DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

INTRODUCTION AND FUNDAMENTALS:
Course on Advances in Radiation, International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Italy, September, 1979

Ralph H. Thomas

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720 USA

"Conception, my boy, *fundamental brain work*, is what makes the difference in all art."[1]
Dante Gabriel Rossetti

INTRODUCTION

Some may think that a lecture on "fundamentals" is perhaps inconsistent with the title of this course which deals with "advances" in the areas of radiation protection and dosimetry in medicine. The Oxford English Dictionary[2] defines fundamental as "Pertaining to the foundations or groundwork, going to the root of the matter." The English language is so abused these days that it may be a shock to some to learn that an equivalent to "fundamental" is "radical." Dante Gabriel Rossetti was able to very clearly perceive that "fundamentals" were, in fact, the basis for all fine creativity--if I may be allowed the presumption that he would have agreed that the distinction between artistic and scientific creativity is a fine one, if indeed it exists at all. This course will discuss advances in the fundamental sciences which underlie that applied science which is variously called health physics, radiological protection, or radiation protection.

It is my hope in this lecture to lay before you, so to speak, the menu. To continue to metaphore I will, as a good waiter should, indicate the special virtues of each course and mention the specialities of the restaurant. In order to do this

effectively I will first discuss some of the underlying assumptions of radiation protection and, later, describe some of the developments in the radiological sciences—both fundamental and administrative acts by the ICRP and ICRU—which have taken place since the first course was given under the auspices of the International School of Radiation Damage and Protection in 1975.[3] These foundations and developments will then be related to the topics to be discussed in this course.

Measuring the Risks of Ionizing Radiations

It is often claimed that more is known about the harmful effects of ionizing radiation than about any other toxic agent, a claim that can probably be supported by the great volume of published literature on the subject. As Morgan has written elsewhere, "Perhaps there has never before been an enterprise that was planned so carefully for its safety and never before a risk that has been so thoroughly studied and guarded against as has been the case with the nuclear energy industry and its concern to avoid unnecessary exposure to ionizing radiation."[4] If this is indeed so, we are presented with the conundrum that of all the toxic agents, the public has the greatest fear of ionizing radiations. Perhaps we have evidence here of yet another variation of that great universal principle known as Parkinson's Law.[5] In this variation it takes the form "Public Apprehension increases in direct proportion to the frequency with which a potential hazard is discussed."

To the great mass of the general public the degree of authoritive standing of the discussion does not seem to carry much weight—it is important only that the potential hazard be discussed. Such is the power of the producers of television news programs that people in California requested whole-body counts for fear that they had been contaminated by the radioactive releases at Three-Mile Island, some 2,500 miles away.

It is perhaps necessary from time to time to stand back and take a broad view of toxicology and be somewhat selfcongratulatory in realizing that the radiation protection is quite soundly based. Any other branch of toxicology that could produce as authoritative a volume as "Sources and Effects of Ionizing Radiations" would consider itself fortunate.[6]

Lawrence[7] suggests that there are four basic lines of investigation to assess the risk of any hazard: "Measurements are made to:

1. Define the conditions of exposure

2. Identify adverse effects

3. Relate exposure with effect

4. Estimate the overall risk."

It is of some interest for us to see how well our assessment of risk measures up to these requirements.

Conditions of Exposure

It is important to remark at the onset that one of the extremely valuable properties of ionizing radiations is that they are readily detected. This property has led to extensive documentation of the sources of exposure to ionizing radiation. Personal dosimetry records are extensive and—compared with estimates of exposure to other toxic agents—relatively accurate. In most cases internal contamination is easily detected by whole body counting or bioassay-techniques. By the same token, the measurements of any releases of radioactivity to the environment may be carried out with great sensitivity.

This ease of detection of ionizing radiation means, in the United States at least, that we have an increasing body of data, which is essentially public information, concerning exposures of both radiation workers and the general public to radiation. It is, for example, the policy of the United States Department of Energy (DOE) to publish annual summaries of personal monitoring and environmental monitoring data of all its programs. We may conclude, therefore, that the conditions and magnitude of exposure are quite well known.[6]

Figure 1 shows a summary of the major sources of human radiation exposure at the present time, as determined by the U. S. Environmental Protection Agency (USEPA), and the figure also gives predictions until the year 2,000 A. D. Ionizing radiation is seen to be an unusual "pollutant" in that the major exposure to man is of natural origin. If low levels of ionizing radiations were dominant in their influence among environmental toxic agents it might therefore be expected that one would be able to observe significant correlations between the incidence of cancer and external radiation levels.

Frigerio has in fact studied the correlation between leukemia rates in the United States and natural radiation background. Perhaps surprisingly, he finds a weakly negative but significant correlation.[9] This is not, of course, to say that ionizing

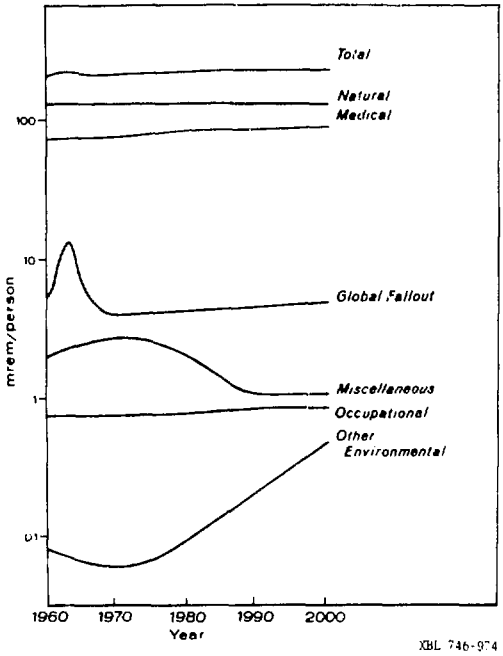


Figure 1. A summary of the major sources of human radiation exposure until 2000 A.D., prediction by the Environmental Protection Agency.

radiation has been demonstrated to be beneficial to man; but perhaps it does indicate that, even if ionizing radiations are carcinogenic in man at dose rates of ~0.1 rem/yr there are environmental agents which are of much greater importance. Nevertheless, this has not prevented many who should know better from making claims that we now know that a significant fraction of cancer is caused by the natural background of ionizing radiation. Thus, for example, Rowe of the USEPA has made the claim that natural background causes 13,000 "health effects" (a euphemism for cancers) per year in the United States.[10]

Figure 1 shows the very important role of diagnostic radiology as a source of radiation exposure in man. It is, and no doubt will continue to be, the dominant source of radiation exposure. However, Chamberlain[11] has made the point that: "Not only is this true, . . . but it would be surprising if it

were not true. Medical radiology is the only legitimate situation in which radiation exposure is purposefully given to human beings for their own benefit. It would be more remarkable, if not alarming, if any other man-made source exceeded it in human exposure."

Thomas and Busick[12] have suggested that, at present exposure levels in the United States, diagnostic radiology is at least ten thousand times more beneficial than harmful. Nevertheless in the absence of a satisfactory resolution to the low dose problem it is prudent to assume that all radiation exposures are harmful—no matter how small the dose. Considerations such as these have led to suggestions, sometimes stated in a rather shrill fashion, that there is an urgent need to reduce exposure to ionizing radiation from medical sources.[13,14]

Morgan supports such a view by citing five arguments:

1. Medical exposures in the United States are higher by a factor of 2 to 10 than in most advanced countries in the world.

2. There is no threshold to the deleterious effects of radiation.

3. Linear extrapolations of biological effects observed at high radiation doses may underestimate radiation effects at low doses.

4. Despite current concern as to the somatic effects of radiation, the genetic risks may still be the limiting form of radiation damage.

5. Low level exposures such as those in medical diagnosis may be harmful.

It is certainly true, as Morgan says, that medical exposures in the United States are higher than in any advanced country in the world. However, the mere fact of exposure does not of itself establish any detrimental health effects. There is much to consider at a meeting such as this in what Morgan says, and I look forward to discussion of these topics particularly in the talks by Silini[15] and Paretzke.[16]

The International Commission on Radiological Protection (ICRP) has published two reports which are great value in reducing patient exposure.[17,18] Both reports are currently being revised by the ICRP, which also plans to issue a third report dealing with the protection of patients during radiotherapy.

There are many other pressures in the United States which tend to reduce radiation exposures from medical sources. These include consumer organizations, trade unions, professional societies, the news media and federal agencies.[19] Recently, for example, the Environmental Protection Agency and Bureau of Radiological Health[20] jointly published in the Federal Register guidelines for the use of X-rays in medicine by agencies of the U. S. Government. These guidelines discourage the routine radiological examinations without symptomatic or other medical reasons.[21]

These and other pressures have led to increasing efforts to reduce radiation exposures to levels as low as readily achievable[22] and to the widespread use of the concept of population dose equivalent as an index of harm resulting from the exposure of populations to low levels of ionizing radiations.[23] While the former effort is of undoubted value, provided it is achieved by some means of risk-benefit analysis, the widespread use of the quantity population dose equivalent has been questioned by some and will no doubt be discussed during this course.

ADVERSE EFFECTS OF IONIZING RADIATION

There are basically three sources of information on the adverse effects of ionizing radiation on humans. These are:

1. Fundamental radiobiology
2. Animal experiments
3. Epidemiological studies.

We will hear more on these separate topics in lectures by Silini, Paretzke, Rossi, Larsson, Broerse, and Curtis in this course[15,16,24-29] and in some of the panel discussions. Nevertheless, I would like to make some comments from the empirical point of view of the health physicist, recognizing full well my lack of qualifications to make such comments.

It is necessary that radiation protection standards at the present time are properly based upon the data obtained from epidemiological studies of humans exposed to ionizing radiation. This is in no way intended to derogate fundamental radiobiology or animal studies. However, even the extrapolation from "mice to men" is fraught with difficulties. Evans has often alluded to the large differences between rats, beagles, and man in radiosensitivity to radium, and to the need to choose the correct radiobiological end-point.[30]

With such difficulties evident in animal studies, it is apparent that extrapolations from cellular radiology, or from studies of particular tumor systems are fraught with uncertainty. When Rossi and his colleagues have pointed to the complexity of tumor induction processes when hormones are involved,[31,32] when discussing the incidence of mammary neoplasms in Sprague-Dawley rates Rossi and Kellerer[31] conclude: "With the complexity of the tumor induction process established, there remains little justification for linear extrapolations, and this conclusion, in turn, removes apparent inconsistences between the dose-effect relation postulates and histological evidence to the effect that carcinogenesis requires the transformation of several contiguous cells. There is, however, at present insufficient evidence for numerical estimation of tumor incidence based on linear or other extrapolations."

If we are to rely upon epidemiological studies it is most important to understand their limitations. The late Sir Ronald Fisher always began his series of undergraduate lectures to his students at Cambridge by demonstrating that there was a highly significant correlation between the population density of storks and the birth rate. He earnestly implored his students not to draw the conclusion that a causal relationship had been established!

Jablon[33] has stated the difficulty with great clarity: "as it happens, it is almost always possible to find flaws in surveys (not excluding the Oxford survey*). By the very nature of the thing we do not have experimental control in a survey. We cannot guarantee that two groups of people are wholly comparable save with respect to the one factor that we wisn to study. We cannot regard any single survey, no matter how carefully done, as the equivalent of the large, well-controlled experiment that, ideally, we would prefer. We therefore invoke what is, I suppose, a new principle: If many surveys, none perfect but conducted in diverse contexts, all point to the same conclusion, then that conclusion is likely to be right. So it has been with the issue of smoking and lung cancer; and similarly, after the first report from the Oxford Survey,* a number of investigators, working in differing settings and using varying materials have studied the question, but here the results have not been unanimous."[33]

---

*The "Oxford Survey" refers to studies of the incidence of leukemia in children irradiated <u>in utero</u> made by A. M. Stewart and her colleagues.[34,35]

Patterson and Thomas[36] have shown, using a simple model, that the number of man years, M, required to form the basis of a study to reveal radiation induced decrease in populations chronically exposed to a radiation level D rem/y greater than the controls given by:

$$M \simeq \frac{4}{rD}\left[1 + \frac{2f}{rD}\right] \qquad (1)$$

where r = risk of cancer per rad
f = "natural" probability of cancer per year.

Substitution into equation (1) gives the results shown in Table 1.

Inspection of Table 1 shows that, taking the risk of radiation induced cancer induction as 10^{-4} rem^{-1} (Ref. 37), we see that a population of radiation workers exposed to 1 rem year of 40,000 would have to be studied for 30 years for an effective epidemiological study! One might therefore be forgiven for viewing with scepticism some recent studies that claim to show significant findings with studies of populations of a few thousand or less and with no reliable dose estimates. The ICRP has, in its most recent recommendations, published a brief summary of the risks of ionizing radiation and recommends risk estimates to be used in radiation protection.[38]

Despite the rather wide-spread unanimity of these risk estimates upon which radiation safety standards presently rest, there has been over the past decade a steady barrage of criticism from a rather small, but vocal, rump group. This group has objected that presently accepted risk estimates are too low by at least an order of magnitude. The literature contains many such

Table 1. Number of Man Years Needed for an Epidemiological Study of Radiation Induced Cancer.

Dose Rate (rem/yr)	Radiation Risk (cancers/rem)	Man Years M
0.1	10^{-2}	1.6×10^4
	10^{-3}	1.2×10^6
	10^{-4}	1.2×10^8
0.1	10^{-2}	5.2×10^2
	10^{-3}	1.6×10^4
	10^{-4}	1.2×10^6

Table 2. Risk Factors for Radiation Protection.

Tissue	Risk Factor
Red bone marrow	2×10^{-3} Sv^{-1}
Bone	5×10^{-4} Sv^{-1}
Lung	2×10^{-3} Sv^{-1}
Thyroid	5×10^{-4} Sv^{-1}
Breast	2.5×10^{-3} Sv^{-1}
All other tissues	5×10^{-3} Sv^{-1}

claims, but it is possible to mention only a few. For example, Sternglass[39] invoked the influences of radioactive fallout from nuclear weapons tests to explain a diminution in the rate of decrease in infant mortality in the early 1960's. This suggestion was ably dismissed by Lindop and Rotblat[40] but, nevertheless, there was great prominence given to the orginal suggestion of Sternglass. Recent studies do not provide support for the view that infant mortality in the 1960's was significantly affected by radioactive fallout.[41]

Sternglass[42] also claimed to be able to show correlations between nuclear power reactor operation and the incidence of leukemia in populations close by. These claims were refuted by Tompkins.[43]

Of more interest are the studies by Stewart[34,35] and other authors[44,46] of the incidence of leukemia and other cancers in children who were irradiated in utero incidentally to diagnostic procedures performed on the mother. For example, the Oxford study of Stewart and Kneale[35] found an increase of ~50 percent per rad in the exposed group when compared with the non-exposed group used for control. They also suggest their study is consistent with a linear dose-effect relationship.

These suggestions, if confirmed, would be of great importance in public health because they would provide evidence of deleterious effects to humans at dose levels of a few tenths of a rad. However, the conclusions drawn from these studies are not generally agreed upon. Stewart herself has drawn attention to the fact that several prospective studies[34] do not show such an effect. Jablon and Kato[47] have indicated inconsistencies between the Stewart data and those of the Atomic Bomb Casualty Commission (ABCC) studies of the Hiroshima and Nagasaki bomb

victims, where no elevation in leukemia or cancer in children irradiated in utero is found. Jablon,[48] in a later paper, speculated that "some of the relationships that have been reported reflect, in reality, selection of gravida for x-ray." More recently Oppenhiem et al.[49] in a prospective study of 1000 children irradiated in the course of routine pelvimetry found no conclusive radiation effect. However, they found several possible sources of error in such studies—particularly in the improper choice of control groups. They suggest that the reported radiation effects on man "have been due to bases introduced in the selection process, rather than to the radiation itself." In addition, Shore et al.[50] have disputed Stewart and Kneale's claim that their data are consistent with a linear dose relationship. When the Stewart data are divided into five year periods, the average case/control ratio fluctuates. For the most recent period (1960-1965) the case/control ratio was -0.05 ± 0.26, indicating no significant elevation of cancer incidence.

There is, then, no general agreement as to whether irradiation of the human foetus to ~1 rad does produce an elevation in observed cancer or leukemia rates. This is due to the intrinsic difficulty in drawing conclusions from epidemiological data.[33] Nevertheless, in the best interests of public health, until this issue is resolved both the ICRP and NCRP have recommended limiting radiation exposure to pregnant women of reproductive capacity.[51,52]

In some cases incorrect conclusions are drawn which suggest risk factor much higher than is likely. For example Morgan[53] has interpreted the data of Modan[54] and his colleagues to suggest that exposures of a few rads to the thyroid will significantly increase the risk of thyroid cancer. Modan et al. noted an elevation of thyroid cancer in individuals whose heads were irradiated in the treatment of tinea capititis. The thyroid gland was in the radiation field and received absorbed doses of a few rads. The pituitary gland was also in the radiation field and the absorbed dose to the pituitary was an order of magnitude higher than the absorbed dose to the thyroid. The most probable cause of the elevation of thyroid cancers observed by Modan et al. is therefore the irradiation of the pituitary and not the thyroid.

Many other examples may be found in the literature and they continue to appear. Recent examples are the Mancuso study,[55] the Tri-State studies[56] and the Portsmouth shipyard workers study.[57] Each must be studied on its merits. If the effects claimed are confirmed, there will be important ramifications on our radiation protection standards.

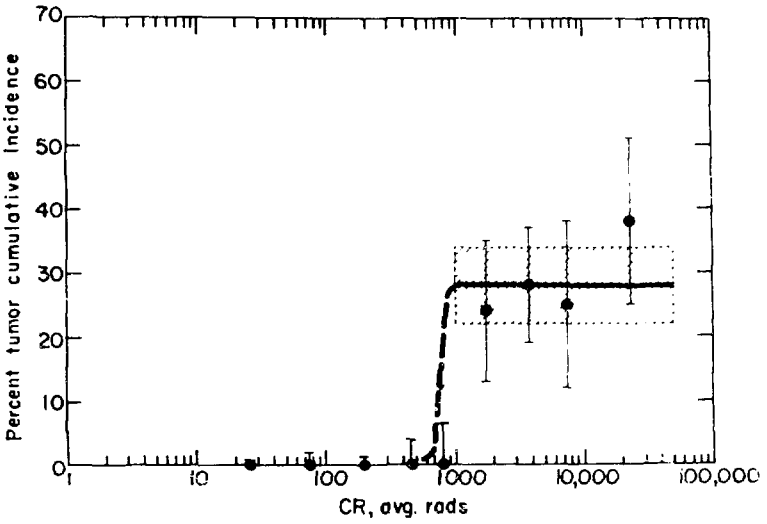
DOSE EFFECT RELATIONSHIPS

Much of the present controversy concerning radiation effects lies in the fact that we are forced to extrapolate risk estimates obtained from epidemiological studies of persons exposed to tens or even hundreds of rads (and usually at very high dose rates) down to the absorbed doses and absorbed doses rates of concern in radiation protection (a few rads per year, or less). This extrapolation has led to a great deal of discussion, and it will be discussed during this course in lectures by Partezke,[15] Silini,[16] and Rossi.[24] Suffice it to say at the present time that two of the pieces of data used as a basis for present radiation protection standards show non-linear dose-effect relationships.

Our protection standards for internal radiation are, in part, founded upon the studies of the radium-dial painters. These studies represent one of the few pieces of chronic human exposure data we have. Figure 2 shows the observed tumor cumulative incidence in epidemiologically suitable cases as a function of average skeletal cumulative rad dose as reported by Evans et al.[58,59] Evans, in fact, hypothesizes that his data may show evidence of an effective threshold. Figure 3 shows a plot of tumor appearance time versus average skeletal cumulative rads. There is a suggestion that the tumor appearance time increases as the dose decreases. When the tumor appearance is longer than the life expectancy for an individual an "effective threshold" may be said to exist.

The concept of an "effective threshold" is of great interest and has been invoked in other areas of toxicology. Thus, in the analysis of data on dose of a carcinogen versus the period between exposure and tumor appearance, Jones and Grendon[60] find that, for all carcinogens examined including radiation and a number of chemicals and in a variety of mammalian species including man, the relationship between latent period, L, and dose, D, can be expressed as: $L = CD^x$, where x is generally close to 1/3. A biological model has been developed to account for this similarity of behavior among such divergent carcinogenic agents. If the generalization proves valid, it will justify the use of "practical thresholds" in estimating the effects of radiation and other carcinogens at low levels. Dinman[61] has persuasively argued that stochastic determinants impose a lower limit on the dose-response relationship between cells and chemicals, and one would assume similar arguments applied to cellular-radiation effects.

It is of great interest whether effective thresholds of absorbed dose or absorbed dose rate exists for all radiation effects in man. It does seem clear from the data presented in



XBL 7512-9836

Figure 2. The observed tumor cumulative incidence or occurrence in an epidemiologically suitable group of radium dial painters (Evans et al., 1972).

Fig. 2 that the dose-effect relationship is non-linear. Gofman and Tamplin[62] have suggested that these data are consistant with linearity but the chance that this is so is 10^8 to 1 against.[59]

External radiations protection standards are, in part, based upon data on the incidence of leukemia and other cancers in the survivors of the nuclear weapons explosions at Hiroshima and Nagasaki. Analysis of the Japanese survivor data is difficult, and this difficulty is compounded by the difference in radiation fields produced by the two weapons. At Hiroshima the influence of a substantial absorbed dose caused by neutrons has made dose estimates and interpretation difficult. At Nagasaki, however, the situation is somewhat simpler in that the neutron contribution to absorbed dose was smaller and "wide ranges in the assumed neutron potency factor cause only a small variation (±10 percent) in the calculated risk rate coefficient for Nagasaki."

Figure 4 shows the estimated annual leukemia deaths per 10^6 persons for the exposed population at Nagasaki during the period 1950-1970. Mays et al.[63] conclude:

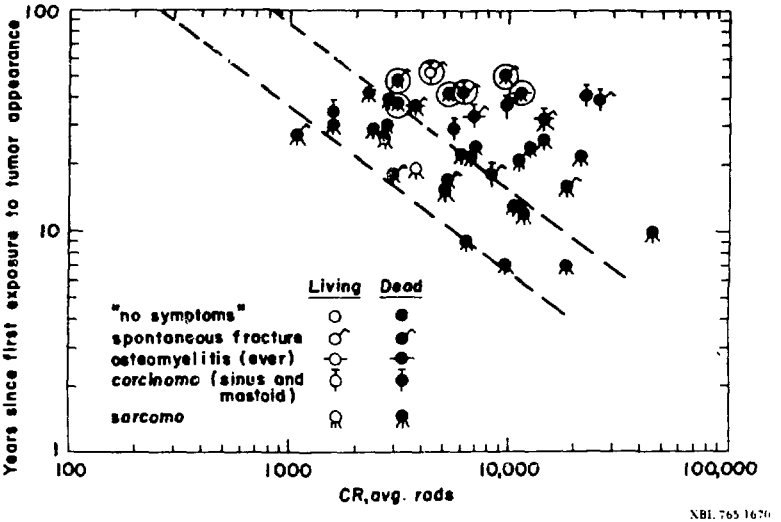
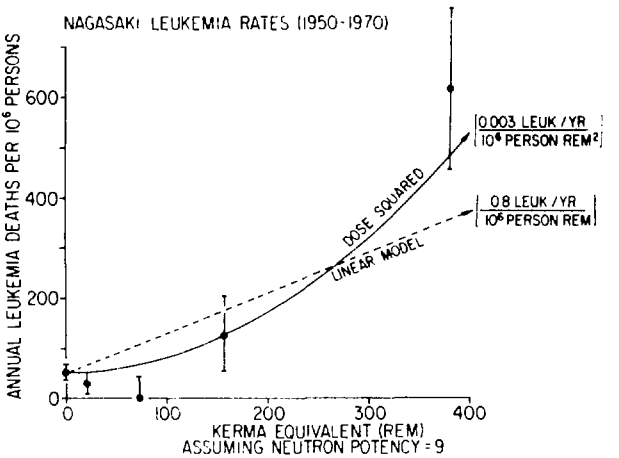


Figure 3. Log-log presentation of tumor appearance time versus average skeletal cumulative rads (CR) for radiogenic tumors (Evans et al., 1972).

"The non-linear appearance of the plotted dose-response curve for Nagasaki raises reasonable doubt on whether the dose-response is really linear (Fig. 4). Among the 4931 persons exposed at Nagasaki to 10-99 rads, 7.2 total cases of leukemia are predicted (4.7 natural plus 2.5 induced according to the 'preferred' linear estimate), whereas only 2 leukemia cases were actually observed. A linear relationship predicting 7.2 cases when only 2 were observed is rejected significantly (P = 0.03). An excellent fit to the Nagasaki incidence rate is made by the fitted dose squared relationship of 0.003 induced leuk per year/10^6 person rem^2 starting at a natural incidence rate of 52 leuk per year/10^6 persons, and assuming an average neutron potency factor of 9. This dose squared relationship will be used to provide alternative estimates of risk.

"Now, the lifetime risks will be estimated for leukemia induced by total body x-ray irradiation at high dose-rates (10-1000 rem/min) such as received



XBL 7512 9837

Figure 4. The leukemia deaths (expressed as deaths per million people) observed among the Nagasaki survivors, plotted as a function kerma equivalent (rem) (A neutron RBE of 9 has been assumed). The error bars show one standard deviation; the darkened line, a dose squared model (Mays et al., 1973).

received by the A-bomb survivors. Assuming the average death rate from induced leukemia was the same in the unobserved interval 0 to 5 years after irradiation as in the observed 5 to 25 year interval, the total incidence during the first 25 years following irradiation based on the preferred linear model would be (25 yr) (0.8 leuk per yr/10^6 person rem) = 20 leuk/10^6 person rem. Based on present trends about 80 percent of the lifetime leukemia risk should be expressed at 25 years. Therefore, the preferred linear estimate for the lifetime risk from leukemia is (20 leuk/10^6 person rem)/0.8 = 25 leuk/10^6 person rem. The higher and lower linear estimates and the dose squared estimate were calculated similarly, and are shown in Table 3."[63]

Table 3. Lifetime Risk from Leukemia at High Dose-Rates (from a total body γ-ray dose "D").

Higher linear estimate	= (40 leuk/10^6 person rem) D
Preferred linear estimate	= (25 Leuk/10^6 person rem) D
Lower linear estimate	= (14 leuk/10^6 person rem) D
Dose squared estimate	= (0.1 leuk/10^6 person rem) D^2

Thus, in some of the better epidemiological data available, there is strong evidence that a linear extrapolation from high dose data to the radiation protection dose region will give conservative risk factors. I would like to go further to stimulate discussion and suggest that, at the present time, we have no generally agreed data upon that demonstrate that exposure to x or γ-radiation below ten rads are harmful to humans. Furthermore, even if such data are eventually forthcoming the effect of dose-rate must be carefully studied.

On the other hand an entirely different situation may exist with high LET radiation and I look forward to the lecture by Silini on the effects of radiation quality upon biological effects.[25]

THE BASIC ASSUMPTIONS OF CURRENT RADIATION PROTECTION STANDARDS

Despite the great increase in our understanding in the biological effects of ionizing radiation, our present protection standards are based upon simplying assumptions that originate from the early 1950's. It is assumed that any radiation exposure may carry with it some detriment.

> "A linear non-threshold model was specifically chosen on a basis of mathematical simplicity and prudence to represent the upper limit of risk in the low-dose domain, for somatic radiobiological effects which had been observed only in a higher-dose domain. The linear nonthreshold model was not based on radiobiological data for somatic effects in the low-dose domain.
>
> "As originally introduced, care was always taken in protection committee reports to point out that the true risk in the low-dose domain would be expected

to lie between zero and the upper limit given by the linear non-threshold approximation."[58]

For the purposes of radiation protection it is assumed that a quantity dose equivalent, H, is related to the presumed radiation risk.

> "In radiation protection it has been found convenient to introduce a quantity that correlates better with the more important deleterious effects of exposure to radiation, more particularly with the delayed stochastic effects. This quantity, called dose equivalent, is the absorbed Dose, D, weighted by the modifying factors Q and N.
>
> "The dose equivalent, H, at a point in tissue is given by the equation: $H = DQN$, where D is the absorbed dose, Q is the quality factor and N is the product of all other modifying factors specified by the Commission. Such factors might take account, for example, of absorbed dose rate and fractionation."[64]

The importance of dose equivalent for radiation protection is also indicated by International Commission of Radiation Units and Measurements. In ICRU Report 19A, Dose Equivalent is stated as being "related to the presumed radiation risk."[65]

> "The quality factor, Q, is intended to allow for the effect on the detriment of the microscopic distribution of absorbed energy. It is defined as a function of the collision stopping power (L_∞) in water at the point of interest. Interpolated values of Q as a function of L_∞ can be obtained from the figure, which is based upon the values shown in the table [Table 4]."[66]

THIS COURSE AND RADIATION PROTECTION

We have seen in the previous sections that the present basis of radiological protection includes many assumptions. The fundamental assumption is that the deleterious effects to man of ionizing radiation are directly proportional to the absorbed dose in the irradiated tissue. This assumption may well be shown to be false or at least an approximation under very special circumstances. Thus, Mole finds that a dose-response of the form $aD^2e^{-\lambda D}$ fits the data for the incidence of both thyroid cancer and breast cancer in the survivors of Hiroshima.[67]

Table 4. L_∞-Q Relationship

L_∞ in water (KeV/μm)	Q
3.5 (and less)	1
7	2
23	5
53	10
175 (and above)	20

Kellerer and Rossi[68] have proposed a theory of dual radiation action which explains radiation effects observed at the cellular level. In general neither the dose-response relationships proposed by Mole or by Kellerer and Rossi are linear. We may expect to hear more of these topics in the lectures by Paretzke[69] and Rossi.[24]

A second assumption used in radiation protection is that there is no diminution in the biological effect produced by a given absorbed dose as the absorbed dose rate is reduced. The recent statement by the ICRP that the risk estimates contained in Publications 26 (Ref. 70) represent best estimates (rather than upper limits) is not universally accepted. Paretzke, in his lecture on "Late Effects of Low Doses and Dose Rates"[15] and Silini on "The Estimation of Radiation Risk in Man"[16] will address some of these issues.

The third basic assumption of radiation protection which may be challenged during this course is L_∞-Q relationship. This relationship is now some twenty years old,[71] and some redifinition is perhaps overdue. There have been recent challenges of the basic concept of this relationship. Mole has suggested that "a question for the future is whether a single value of Q for a given quality of radiation can continue to be used in radiological protection, regardless of the particular tissues exposed and the nature of the biological effects which is to be minimized."[72] Rossi has in fact proposed substantial increase in the Quality Factor for neutrons,[73] based upon studies of the incidence of leukemia in the survivors of Hiroshima and Nagasaki[74] and other considerations. Furthermore, Rossi has suggested that radiation quality may be better described by a

microscopic quantity which he terms the lineal energy, rather than by L_∞.[75] Lectures by Paretzke,[69] Rossi,[76] and Silini[25] will discuss some of these issues. Because their is no unanimity evident in the literature we may expect some lively discussions.[32,77-81]

One of the facts that will make these discussions informative is that we are now beginning to accumulate a great deal of information on high LET radiation effects. Following the first acceleration of heavy ions to high energies at Princeton[82] and a few months later at Berkeley,[83] high LET radiations have been available which permit not only studies of cellular radiobiology but also whole body irradiation of small mammals. Schimmerling[84] will discuss the new sources of radiation that have become available in the past decade, while Curtis will discuss their application to medicine.[85]

Perhaps we can hope that, for this course at least, the views of Francis Bacon will prevail: "If a man begin with certainties, he shall end in doubts; but if he will be content to begin with doubts, he shall end in certainties."[86]

REFERENCES

1. D. G. Rossetti, 1882, Letter to Hall Caine in "Recollections of Rossetti" by H. Caine.
2. Oxford English Dictionary, Compact Edition, 1971, Oxford University Press, New York.
3. R. H. Thomas and A. Rindi, Eds., 1976, "Proceedings of the First Course on High Energy Radiation Dosimetry and Protection" Erice, Sicily, Italy. IEEE Trans. Nuc. Sci. NS 2, 1315-1427.
4. K. Z. Morgan, 1975, Suggested Reduction of Permissible Exposure to Plutonium and other Transuranium Elements. Am. Ind. Hyg. Assoc. J., 36, 567.
5. C. Parkinson, Northcote, 1957, "Parkinson's Law." Houghton Mifflin Co., Boston.
6. United National Scientific Committee on the Effects of Atomic Radiation Sources and Effects of Ionizing Radiations, "UNSCEAR 1977 Report to the General Assembly," United Nations, 1977.
7. W. W. Lawrence, 1976, "Of Acceptable Risk: - Science and the Determination of Safety" William Kauffmann, Inc., Los Altos, California.
8. op. cit. ref. (7) p. 18.
9. N. A. Frigerio, and Stowe, R. S., 1975. "Carcinogenic and Genetic Hazard from Background Radiation," IAEA SM 202/805 Symp. On Biological Effects of Low Level Radiation.

10. W. D. Rowe, 1974, "EPA Approach to Environmental Analysis and Control of Radiation," Course on Environmental Analysis and Environmental Monitoring for Nuclear Power Generation, University of California, Berkeley.
11. R. H. Chamberlain, 1973, Facts, Fables and Follies in Medical Radiology in Proc. Third International Congress of IRPA. Sept. 9-14, Washington, D. C. USAEC Report CONF - 73-0097. (2 Vols.) p. 791.
12. R. H. Thomas and D. D. Busick, 1976, "Reducing patient exposure to Ionizing Radiation - is it really necessary?" Am. Ind. Hy., Assoc. Journal. 37, 567.
13. K. Z. Morgan, 1975, Reducing Medical Exposure to Ionizing Radiation - Landauer Memorial Lecture. Am. Ind. Hyg. Assoc. J. 36, 358.
14. C. Nader, 1975, The Dispute Over Safe Uses of X-Rays in Medical Practice, Health Phys. 29, 181.
15. H. G. Paretzke, 1979, Late Effects of Low Doses and Dose Rates, Lecture No. 6 in "Advances in Radiation Protection and Dosimetry in Medicine" Course Proceedings, International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Italy.
16. G. Silini, 1979. The Estimation of Radiation Risk in Man, Lecture No. 7, in "Advances in Radiation Protection and Dosimetry Medicine" Course Proceedings, International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Italy.
17. ICRP Publication 16, 1970, "Protection of the Patient in X-ray Diagnosis," Pergamon Press, Oxford.
18. ICRP Publication 17, 1971, "Protection of the Patient in Radionuclide Investigation," Pergamon Press, Oxford.
19. V. Cohn, 1979, "Anybody Can Administer X-Rays, Critics Complain" Washington Post (July 25, 1979. p. A2).
20. U. S. Dept. of Health Education and Welfare, 1979, "Califano Calls for Accelerated Efforts to Reduce Medical X-Ray Exposure," Bureau of Radiological Health Bulletin XIII No. 5.
21. Radiation Protection Guidance to Federal Agencies for Diagnostic X-Rays. Federal Register 43, No. 22 (Wednesday, February 1, 1978, Part 5, Title 3. p. 4377).
22. ICRP Publication 22, 1973, "Implications of Commission Recommendations that Doses be kept as Low as Readily Achievable," Pergamon Press, Oxford.
23. ICRP Publication 27, 1977, "Problems of Commission Recommendations that Doses be kept as Low as Readily Achievable," Pergamon Press, Oxford.
23. ICRP Publication 27, 1977, "Problems Involved in Developing An Index of Harm," Pergamon Press, Oxford.
24. H. H. Rossi, 1979, The role of the Theory of Dual Radiation Action in Radiation Protection, Lecture No. 8, in "Advances in Radiation Protection and Dosimetry in Medicine" Course Proceedings, International School of Radiation Damage and

Protection, Ettore Majorana Centre for Scientific Culture, Erice, Italy.
25. G. Silini, 1979, Biological Effects of Radiation and their variation with Radiation Quality, Lecture No. 5, "Advances in Radiation Protection and Dosimetry in Medicine" Course Proceedings, International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Italy.
26. B. Larsson, 1979, Dosimetry and Radiobiological Effects of Protons. Lecture No. 16, Advances in Radiation Protection and Dosimetry in Medicine" Course Proceedings, International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Italy.
27. T. J. Broese, 1979, Radiogiological Effects of Neutrons, Lecture No. 18, "Advances in Radiation Protection and Dosimetry in Medicine" Course Proceedings, International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Italy.
28. J. DiCello, 1979, Radiobiological Effects of Pions, "Advances in Radiation Protection and Dosimetry in Medicine" Course Proceedings, International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Italy.
29. S. B. Curtis, 1979, Radiobiological Effects of Heavy Ions, Lecture No. 22, in "Advances in Radiation Protection and Dosimetry in Medicine" Course Proceedings, International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Italy.
30. R. D. Evans, Private Communication.
31. H. H. Rossi and A. M. Kellerer, 1972, Radiation Carcinogenisis at Low Doses, Science 175, 200.
32. H. H. Rossi and W. E. Mays, 1979, Reply to G. W. Beebe and C. W. Lande, Health Physics 36: 4666.
33. S. Jablon, 1973, Letter to the Editor, Health Physics 24: 223.
34. A. M. Stewart, 1973, The Carcinogenic Effects of Low Level Radiation, A re-appraisal of Epidemiologist's Methods and Observations, Health Physics 24: 223.
35. A. M. Stewart and G. W. Kneale, 1968, Lancet 1: 104.
36. H. W. Patterson and R. H. Thomas, Radiation and Risk - the Source Data, in "Proc. Sixth Berkeley Symposium on Mathematical Statistics and Probability," University of California Press, Berkeley, p. 313.
37. ICRP Publication 26, 1977, "Recommendations of the International Commission on Radiological Protection," Pergamon, Oxford.
38. op. cit. ref. 37, "Tissues at risk," pp. 9-13.
39. E. J. Sternglass, Bull, Atomic Scientists XXV (No. 4): 18.
40. P. J. Lindop and J. Rotblat, 1969, Nature, Dec. 27, 1969: 224.
41. V. R. Fuchs, Private Communication.

42. E. J. Sternglass, "Environmental Radiation and Human Health," op. cit. ref. 36, p. 145.
43. E. Thompkins, "Infant Mortality Around Three Nuclear Plants," op. cit. ref. 36, p. 279.
44. T. L. T. Lewis, 1960, Brit. Med. J. ii: 1551.
45. J. Wells and C. M. Steer, 1961, Am. J. Obstet. Gynocol. 81: 1059.
46. W. M. Court-Brown, R. Doll, and A. B. Hill, 1960, Brit. Med. J. ii: 1539.
47. S. Jablon and H. Kato, 1970, Lancet ii: 1000.
48. S. Jablon, 1974, "The Late Effects of Acute External Exposure to Ionizing Radiation in Man," paper read at the Fifth International Congress of Radiation Research, July 14-20, 1974, Seattle.
49. B. F. Oppenheim, M. L. Griem, and P. Meier, 1975. "The Effects of Prenatal Exposure to Diagnostic X-rays; Are they real ", paper read at the twentieth Annual Meeting of the Health Physics Society, Buffalo.
50. F. J. Shore, et al., 1973, Childhood Cancer Following Obstetic Radiography, Health Physics. 24: 258.
51. op. cit. ref. 37 Paragraphs. 115 and 116.
52. NCRP Rep. 53, 1971, Review of NCRP Radiation Dose Limit for Embryo and Fetus in Occupationally Exposed Women.
53. K. Z. Morgan, 1976, "Yes is the answer to the question of R. H. Thomas and D. D. Busick, "Is it really necessary to reduce patient exposure" Am. Ind. Hyg. Assoc. J. 37, 655.
54. B. Modan, H. Mart, D. Baidatz, R. Steinitz, and S. G. Levin, 1974, Radiation-induced Head and Neck Tumors, Lancet 1:277.
55. T. F. Mancuso, A. Stewart, and G. Kneale, 1979, Radiation Exposures of Hanford Workers Dying from Cancer and other Causes, Health Physics 33: 369.
56. I. D. Bross, and N. S. Natarajan, 1977, Genetic Damage from Diagnostic Radiation, JAMA 237: 2399.
57. T. Majarian, and T. Colton, 1978, Mortality from Leukemia and Cancer in Shipyard Nuclear Workers, Lancet May 13, 1978: 1018.
58. R. D. Evans, A. T. Keane, and M. M. Shanahan, 1972, Radiogenic Effects in Man of Long-Term Skeletal Alpha Irradiation, in Radiobiology of Plutonium, Eds., B. J. Stove and W. S. S. Jee, J. W. Press, Salt Lake City, p. 431.
59. R. D. Evans, 1974, Radium in Man, Health Physics, 27: 497.
60. H. B. Jones and A. Grendon, 1975, "The Effect of Dose on Latent Period in Carcinogenesis," paper read at the Twentieth Annual Meeting of the Health Physics Society, Buffalo, July, 1975.
61. B. D. Dinman, 1972, "Non-Concept of No Threshold Chemicals in the Environment," Science 175: 495.
62. J. Gofman, and A. Tamplin, 1971, The Question of Safe Radiation Thresholds for Alpha Emitting Bone Seekers in Man, Health Physics 21:47.

63. C. W. Mays, P. Lloyd, and J. H. Marshall, 1973, "Malignancy Risks to Humans from Total Body γ-Irradiation," Proc. Third Int. Cong. of the International Radiation Protection Association, September 1973, Washington D. C., USAEC Report, CONF 730907-VI, p. 47.
64. op. cit. ref. 37, paragraphs 17 and 18.
65. International Commission on Radiation Units and Measurements, 1973, "Supplement to ICRU Report 19 - Dose Equivalent," ICRU, Washington, D. C.
66. op. cit. ref. 37, paragraph 19.
67. R. H. Mole, 1972, British Journal of Radiology, 48: 1571975.
68. A. M. Kellerer and H. H. Rossi, 1978, A Generalized Formulation of Dual Radiation Action, Radiation Res. 75: 2.
69. H. G. Paretzke, 1979, Advances in Energy Deposition Theory, Lecture No. 3, in "Advances in Radiation Protection and Dosimetry in Medicine" Course Proceedings, International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Italy.
70. ICRP, 1978, ICRP Statement from the 1978 Stockholm Meeting of the ICRP, Annuals of the ICRP 2, No. 1.
71. RBE Committee, 1963, Report of the RBE Committee to the International Commissions on Radiological Protection and on Radiological Units and Measurements, Health Physics 9: 357.
72. R. H. Mole, 1979, RBE for Carcinogenis by Fission Neutrons, Health Physics 36: 463.
73. H. H. Rossi, 1977, A Proposal for the Revision of Quality Factor, R. Envir. Biophys. 14: 275.
74. H. H. Rossi, and C. W. Mays, 1978, Leukemia Risk from Neutrons, Health Physics 34: 353.
75. J. A. Dennis, 1978, The Sixth Symposium on Microdosimetry, Brussels, May 1978 (A Review), Radiological Protection Bulletin. No. 25: 36.
76. H. H. Rossi, 1979. Microdosimetry and its Application to Biology and Medicine. Lecture No. 4, in "Advances in Radiation Protection and Dosimetry in Medicine" Course Proceedings, International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Italy.
77. G. W. Beebe, and C. E. Land, 1979, Comments on "Leukemia Risk from Neutrons," Health Physics 36: 465.
78. H. H. Rossi, and W. E. Mays, 1979, Reply to Dr. Mole, Health Physics 36: 464.
79. V. P. Bond, Effects of Quantitative Risk on Modifying Factors and Dose Equivalent (submitted to Health Physics).
80. V. P. Bond, 1978, The Risk from Fast Neutron Exposure, paper presented at the Health Physics Society Meeting, Minneapolis, June 18-23, 1978 (submitted as a note to Health Physics).
81. C. E. Land, G. W. Beebe, and S. Jablon, 1978, Role of Neutrons in Rate Effects of Radiation Among A-Bomb Survivors,

paper presented at the Health Physics Society Meeting, Minneapolis, June 18-23, 1978.

82. M. G. White, 1971, The acceleration of heavy ions to very high energies and their scientific significance in Proc. Particle Accelerator Conference, Chicago, p. 1115.
83. H. A. Grunder, et al., 1971, Acceleration of Heavy Ions at the Bevatron, Science 174: 1128.
84. W. S. Schimmerling, 1979, New Sources of Radiation, Lecture No. 11, in "Advances in Radiation Protection and Dosimetry in Medicine." Course Proceedings, International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Italy.
85. Curtis, S. B., The New Particles and Their Application to Medicine, Lecture in "Advances in Radiation Protection and Dosimetry in Medicine." Course Proceedings, International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Italy.
86. F. Bacon, Advancement of Learning. Book I, V 8 (1605).

ACKNOWLEDGEMENT

This work was supported by the U. S. Department of Energy under contract No. W07405-ENG-48.