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A SUGGESTED GUIDELINE FOR LOW-DOSE RADIATION EXPOSURE
TO POPULATIONS BASED ON BENEFIT-RISK ANALYSIS *

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A SUGGESTED GUIDELINE FOR LOW-DOSE RADIATION EXPOSURE TO POPULATIONS BASED ON BENEFIT-RISK ANALYSIS*

Jerry J. Cohen

Current standards for allowable exposure of general populations to ionizing radiation prescribe for a maximum exposure of 500 mrem/yr to individuals and an average exposure of 170 mrem/yr to suitably sized groups. These standards, as set by the International Commission on Radiological Protection (ICRP), the National Council on Radiation Protection (NCRP), and the Federal Radiation Council (FRC) have been generally accompanied by such admonitions as; and I quote from NCRP,¹ "It is recommended that all doses be kept as low as practicable, and that any unnecessary exposure be avoided," or from FRC,² "It is critical that this guide be applied with reason and judgment."

The 170 mrem/yr standard is the most widely used as a basis for comparison in reactor siting studies or Plowshare effects evaluations, and is the one with which we will deal primarily in this report.

The various bases given for the establishment of this figure are:

- 1) The radiation protection guide for population exposure of 5 rad over the first 30 years of life, based on genetic damage. This figures out to 170 mrem/yr.
$$5 \text{ rem}/30 \text{ yr} \approx 0.17 \text{ rem/yr}$$
- 2) The arbitrary assumption of a factor of 3 between average and maximum exposure of populations.
$$\frac{0.5 \text{ rem/yr}}{3} \approx 0.17 \text{ rem/yr.}$$
- 3) Use of natural background assumed to be between 100 and 125 mrem/yr as a guide for acceptable exposure.
$$100 \rightarrow 125 \text{ mrem/yr} \approx 0.17 \text{ rem/yr}$$

A fourth possible origin which has been rumored to be the basis of this standard is depicted in (Slide #1). This is an artist's conception of an early meeting of the NCRP.

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I should point out, however, that I have found no evidence indicating that the radiation standards have been divinely inspired. It is therefore my opinion that questioning the propriety of the standards does not constitute sacrilege. Indeed, the practice seems to have become in vogue recently in some sectors of the scientific community.

Two alleged infidels from our way who have done so are Drs. Gofman and Tamplin.³ They base their objections to current standards on their "doubling dose" concept. A doubling dose may be defined as the amount of radiation exposure which would double the spontaneous incidence of malignant disease. Their analysis of current radiation exposure data led them to the conclusion that about 50 rad of exposure constituted one doubling dose. This, in turn, led to their rather famous calculation shown in (Slide #2), indicating that 32,000 additional deaths would occur in this country if the population were to receive an average exposure of 170 mrem/yr.

One needn't accept Gofman and Tamplin's assumptions to perform such a calculation. (Slide #3) If you accept the figures of Anspaugh and Robison among others,⁴⁻⁹ of $\sim 10^{-3}$ genetic plus somatic deaths per man-rad of exposure and go through the same type of exercise, you can get essentially the same result. The trouble with this kind of calculation is that it is based on some dubious, if not erroneous, premises. First, discussion of mortality risk, or numbers of deaths, can be rather misleading. Let me assure you that under any circumstances, the death rate is exactly one per person; no more, no less. Since everyone must die, the only question is when and ~~maps~~ how. I believe effect on longevity would be a far more rational and understandable basis for expressing biological risk.

Another questionable presumption is that an average exposure of 170 mrem/yr to the entire population is indeed a credible possibility. Let's explore that.

(Slide #4) shows the results of air samples taken (at some of the major cities in this country) by the National Air Sampling Network for gross β activity in air.¹⁰ As we are aware, the atmosphere is far from an homogeneous entity. Indeed, it can be characterized as being quite "lumpy". For this reason air sample results are log variant. This variance is

described by the geometric standard deviations (σ_g) shown in the column at the right. Now, if we may use this as an indication of the nature of variance of human exposure to man-made radiation, certain inferences become possible. From this data it would seem reasonable to ascribe a value of 2.5 as the typical σ_g .

If we look at the 500 mrem/yr standard for maximum exposure to individuals in the population and attempt to interpret the intent of the standard setting bodies, it would seem unreasonable to assume that not even one person out of our entire population could be allowed to receive that level of exposure. Monitoring for compliance with such a standard could create horrendous problems. One might assume that the standard was meant to apply only to persons living at the site boundary of nuclear installations, but then it's quite possible that people living at greater downwind distances could receive even larger doses under particular circumstances. Anyway, for this analysis, let us conservatively assume that the 500 mrem/yr standard would be complied with if not more than one person in 1000 were exposed in excess of this level. This assumption is also mathematically convenient since it is roughly the $+3 \sigma$ level.

In log-normal statistics the ratio between the mean and the $+3 \sigma$ level is the σ_g^3 which, in our case, would be 2.5^3 or roughly 15.7. This would mean that if the radiation standards were enforced in such a manner that not more than one person in 1000 received a dose $\geq$ 500 mrem/yr, the mean exposure would be $500 \div 15.7$, or ~ 32 mrem/yr. The average exposure would be slightly higher but certainly nowhere near the 170 mrem/yr level.

Conversely, should the condition ever occur where the average population exposure were indeed 170 mrem/yr, then roughly 12% of the population would receive doses in excess of 500 mrem/yr. Clearly, this would exceed the 500 mrem/yr limit for exposure to individuals.

A similar analysis has been performed by Knox¹¹ (Slide #5). His study considers the distribution of nuclear reactor effluent as caused by some typical atmospheric diffusion conditions. It shows that the average annual dose to individuals residing within 100 km of a nuclear site would be a factor of less than .03 of the "fence line" dose. Therefore, assuming

a "fence line" dose of 500 mrem/yr, the average exposure would be about 15 mrem/yr. Bond¹² has stated that actual operating experience with 11 power reactors indicates doses of 5 and .01 mrem/yr, respectively, at the site boundary and as an average to all persons within a 50-mile radius. This is a ratio of 50. Wright,¹³ discussing "design basis" releases from pressurized water reactors, gives data indicating a ratio of over 200.

From the foregoing it appears that the arbitrary assumption of a factor of three (3) between maximum and average dose is quite low. A factor of one or even two orders of magnitude might more closely reflect reality. This being the case, adherence to the 500 mrem/yr standard for maximum dose would, in itself, assure an average dose far lower than the prescribed 170 mrem/yr. Partially for this reason, I think it would be a good idea to abolish the 170 mrem/yr standard completely. I, for one, cannot see that it serves any useful purpose. If anything, its existence is detrimental. Being based on some rather untenable premises, it can and has given certain environmental alarmists a focal point for attacking nuclear development. From a monitoring standpoint it would be nearly impossible to judge compliance with this standard because it requires rather precise measurement of extremely small concentrations which, at best, are highly variant. In addition, it is difficult, if not impossible to determine specifically what was meant by the "suitable population group" to which the standard was meant to apply. Guidance on this point has been somewhat vague. All these problems would be eliminated if the 170 mrem/yr standard were dispensed with completely.

While we're at it, let's also rid the standards and guidelines of such nebulous phrases as "low as practicable," "no unnecessary exposure," or "avoidance of undue hazard". It is difficult to see how one can put such guidance to practical application. I have personally seen examples where literally thousands of dollars have been spent to avoid the possibility of exposing people to what, at most, would be a few mrem. I would personally question the practicability of such an expenditure, but there are many who don't, especially when their own personal money is not involved. If I had my way, I would ban such words as "practicable," "necessary," "proper," "reasonable," and "suitable" from the lexicon of the standard setters unless

they were required to explicitly define them. I assure you that for any given set of circumstances, if you polled a large enough group of people, you would get very wide spectrum of opinions on just what is "practicable" or "reasonable". If standards are not definitive they simply are not standards. I suspect that the vagueness and equivocation found in many of the radiation guidelines is due to a reluctance to come to grips with the basic issues, or stated more succinctly, a "cop-out".

Having dispensed with the 170 mrem/yr standard and the weasel words, what could we substitute as a guideline for low-dose radiation exposure to populations? First, let me submit that the mere elimination of these items would in itself constitute a distinct improvement. However, I believe a far greater improvement would be achieved by incorporating the results of benefit-risk analysis into radiation protection guidelines.

We've all heard that the risk of radiation exposure should be balanced against the benefit to be derived from such exposure. This concept, like the weather, is something that everyone seems to talk about, but nobody does anything about. In recent years, a growing number of people, including myself, have begun thinking and doing something about it. Some studies along the line of benefit-risk analysis have been already performed, albeit at a fairly primitive level.¹⁴⁻¹⁷ At this year's mid-year topical symposium on standards to be held in Richland this fall, a complete session is planned to be devoted to the subject. For those of you not familiar with the nature of this work, the objective of benefit-risk analysis is to determine a rational, definitive, and generally-acceptable means of evaluating the potential benefits of any given operation, program, or technology against the possible risks. Two years ago, at the Pittsburgh meeting of this society, I presented a paper in which I proposed the use of a new unit called the "Mer".⁵ (Slide #6) The Mer is defined as that amount of benefit required to justify an exposure to one rem. Now I'll admit that, at the time, this idea was presented somewhat with tongue in cheek, but let me assure you that now the tongue is out of the cheek, and I'm quite serious. The tangible and, hopefully, comprehensive Mer equivalents I proposed at the time were 25 days of life, 2000 motor vehicle miles, and, most important, \$250. Use of the

latter figure would conveniently enable one to calculate, in dollars, the biological damage resulting from various radiation exposures and compare this to the cost of the remedial measures necessary to reduce or avoid such exposures. One problem with this approach is that it rather explicitly infers a monetary value on human life (specifically \$250,000). This appears to be morally objectionable to some.¹⁸ However, in the subsequent two years, others,¹⁹⁻²² using entirely different assumptions, have also placed monetary values on radiation risk. These values, shown in (Slide #7), appear to be remarkably consistent. Those advocating this approach feel it is neither unreasonable nor immoral to explicitly state a type of judgment that is implicitly being made by mankind continually.

As an example of how one might apply the Mer (Slide #8), we refer to a study performed by Otway²³ on the risks of siting the Omega West Reactor in the Los Alamos Canyon. In his analysis, Otway considered all the various reactor failure mechanisms and their probability of occurrence. He also considered meteorology and all the other factors he could think of which had a bearing on reactor releases. His analysis enabled him to draw these isopleths of mortality risk per year of exposure. Now, using the Mer, it becomes a simple exercise to substitute monetary values, as seen on (Slide #9). Here it can be seen that anyone residing at the site boundary would undergo a risk equivalent to \$.25/yr. In this particular case nobody would live at the site boundary. The closest residents would actually be about a mile away, where the price would scale down to about 1¢ for every 400 years of exposure. Now, if we accept the concept of hazard duty pay which is quite common and well accepted in the military as well as certain other high-risk occupations, then it might be right and proper to compensate these people for the risk they would undergo. I believe that, at these rates, any reactor operator would be delighted to do so.

Application of some form of benefit-risk analysis into radiation guidelines would have the effect of placing low-dose exposure risks into a commonly comprehensible perspective. By retaining the 500 mrem/yr limit for individual exposure, we avoid the possibility of giving excessive exposures to any segment of the population.

Metzger²⁴ has suggested the elevation of benefit-risk analysis to the status of a science incorporating social scientists, lawyers, theologians, and even soliciting the involvement of the technically naive. Why not also involve such groups in the process of setting radiation standards.

Believing that expeditious development of nuclear energy in this country would be advantageous, if not essential, I was rather dismayed at seeing the latest AEC proposed amendments to its licensing regulations for light water reactors.²⁵ Regardless of their protestations, I view the new guidelines (5 Mr/yr) as a capitulation by the Commission to the attacks of Drs. Gofman and Tamplin, among others. It's the same old numbers game, and no matter who plays it, it's still wrong! If one accepts the often stated proposition that no safe radiation threshold exists, then any exposure could result in some harm (apparent or not). No amount of bureaucratic gobbledegook can obscure the fact that there is a finite element of risk involved with low dose radiation exposure regardless of what absolute limit is set. Lowering the dose limits to whatever happens to appear "practicable" at a given time merely evades the basic issue and can accomplish little more than temporarily to cater to the mentality of the environmental paranoids. Like the old saying goes, "If you give them an inch . . ."

Forgive me if I should sound like an "ecology freak" myself, but let me show you the sort of thing that can be done with these reduced standards. (Slide #10) According to the federal register²⁴, under the newly proposed regulations, average population exposures will be less than 1 mrem/yr and/or less than 400 man-rem/10³ MWe capacity. Calculating this out Gofman-Tamplin style, (by assuming that sooner or later, everyone will reach this dose level) we see that adherence to these new regulations could result in an additional 200 deaths/year in this country.

By what calculus, one might ask, has it been concluded that this effect is justified by the benefit anticipated from light water reactors? I, for one, think that such calculation can and should be made. It would probably reveal that this means of power generation is easily worth the attendant risk. An analytical approach toward solving benefit-risk questions could go a long way toward eliminating much of the conjecture, emotionalism and recrimination which often accompany deliberations on nuclear applications.

Man's history is replete with examples of risks taken as the cost for real or assumed benefit. Mostly these were taken on an intuitive basis. However, it is quite possible to explicitly and quantitatively define risks as well as benefits. Such benefit-risk analysis could well serve as a meaningful basis for radiation protection guidelines.

As a starting point, I would submit, for serious consideration of those groups charged with the responsibility for establishing radiation standards, the substitution of the Mer, or some similarly definitive benefit risk concept for the 170 mrem/yr limit as a guideline for low-dose population exposures. It might not solve all the problems, but I believe it would be a substantial improvement. At least it would be worth a try.

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GOFMAN AND TAMPLIN DOUBLING DOSE CONCEPT

A DOUBLING DOSE IS THE AMOUNT OF RADIATION EXPOSURE THAT WILL DOUBLE THE SPONTANEOUS INCIDENCE OF MALIGNANT DISEASE.

ONE DOUBLING DOSE $\approx$ 50 RAD.

- 0.17 RAD/Yr TO ONE GENERATION (30 Yr) = 5 RAD = 0.1 DOUBLING DOSE.
- SPONTANEOUS INCIDENCE OF MALIGNANT DISEASE = $\frac{2.8 \times 10^{-3} \text{ CASES}}{\text{MAN-YEAR}}$
- $0.1 (2.8 \times 10^{-3}) (1 \times 10^8)^* = 28,000 \text{ CASES/YEAR} + 4,000 \text{ ESTIMATED CASES FOR AGE LESS THAN 30 YEARS} = \underline{\underline{32,000 \text{ CASES/YEAR}}}$.

* ESTIMATED U.S. POPULATION OVER 30 YEARS OF AGE.

MORTALITY RISK DUE TO RADIATION EXPOSURE

AUTHOR	REF. NO.	ESTIMATED PROBABILITY OF DEATH/MAN-RAD
ANSPAUGH AND ROBISON	4	10^{-3}
COHEN	5	10^{-3}
GOFMAN AND TAMPLIN	3	10^{-3}
OTWAY	6	7×10^{-4}
BARRY	7	10^{-4}
HULL	8	10^{-4}
STORER	9	10^{-4}

ASSUME 10^{-3} ; AT EQUILIBRIUM:

$$0.17 \text{ RAD/YR} \times 10^{-3} \frac{\text{INCREASED DEATHS}}{\text{MAN-RAD}} \times 2 \times 10^8 \text{ PEOPLE}^* = 34,000 \frac{\text{INCREASED DEATHS}}{\text{YEAR}}$$

* ESTIMATED TOTAL U.S. POPULATION.

NATIONAL AIR SAMPLING NETWORK

1957 - 1958

STATION LOCATION	MEAN ($\mu\text{c}/\text{M}^3$)	GEOMETRIC STANDARD DEVIATION σ_g
BALTIMORE, MARYLAND	3.1	1.928
CHICAGO, ILLINOIS	6.0	2.360
CLEVELAND, OHIO	8.5	1.582
DETROIT, MICHIGAN	3.6	2.642
HOUSTON, TEXAS	6.4	4.787
LIVERMORE, CALIFORNIA	4.1	2.528
LOS ANGELES, CALIFORNIA	4.4	2.006
NEW YORK, NEW YORK	4.0	2.617
PHILADELPHIA, PENNSYLVANIA	4.2	2.764
ST. LOUIS, MISSOURI	15.5	3.637
WASHINGTON, D.C.	4.8	2.507

COMPARISON OF MAXIMUM TO AVERAGE
RADIATION EXPOSURES TO POPULATIONS
SURROUNDING NUCLEAR FACILITIES

AUTHOR	REF. NO.	<u>MAXIMUM EXPOSURE</u> <u>AVERAGE EXPOSURE</u>
J. J. COHEN	—	15.7
J. B. KNOX	11	33.3
V. P. BOND	12	50.0
J. H. WRIGHT	13	209.0

MER

A UNIT OF BENEFIT: THE MER IS THE AMOUNT OF BENEFIT REQUIRED TO JUSTIFY AN EXPOSURE TO ONE REM.

MER EQUIVALENTS

1. 25 DAYS OF LIFE.
2. 2,000 AUTOMOBILE MILES.
3. \$250.

BIOLOGICAL COST OF RADIATION DAMAGE

AUTHOR	REF. NO.	\$/MAN-RAD
COHEN (LRL), 1969	5	\$250.00
HEDGRAN, LINDELL (SWEDEN), 1970	19	\$100.00
DUNSTER (UK), 1970	20	~ \$ 10.00*
OTWAY (LASL), 1971	21	\$200.00
LEDERBERG (STANFORD), 1971	22	\$100.00

* A FEW POUNDS STERLING

INDIVIDUAL MORTALITY RISK CONTOURS SUPERIMPOSED ON PLAN OF LOS ALAMOS, NEW MEXICO

EFFECTS OF PROPOSED AEC REGULATIONS

1. 1.0 MREM/YR BASIS

$$1.0 \text{ MREM/YR} \times 10^{-3} \text{ MREM/REM} \times 2 \times 10^8 \text{ PEOPLE} \times 10^{-3} \text{ DEATH/MAN-REM} \\ = \underline{\underline{200 \text{ DEATHS/YR}}}$$

2. 400 MREM/10³ MWe BASIS

$$\text{INSTALLED NUCLEAR REACTOR CAPACITY ANTICIPATED BY THE YEAR 1990} \\ = 500 \times 10^3 \text{ MWe} \quad (\text{REFERENCE 26})$$

$$500 \times 10^3 \text{ MWe} \times 400 \frac{\text{MAN-REM}}{10^3 \text{ MWe}} \times 10^{-3} \text{ DEATHS/MAN-REM} = \underline{\underline{200 \text{ DEATHS/YR}}}$$