert⁽¹⁶⁾ of patients treated by x-rays for tinea capitis (or ringworm). In this case, among the 4,000 member study group there were nine times as many malignancies and four times as many mental disorders among the children whose tinea capitis was treated with x-rays as among those for whom other treatments were used. Although the dose to the brain in this case was fairly large, probably about 100 rad, the average dose to other tissue such as the active bone marrow where many of the malignancies originated was very small. Sigler and other investigators⁽¹⁷⁾ at Johns Hopkins University carried out a study involving 216 families, each with a Mongoloid child, living in the city of Baltimore. Their investigations revealed that mothers of Mongoloid children had received seven times as much x-ray exposure as the group of control mothers. Studies of Court-Brown and Doll⁽¹⁸⁾ of a large number of persons suffering with ankylosing spondylitis whose spines were treated with x-rays have indicated a coefficient of about 2×10^{-5}

leukemias per rad delivered to the active bone marrow (approximately the figure given in Fig. 1). A study of Doll and Smith⁽¹⁹⁾ of 2,000 women whose ovaries were irradiated for artificial menopause indicated that mortality from leukemia as a result of irradiating these small volumes of tissue was six times higher than would otherwise be expected five or more years after treatment. They concluded, "The results are therefore consistent with the hypothesis that the risk of leukemia induction is proportional to the total energy absorbed in the marrow." The work of Hempelmann⁽²⁰⁾ (a speaker at this symposium) is particularly impressive in that it lends strong support to a linear relationship between dose and effect down to relatively low doses. He states, "The incidence of thyroid and extra-thyroid tumors in the Rochester series is dose dependent, and the frequency of thyroid neoplasms is age dependent until age 18. Some evidence is presented suggesting that (1) the dose response to thyroid tumors is linear in the lower dose range, and (2) there is no threshold or at least the threshold is below 20 rad." Present evidence seems to show that the most sensitive members of the population are probably the fertilized ovum and the fetus. The curve of radiosensitivity as a function of age is probably an inverse parabola because there is some evidence of an increasing radiosensitivity also with advancing age. For example, Lewis⁽²¹⁾ after examining data published by Saenger et al⁽²²⁾ points out that in the case of medical exposure to iodine-131 delivering rather low doses of 7 to 15 rad to bone marrow, there is a significant increase in leukemia among the persons in this study between ages 50 and 79. Regarding exposure to younger members of the population and, in particular, in utero children, some of us believe this to be a very serious matter. For example, Hammer-Jacobsen⁽²³⁾ points out that relatively firm measures are taken in Denmark which suggest the need for therapeutic abortion in cases where the fetal doses are estimated to have exceeded 10 rem. Because of concern for what we believed to be excessive fetal exposure, Muller and I, beginning about 1959, worked very hard toward obtaining an ICRP recommendation which would discourage unnecessary medical diagnostic exposure to unborn children. As two of the 13 members of ICRP, we were rather proud when in 1964 ICRP⁽²⁴⁾ came out with the recommendation that diagnostic exposure of women in the childbearing age to ionizing radiation be limited to the 10-day interval following the onset of menstruation except in those cases where

the immediate x-ray was needed because of illness of the woman. Muller and I were disappointed, however, when some months later we read in the Bulletin of the American College of Radiology,⁽²⁵⁾ "ACR differs with international body . . . The College agrees with the minority opinion taken in the ICRP that the problem is neither so simple nor so serious as the Commission statement might indicate. College members Robert S. Stone of San Francisco and L. S. Taylor of the National Bureau of Standards, Washington, D. C., sit on the ICRP and among those taking the minority position . . . ." In spite of such opposition to this recommendation, I believe it has been one of the more important developments toward reducing unnecessary risks throughout the world from diagnostic x-ray exposure. We were pleased that the American College of Obstetricians and Gynecologists⁽²⁶⁾ recognized the risk of in utero exposure when it stated, "The risk of radiation injury is real . . . and physicians should avoid the use of routine pelvimetry and routine radiologic examination of the abdomen throughout the prenatal era."

There have been many studies on the effects of pelvimetries, the vast majority of which have indicated an increased incidence of malignancy among children who received in utero exposure. One of the more careful survey studies was carried out by MacMahon⁽²⁷⁾ in which he reported that after Alice Stewart's original observations in 1953, some 12 studies of the question of the relationship between pelvimetry and other x-ray exposure in utero and cancer in children have been published. He pointed out that although there were positive and negative findings, a combination of the data from all of them weighed according to the number of cases studied, indicated that the mortality from leukemia and other forms of cancer is about 40% higher among children exposed to diagnostic x-ray study in utero than among children not so exposed. He indicated that over the first 10 years of life of the child the risk amounts to about one cancer death per 2,000 children so x-rayed. This may seem a small number, but if all women received pelvimetries during pregnancy in 1970, this would amount to about 2,000 deaths per year in the United States. Again, this is a small number but not so small if one's child happened to be one member of this statistic. The studies of Alice Stewart⁽²⁸⁾ (a speaker at this symposium) of the effects of diagnostic x-ray exposure on children are particularly impressive. Fig. 5 is a plot of some of her data

NUMBER OF DIAGNOSTIC X-RAY FILMS DURING PREGNANCY
(Data from Alice Stewart and G.W. Kneale, *Lancet*, June 1970)

Figure 5

which lend strong support to the suggestion of a linear relationship between dose and effect at least down to 1 rem and perhaps as low as 0.25 rem. Of recent date, some members of the medical profession have delighted in pointing out that Alice Stewart's data are not consistent⁽²⁹⁾ with that reported by Jablon⁽³⁰⁾ on the effects of in-utero exposure of children who survived the atomic bombings at Hiroshima and Nagasaki. I have been interested for many years in both studies and consider them among our best sources of data indicating the effects of radiation on man. In fact, our Health Physics Division at Oak Ridge has been responsible for determining the dosimetry of the survivors at Hiroshima and Nagasaki. Having examined both sets of data, I can only conclude there are no inconsistencies in the results, and the two sets of data are completely in line with what one might expect. In Table 3, I have listed some of the reasons why there is an apparent difference in the two sets of data, i.e., there have not been as many cancers observed in the children who survived in utero exposure at Hiroshima and Nagasaki as one might expect from casual application of the Stewart data. First, we should recall that only children of age greater than two have a high risk of juvenile cancer, and there was a very high infant mortality among in utero exposed children and a very high abortion rate.⁽³¹⁾ Thus, many children who received in utero damage from radiation exposure were aborted or did not survive the two-year period to die of a malignancy, i.e., many children who received sufficient in utero radiation damage to otherwise be programmed to die of a malignancy after age two did not survive this period. In the second place, many studies⁽³²⁾ have indicated that during the time of community disasters it is the young children and older people who suffer most and die of a variety of causes including cancer. It is well recognized that during such periods incipient cancers are often very easily mistaken for acute infections. Another possibility (but I believe an unlikely one) is the fact that neutrons were present as a component of exposure to the Japanese survivors of the atomic bombings, and this may have favored early deaths from causes other than malignancies. It could well be that there were species differences of considerable importance in these two populations. For example, marked species differences have been observed in animal studies carried out by Warren and Gates⁽³³⁾ and by many others. I believe, most important of all, the Jablon data included 33 Japanese children who had received

Table 3

**SOME POSSIBLE REASONS WHY ALICE STEWART'S X-RAY DATA
DIFFER FROM JABLON'S JAPAN DATA**

1. Only children of age greater than two years have a high risk of juvenile cancer. Infant mortality was 43% among in utero children who received high exposure, and there was a very high abortion rate among them. In utero initiated cancers concurrently with other body insults tipped scales for early nonmalignant death.
2. In most catastrophic situations (floods, war, disease, starvation), children and older people suffer most.
3. Neutron irradiation at Hiroshima and Nagasaki.
4. Japanese children may differ from European children, and/or European children may be uniquely exposed to a co-carcinogen.
5. Jablon data included 33 children who received greater than 300 rad. Stewart's data do not apply to doses at the far end of the parabola relating leukemia to dose.
6. Incipient cancers during the bomb aftermath were likely mistaken for acute infection.
7. Japanese control group of bomb survivors probably had a greater cancer risk than normal controls.
8. It has been suggested the average fetal dose in the United Kingdom may have been greater than 500 mrad per examination and perhaps about 800 mrad.
9. The Japanese exposures above 300 rad probably were on the far side of the parabola relating leukemia to dose. Thus, perhaps no cancers would be expected, and none were observed in this range. Among Japanese exposures from 0 to 39 rad, no cancers were observed and none were to be expected. Among Japanese exposures from 40 to 299 rad, Stewart's minimum coefficient (correcting Jablon's data for fetal dose) would predict two cancers and one was observed. Thus, the two sets of data are in good agreement.

in utero exposure of more than 300 rad. I do not believe Stewart's data can be applied to this population group because it would seem likely their doses were so high that they would fall at the far end of the parabola for leukemia similar to the curves shown in Fig. 4 for sarcoma and carcinoma. Marinelli⁽³⁴⁾ and many other investigators have indicated in their publications that although you may have a linear relationship between dose and the effects on animals at low doses, the curves cannot continue this linearity indefinitely. In the first place, one cannot kill more than 100% of the animals from radiation exposure, and at the higher exposure levels many of the animals may begin dying of other causes before they have time to die of a malignancy. Stewart has pointed out that the control group of bomb survivors in Hiroshima and Nagasaki probably had a higher cancer risk than a normal population which, in turn, would tend to reduce any observed effect of radiation. Finally, it has been suggested that perhaps Stewart may have used a low figure for the average fetal dose from pelvimetries in the United Kingdom. Making this correction and using the minimum coefficient found by Stewart for her Oxford study group and applying a correction of 1/2 to the Jablon data to obtain the fetal dose from the skin dose, one would expect to find two cancers among the Japanese in utero exposures in the range of 40 to 299 rad, and one was found. No cancers would be expected in the group exposed in utero to 0 to 39 rad, and because exposures probably were on the far side of the parabola for the group receiving exposures greater than 300 rad, no cancers would be expected. In view of the uncertainties in the data, I consider this perfect agreement between the number of cancers observed among the in utero exposed children in Japan and the diagnostically exposed children in the Oxford study.

Comparative Radiation Risks

From the above discussion, I believe it seems reasonable to assume the validity of the linear hypothesis for the purpose of making comparisons of risks from medical diagnosis and the nuclear energy industry. If one knows the average or effective dose to the critical body tissue, it then becomes a simple matter of multiplication to determine the deaths caused each year from these two sources of exposure. In previous publications, I have attempted to use the data published in the UNSCEAR reports^(35,36) and in the U. S. Public Health Service reports^(37,38) to estimate the x-ray doses to various body

organs from medical diagnoses and multiply these values by the appropriate coefficients, as indicated in Fig. 1, to determine the number of deaths per year. However, the 1970 survey of the Public Health Service has now been completed, and the data are in the process of final analysis, so I will simply use their most recent estimate that the genetically significant dose to the U. S. population from medical diagnoses may have dropped from 55 mrem/yr to 36 mrem/yr. I will further make the approximate assumption that the effective somatic dose is three times this 36 mrem/yr. This probably is not far wrong, but it is the best that can be done until additional information from the survey becomes available. In the case of the nuclear energy industry, Struxness and I⁽³⁹⁾ made some estimates two years ago of the upper limit of the dose from all nuclear sources (occupational exposure of the nuclear power plant employees, occupational exposure of national laboratories and other AEC contractors and employees, exposures at chemical processing plants, and environmental exposure from all of these sources but excluding the lung carcinoma deaths resulting from exposure to uranium miners in the United States) and concluded the average dose could not be in excess of 1/2% of the exposure limit of 170 mrem/yr. Subsequent studies of the problem suggest that it is definitely less than 0.5 mrem/yr. Therefore, the comparative estimates of risk from the nuclear power industry and from medical diagnostic exposure are given in Table 4 where it is assumed the upper limit of exposure is 0.5 mrem/yr in the nuclear energy industry and is 36 mrem/yr and 3×36 mrem/yr for the genetically significant dose (GSD) and somatic dose, respectively, from medical diagnoses. In making these estimates, the coefficients for genetic damage in the case of medical diagnostic exposure were taken to be six times those indicated in Fig. 1 because of the high exposure rate. From these results, the contrast as shown in Table 4 is very striking. The number of deaths in the nuclear energy industry would be 11 compared to 3,000 from medical diagnosis each year. The corresponding figures are 40 and 33,000 when one considers the highest estimate of deaths introduced into the population each year as a result of recessive mutations. From such a comparison, I do not wish to leave the impression that we have no concern for possible chronic damage to the population from the nuclear power industry, for we must do all possible to further reduce the dose and the possible effects on man. I would emphasize, however, that if one is truly concerned

Table 4

Consequences of Present United States X-Ray Diagnostic Exposures Compared
With Those of A Possible Population Exposure of 0.5 Mrem/Year From The
Nuclear Power Industry*

<u>Types of Radiation Damage</u>	<u>Medical Exposure*</u> <u>(deaths/yr)</u>	<u>Nuclear Power Industry</u> <u>at 0.5 Mrem/Yr (deaths/yr)</u>
Genetic (First Generation)	700	1
Genetic (Future Generation)Δ	30,000	30
Cancer**	2,000	10
Total Deaths/Yr	~ 3,000	11
Deaths Introduced Into Population Each Year	~ 33,000	40

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*Assume population of 2×10^8 in the United States.

*Assume medical GSD of 36 mrem/yr at a high dose rate.

**Assume effective somatic dose is three times the GSD.

ΔUpper limit of estimate of risk from recessive mutations.

about radiation effects on man of man-made radiation, most of his efforts could better be spent in reducing unnecessary diagnostic exposure.

Excessive Medical Diagnostic Exposure

There is no question that medical diagnostic exposure is one of the most valuable of all medical tools and should be made use of when there is an indicated need and the expected benefits are greater than the radiation risks. However, there is overwhelming evidence that this exposure in the United States is excessive. Many of the x-ray diagnoses are unnecessary, of no benefit to the patient and of questionable value to the doctor. Those x-rays which are given could be carried out in such a way that the average patient absorbed dose (rem) would be less than 10% of the present value; the average energy dose (gram . rem) would be less than 1% of the present value, and the genetically significant dose (GSD) would be less than 0.1% of the present values received in the United States. Table 5 summarizes some data indicating that the GSD in the United States is higher than that in other advanced countries. As stated above, preliminary estimates from the 1970 U. S. Public Health Service survey indicate the GSD may have dropped since 1964 from 55 to 36 mrem/yr. There are indications,⁽⁴⁰⁾ also, that there have been similar reductions in the other indicated countries. Adrian⁽⁴¹⁾ of the United Kingdom stated that if all the radiological departments in the United Kingdom employed the techniques in use already in 25% of the departments in 1958, the population gonad dose from diagnostic radiology would probably be reduced by a factor of 7. In other words, he has indicated that by this simple procedure the dose could be reduced in the United Kingdom to 2 mrem/yr. Following the 1964 survey, the U. S. Public Health Service⁽³⁸⁾ stated, "Restriction of the x-ray beam to an area no larger than that of the film size would result in a reduction of the GSD from 55 to 19 mrem/person/yr." In Congressional testimony⁽⁴²⁾ and in a number of publications,⁽⁴³⁻⁴⁵⁾ I have listed over 100 ways by which the diagnostic exposure in the United States could be reduced to less than 5 mrem/yr. You may ask why is the genetically significant dose in the United Kingdom and other advanced countries less than that in the United States. We cannot give an accurate answer to this question. Some radiologists have suggested we may have better

Table 5

**Genetically Significant Dose (mrem/yr) from Medical Diagnosis
in Various Advanced Countries**

United States	55*
Japan	39
Sweden	38
Switzerland	22
United Kingdom	14
New Zealand	12
Norway	10

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*The 1964 survey of the USPHS reported the GSD as 55 mrem/yr. Preliminary estimates from the 1970 survey indicate it may have dropped to 36 mrem/yr.

medical practice in our country. This may or may not be true, but it goes without question that they have had medical physics and radiation protection programs in some of these countries much longer than in the United States. In fact, during the period beginning with World War II a number of leading medical physicists (health physicists) were imported to this country. Some of these countries have had effective programs for inspection and upgrading of equipment and diagnostic techniques for many years--something that is still lacking in most of the United States. I believe, also, members of the medical profession in some of these countries have a greater knowledge and appreciation of the genetic and somatic risks of medical exposure and a stronger motivation to avoid its excessive use. Probably the best evidence that unnecessary and excessive diagnostic exposure is being delivered to our population derives from an examination of the wide range in values of exposure for a given diagnosis as shown in Table 6. Here it will be noted that the average skin dose from a chest x-ray when delivered to employees of our Laboratory (Oak Ridge National Laboratory) by a certified x-ray technologist using modern techniques and equipment is only 15 mrem, whereas a U. S. Public Health Service⁽³⁷⁾ survey indicated the average in the United States for a chest radiograph was 45 mrem, and when using the photofluorographic technique the average was 504 mrem. Our studies have shown a range in skin dose from photofluorograms of between 200 and 2,000 mrem. The spread in dose values is even greater in terms of energy dose (gram . rem) and GSD. For example, Penfil and Brown⁽⁴⁶⁾ and others have shown the x-ray beam cross-sectional area to film area for chest x-rays in the United States ranges between 1 and 4.1. Even worse, there are many chest x-rays made which should be avoided. For example, in 1965 the Public Health Service⁽⁴⁷⁾ stated, "Mass chest x-ray programs should not be given to all population groups but instead should be focused on groups within communities where the incidence of tuberculosis is known to be high." As seen in Table 6, there is a similar variation in the skin dose from a dental series. Unfortunately, the energy dose variation is much greater because only about 1% of the dentists are using the long, open-ended cones with rectangular collimation. The American Dental Association⁽⁴⁸⁾ has pointed out that the long, open-ended cones are preferable to the stubby, pointed, plastic cones. The long, open-ended cones can

Table 6

Common Diagnostic X-Ray Exposures (Mrem to Skin) in the United States . . .

	<u>Range</u>	<u>Average</u>
Chest X-Ray at ORNL	10-20	(15)
Chest X-Ray (Photofluorographic)	200-2000	(504)
Chest X-Ray (Radiographic)	10-300	(45)
Dental X-Ray Series	400-100,000	(20,000)

be provided with a precision rectangular collimator⁽⁴⁹⁻⁵¹⁾ such that the cross-sectional area of the beam is essentially the same as that of the film. This device, also, provides a metal backing behind the film to limit the amount of the beam passing on into the critical tissue of the body and is constructed in such a way that retakes will not be necessary because of film cutting (improper alignment). Another promising device for limiting the cross-sectional area of the x-ray beam to more or less the area of the film is the automatic collimator.⁽⁵²⁾ Surveys of the Public Health Service⁽³⁷⁾ indicate that for dental x-rays in the United States the ratio of beam cross-sectional area to film area is greater than 6.8 for 2.1% of exposures, 3.8 to 6.8 for 18.4%, 3.2 to 3.8 for 35.7%, and less than 3.2 for 43.8%. It is hard to understand why about 99% of the dentists are using a beam with a circular, cross-sectional area when the film is rectangular. The portion of the beam beyond the area of the film not only unnecessarily exposes the patient but produces additional x-ray scattering onto the film so that the image of the teeth suffers from loss of resolution and detail. Public Health surveys⁽⁵³⁾ have indicated that most of the dentists do not even have a thermometer in their darkroom although specifications for best results in developing dental films indicate the temperature control of developing solutions should be maintained within a few degrees. Until recently, most of the dentists were using slow-speed dental films. For example, in 1967 65% of the dentists in New York City were still using slow-speed films, and 72% were still using mechanical timers which were inadequate for fast-speed films. I do not have the statistics on the present situation in New York City, but I understand in this respect dental exposure has improved considerably. I believe with this observation we should keep in mind that the medical surveillance program in New York City is very likely the best in the United States. As with chest x-ray programs, many unnecessary dental x-rays are given. The American Dental Association⁽⁵⁴⁾ has said, "Radiologic examinations should not be used as an automatic part of every periodic or routine dental examination." In other words, dental and chest x-rays should be given only where there is an indicated need and not as a routine procedure unless there are unusual circumstances. Even then they should be given only when using the best of techniques with modern equipment. I believe, for example, if a person has reached the age of 50, it is a good investment

to have an annual chest x-ray but not if the skin dose is greater than 50 mrem. Similarly, if a person has something wrong with his jaw that cannot be diagnosed adequately from visual inspection, he should have a dental x-ray, but, hopefully, the single exposure dose would be less than 1,000 mrem (the mean exposure per film for dental x-rays in the United States in 1964 was 1,140 mrem), and the ratio of beam area to film area would be close to one. Unfortunately, many of our well meaning city fathers and public school officials often sponsor mass chest x-ray and dental survey programs that are not warranted. In 1964 over 1/4 of the non-institutional civilian population in the United States was exposed to dental x-rays.

In the case of dental exposure, as with other sources of population exposure, more attention should be given by our state and federal public health agencies to new sources or types of exposure which become commonplace before any of us give consideration to possible excessive exposure. For example, in 1971 the International Commission on Radiological Protection called attention to the new radiation protection problem posed by the use of intra-oral x-ray tubes in dental radiography. With the present trend to use tubes of decreasing diameter, the radiation dose at the surface of the tube may amount to 50 to 100 rad or even more per exposure. It indicated that such uses clearly should be depreciated and that if appropriate filtration were used with extra-sensitive films, the doses could be reduced by an order of magnitude.

The most important steps toward reducing unnecessary medical diagnostic exposure are summarized in Table 7. Of these, education, training and certification are by far the most important. Only the States of New York, New Jersey and California require education, training and certification of x-ray technologists who operate most of the x-ray equipment in the United States, and only one State, California, requires that there be courses on x-ray and radiation protection offered in the medical schools and that there be questions on the state board examinations on these subjects. I am sure it is almost inconceivable to you that in all 50 of our states a person is required to have a driver's license before he can operate a school bus, but, in the case of x-rays, the only requirement is how to press the red button on the machine and hope the timers and other equipment operate properly. Even some of the better x-ray departments do not have meters with which they can calibrate

Table 7

IMPORTANT STEPS TO REDUCE UNNECESSARY MEDICAL EXPOSURE TO X-RAYS

1. Education, Training and Certification Requirements
  - (a) Presently required of doctors only in California
  - (b) Presently required of x-ray technologists only in New York, New Jersey and California
  - (c) Establish a grade of senior x-ray technologist
2. Improve Techniques
  - (a) Require better techniques in developing x-ray films
  - (b) Require edges of x-ray field to show on film
  - (c) Require dark adaptation of eyes even with improved fluoroscopy
3. Reduce Number of Diagnostic X-Rays
  - (a) Transfer x-ray films from one doctor to another
  - (b) Limit requirements of insurance companies for medical x-rays
  - (c) Discontinue and/or curtail certain types of medical x-rays
4. Use Better Equipment
  - (a) Require use of long cones with rectangular collimation for dental x-rays
  - (b) Forbid use of medical x-ray machines unless equipped with proper meters
  - (c) Require use of patient shields and lead aprons
5. Require Records of Patient Exposure
  - (a) Require a permanent record of dose for each patient exposure
  - (b) Furnish patient with record of x-ray exposures
  - (c) Obtain information to aid in avoiding exposure of fetus
6. Increase Inspections
  - (a) Inspect all medical x-ray machines and associated equipment annually
  - (b) Inspect techniques used in medical diagnoses annually
  - (c) Post conspicuously a dated inspection record for each x-ray machine and its use

the x-ray beam. Even worse, most of the diagnostic x-ray equipment in the United States is owned and operated by non-radiologists who have little or no training in its use. Fortunately, the x-ray workload of this equipment by practitioners, chiropractors, osteopaths, etc., is relatively low. It seems to me, unthinkable that a practitioner or his secretary without training and certification in the proper use of x-rays would be allowed to operate these machines and almost as unacceptable that a doctor would be permitted to prescribe an x-ray for his patient when he has no education, training and certification in its use and is not able to weigh the benefits against the risks from such an examination. There is a bill in Congress, S.426, sponsored by Senator Randolph which is designed to require appropriate education, training and certification of all x-ray technologists. I hope this bill has successful passage through Congress and that it will be followed by other legislation which will require similar education, training and certification of all members of the medical profession. I think it is important we establish a grade of senior x-ray technologist and give him complete responsibility for the calibration and operation of the diagnostic x-ray machine. He should complete a minimum of four years of specified education and training and be given a special certification examination. Such a professional grade of technologist could assure much better and safer x-ray diagnoses and would save the public many millions of dollars by obviating the need for thousands of additional radiologists.

Regarding the improvement in techniques, little more need be said except perhaps to give another example where poor techniques are used which result in the average exposures being many times what they should. Surveys of the Public Health Service⁽⁵³⁾ have indicated that most dentists in the United States overexpose x-ray films and underdevelop them. This assures an image of the teeth on the film but guarantees the patient will be overexposed and that the film will be of poor quality. I have over 200 letters in my file from persons from all over the United States who apparently have received an excessive number of diagnostic x-rays. For example, I have a letter from a medical physicist dated January 13, 1971, which states, "A pediatrician brought up the fact that he was furious because Radiology had taken 22 chest x-rays of one of his patients (an infant) between October 2, 1970, and November 30, 1970.

When the matter was brought to the attention of the Radiology Department, the radiologist replied it was not the responsibility of the X-Ray Department to keep track of the times a patient is x-rayed and that if an order comes down for an x-ray, they will give it." Hopefully, there are very few departments where the head radiologist takes this attitude. However, where this is the case, he is not practicing radiology but rather doing the job of an unqualified technician, taking orders for the mass production of x-rays. Regarding the need for better x-ray equipment, we may add, for example, to what has been stated above the results of a survey by the Public Health Service of x-ray facilities within the Bureau of Prisons during 1968.⁽⁵⁵⁾ In this survey, they found, for example, the improper cone was used and that the proper cone was not available in 20.6% of the medical x-ray machines surveyed, and the timers were inaccurate and/or gave non-reproducible results in 68% of the dental x-ray machines.

Regarding item 5 in Table 7, the matter of keeping records of patient exposure, I readily concede there will be some problems, but the principal problem is that of the reluctance of members of the medical profession to change established practices. They point out the difficulties and time-consuming efforts in making these measurements and recordings, but there have been several publications pointing out how this could be done mechanically while taking very little additional time of the medical man or the x-ray technologist. For example, Hurst et al⁽⁵⁶⁾ have described a recording ionization chamber which can be adopted to any diagnostic x-ray machine. The recording of the dose would be made automatically on a card containing the name of the individual, type of exposure, target-skin distance, kvp, filtration, and exposure area. It is difficult to understand why such equipment is not already in use in this day of computers and information retrieval devices. One can walk into an airport and in a matter of seconds receive information on the availability of airline connections in any part of our country. Such information should be equally retrievable regarding an individual's entire exposure history. This information should be stored in such a way that the doctor by pressing a few buttons would have it displayed before him.

It is well known that natural background radiation exposure and medical exposure are not included as components of the ICRP upper limit of 500 mrem/yr to the individual

or 170 mrem/yr average to the population. I firmly believe medical diagnostic exposure should be included as part of this 170 mrem/yr limit for the average population exposure. If this were done, greater attention would be given to weighing the benefits against the risks by members of the healing arts as well as by those concerned with the future of the nuclear energy industry. I think it goes without saying that more frequent and more thorough inspections of medical facilities and practices by properly qualified state public health organizations would go a long way toward improving the equipment used for medical diagnosis, upgrading the techniques employed and assuring proper education, training and certification of all those involved. In order to accomplish these objectives, we will require cooperation at all levels of society and government beginning with widespread education of the public not to fear radiation but to give it proper respect; not to avoid a needed diagnosis or x-ray treatment, but when it is required to seek the best medical advice and make use of those medical facilities most likely to deliver the minimum dose consistent with the radiographic information needed. In order to reduce unnecessary medical diagnostic exposure, it will require the concern and active assistance of many professional groups and especially of those knowledgeable in matters of radiation exposure (such as health physicists, nuclear engineers, radiologists, x-ray technologists, etc.). Even the legal profession will have an important part to play in these efforts because many x-rays are given not for the benefit of the patient but to protect the doctor from possible legal implications and to establish legal claims in case of an accident. I believe in legal matters the Special Committee on Atomic Energy Law of the American Bar Association can be of considerable benefit. For example, in 1968 it was instrumental in correcting a serious disparity in many state laws which applied the statute of limitations to claims for radiation injury. Prior to this committee's decision, in order to lay claim for radiation injury a claimant would have to establish that he received radiation injury within a period of about five years after his radiation exposure in order that his case be given legal consideration. The recommendations of this committee were adopted by the House of Delegates and have been instrumental in modifying state laws and their interpretation such that a person receiving chronic damage from radiation (i.e., more than five years after radiation exposure) may expect to receive just compensation

through court procedures. I have information concerning persons who have been required by insurance companies to receive 10 to 30 x-ray exposures in order to establish the existence or cause of rather minor injuries from automobile accidents. It seems to me that such use of x-rays is not acceptable, and the Public Health Service should seek the assistance of the Special Committee on Atomic Energy of the American Bar Association in avoiding such misuse of x-rays.

Perhaps the picture I have painted so far regarding the misuse and excess of medical diagnostic x-rays appears a bit discouraging, but there are some signs of slow progress as indicated in Table 8. Some of us were instrumental in the passage of Public Law 90-602 which has given important authority to the Surgeon General to bring about some of these corrections. However, in order to implement some of the things discussed in this paper, it will be necessary for the various states to pass a number of laws, and here is where all of us as concerned citizens should come into the picture. Perhaps one of the most encouraging recent developments is that radiologists themselves are chiding and rebuking their profession in their own publications because of unnecessary and harmful patient exposure. For example, Table 9 is a summary of some of the comments made in a paper by Dr. McClenahan⁽⁵⁷⁾ entitled "Wasted X-Rays." Here, he is saying that the ordering of a radiogram has become more or less a mechanical and foregone conclusion even when there is no question about the diagnosis or need for an x-ray. Such practice is justified in the eyes of the doctor because it rules out some finite or remote chance that something else was overlooked (and I might add that it adds a significant cost item to the bill). A number of papers in the medical journals, however, have pointed out that these low yield x-ray diagnoses should not be conducted, not only because of possible damage to the patient, but, also, because they add substantially to the soaring cost of medical care. Drs. Bell and Loop⁽⁵⁸⁾ point out there are certain types of examinations, for example, where only one fracture in 435 radiographic examinations yielded positive results and even in this case the information was not needed in the treatment of the patient. They point out further that if x-ray examinations of this type would be deferred or omitted, such a strategy on a national scale potentially could result in a yearly saving of 15 million dollars in health care. Brook and Stevenson⁽⁵⁹⁾ reported on the outcome

Table 8

**FAINT SIGNS OF PROGRESS IN REDUCING UNNECESSARY
MEDICAL EXPOSURES**

1. Passage of Public Law 90-602 in 1968.
2. Several states have pending legislation designed to reduce medical exposure.
3. Genetically significant dose from medical diagnosis may have been reduced from 55 mrem/yr (1964) to 36 mrem/yr (1970).
4. For the first time, radiologists are chiding their profession because of unnecessary patient exposure.

Table 9

SOME PRACTICES CAUSING EXCESSIVE PATIENT EXPOSURE

1. Easier to order an x-ray than think.
2. Exercise "ruling out," i.e., order x-rays when accurate diagnosis has been made with the naked eye.
3. Heavy legal penalties for failure to x-ray but no penalties for unnecessary exposure of patient.
4. Insurance covers most x-ray costs.
5. More films per diagnosis now required than formerly.
6. Shortage of trained workers leading to hasty, hazardous techniques.
7. Folkways and traditional rites.

of 141 emergency room patients who were given various diagnostic x-ray procedures and found that these examinations resulted in effective medical care for 27%, ineffective care for 60%, and neither effective nor ineffective for 13%. Dr. Sutherland⁽⁶⁰⁾ reported skull x-ray examinations showed the lowest incidence of clinical radiological agreement in his study. Only one lesion, a pituitary adenoma, was detected in 70 requests from the medical department. Dr. Sagan⁽⁶¹⁾ was particularly forthright and effective in some of his comments regarding the need for improvement in medical diagnosis. Regarding Dr. McClenahan's reference to folkways and to regional rites, probably he had in mind the prevalent practice until a few years ago, when brought into the limelight by Nader,⁽⁶²⁾ of x-ray technologists in our country giving more exposure to black patients than to white patients. In fact, one of the textbooks commonly used for the training of x-ray technologists recommended this as a general procedure. McClenahan in his article goes on to point out that many x-rays are given for psychological reasons because the doctor wishes to satisfy the patient. I agree this is an important use of x-ray diagnosis and should be continued, but in such case there is no need to turn on the high voltage on the x-ray machine--perhaps add a buzzer that could be activated.

Fig. 6 summarizes some of the foregoing discussion, emphasizing again the relative insignificance of exposure in the nuclear energy industry in comparison with that from medical x-ray diagnosis. I, for one, believe the potential for population exposure as a result of accidents with nuclear power plants is much more important than the risk of exposure from their routine operations. However, even when we take this into account, the risk again becomes relatively insignificant. In this case in which I consider what I believe are the worst credible consequences of a nuclear accident, I estimate the average number of deaths per year would be about 25, and I believe a more reasonable figure would be three. These figures were obtained by what I consider to be an appropriate scaling and adjusting of some of the factors given in the earlier major accident report, WASH-740.⁽⁶³⁾ In this case, I applied risk estimates to 1,000 MW(e) power reactors having a probability of 10^{-4} accidents per reactor per year. I assumed in this case 25% release of iodine and 100% release of noble gases (or a few 100 million curies), and concluded the exposure, at least with proper

DEATHS/YEAR IN U.S. (NOT INCLUDING DEATH BEYOND 1st. GENERATION)

Fig. 6

preparations, could be maintained at less than 2.5×10^6 man-rem to the total body and 30×10^6 man-rem to the thyroid. This would correspond, for example, to an average of 10% of the USAEC accident design doses (i.e., 10% of 25 rem to the total body and 10% of 300 rem to the thyroid to 10^6 people). Using the coefficients given in Fig. 1, this would correspond to 500 deaths. If we have an average of 500 operating nuclear power plants of 1,000 MW(e) over the next 20 years, this corresponds to one accident or an average of 25 deaths/yr plus a possible 100 to 150 genetic deaths introduced into future generations. Certainly, from past experiences one would expect more likely the release of something between a few thousand curies, and this amount representing a worst possible accident, and on this basis I rather arbitrarily arrived at what I believe is a more reasonable upper figure of three deaths/yr. Table 10 compares the risks from medical diagnosis and the nuclear energy industry with the risks of dying from other causes. Here it will be noted that even on the worst assumptions regarding risk from the routine operations and accidents in the nuclear power industry, we should be more concerned about reducing the risk from getting struck by lightning. However, these low reactor risk estimates assume continued isolation of nuclear power plants and an adequate health physics program in each of them--something which is not necessarily assured by present plans. Finally, referring again to Fig. 6, we should keep in mind that in choosing nuclear power we do so after comparing the risks in the use of fossil fuels. We know far less about the risks from chemical environmental pollutants such as hydrocarbons, oxides of nitrogen, oxides of sulphur and particulates than about radiation risks, but the evidence is rather clear that they lead to an increased incidence of chronic bronchitis and emphysema and seem to relate to many other diseases. Furthermore, we must not overlook the fact which was pointed out by Martin et al⁽⁶⁴⁾ that the radioisotopes discharged from a modern coal plant exceed in quantity and toxicity those discharged from some of the more modern pressurized water reactors. I agree with them that it is fair to say the risk in terms of the fraction of ICRP population dose limit is at least 400 times greater in the case of the fossil fuel plant than the pressurized water reactor plant. Considering, also, the 1,600 year half life of radium-226 (the principal radionuclide of concern with fossil fuel plants) in comparison with the short-lived

Table 10

Radiation Risks on the Linear Hypothesis (Deaths/Yr)*

Medical Diagnosis   3,000 (30,000)

Nuclear Energy Industry

Routine at 0.5 mrem/yr   11 (40)

Accidents**

Worst Assumptions   25 (150)

More Reasonable   3 (15)

Deaths Per Year From Other Causes in 1967

Heart Disease   721,000

Cancer   311,000

Stroke   202,000

All Accidents   113,000

Struck by Lightning   ~ 100

*Values in parentheses are upper limits of genetic deaths introduced into the population each year on the average.

**Figures do not include acute deaths from blast and radiation sickness.

tritium and the fact that the residence time of tritium, the noble gases, and iodines in the local environment is far less than that of radium, the relative radiation risks are probably at least an order of magnitude greater than this figure of 400.

References will be attached to final copy. Due to shortage of time, paper is submitted for declassification and release without references since they are in the process of being typed.