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Estimation of Health Risks from Radiation Exposures

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Health and Safety Research Division

ESTIMATION OF HEALTH RISKS FROM RADIATION EXPOSURES

M. L. Randolph

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ABSTRACT

An informal presentation is given of the cancer and genetic risks from exposures to ionizing radiations. The risks from plausible radiation exposures are shown to be comparable to other commonly encountered risks.

1. INTRODUCTION

This report* is intended to provide a means for estimating potential radiological health risks given radiation doses from - for example - past, present and future phosphate mining activities in Florida.

Risks to individuals and populations can be calculated on the basis of measured or calculated doses resulting from radiological conditions at sites of interest. Risks can be expressed in terms of the probability (chance) of injury, illness, or death resulting from some kind of activity, percent change in the incidence of a disease, or life shortening. However, the individual view of risk usually is tempered by (1) the probability of the risk, (2) the severity of the risk, and (3) choice of being exposed to the risk. The information provided here on health risks from exposure to ionizing radiation is based on the most recent literature from international and national experts in radiation biology and radiation protection. The literature is referenced with little explanation of how the risk factors were derived.

The health effects expected from exposure to low levels (e. g., less than 0.1 rem/y or 0.001 sievert/y) of ionizing radiation are not different kinds of pathological effects, but rather increased probabilities of otherwise observed effects. These include a small (unmeasurable) increase in a group of cancers, depending on which organ is irradiated. Also included in calculations of risk are possible genetic effects that may be expressed in future generations. The public appears to be

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*This presentation is adapted with little conceptual modification from U. S. Department of Energy report, ORO-831, Chapter 3 (1983).

aware of these risks as possible effects of radiation exposure, but does not seem to have a sound quantitative perception of the risks involved. The general perception of the public relative to risks from radiation appears to be that such risks are undesirable; furthermore, from newspaper and magazine accounts, it appears that the magnitude of these risks are greatly overestimated by the public (Slovic, Fischhoff, and Lichtenstein, 1979; Cohen and Lee, 1979).

2. ESTIMATION OF THE RISK OF HEALTH EFFECTS

Estimates of risk factors for exposure to radiation, both for individuals and populations, are available in a number of publications prepared by groups of well-trained, objective persons. The National Academy of Sciences issued a report from the Advisory Committee on Biological Effects of Atomic Radiation called the BEAR Report (NAS, 1960). In 1972, the National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation issued a report commonly referred to as "BEIR I" (NAS, 1972). The committee later was asked to review the risk estimators for health effects from radiation; and the results of that review were issued in the 1980 report referred to as "BEIR III" (NAS, 1989). Other groups of experts also have published risk estimators for radiation exposure; for example, both the International Commission of Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP) have long studied radiation effects. The ICRP issued Publication 26 in 1977 (ICRP, 1977). In the same year, the United Nations Scientific Committee on the Effects of Atomic Radiation published an extensive report that included estimates of risks of cancer from ionizing radiation (UNSCEAR, 1977).

2.1 CANCER

The cancer risk* estimators developed by various organizations are presented in Table 1. These values represent the estimated range of added cancer mortality (above the normal mortality from such cancers) in a population of 1 million people exposed to 0.5 rem external gamma radiation. These estimates indicate the range of health effects predicted for given radiation exposures.

Comparison of the three sets of values in Table 1 indicates that there is general agreement between mortality estimates developed by the three studies. In application of the risk estimators, care must be taken to identify the limitations of each study. The UNSCEAR and ICRP approaches provide age-weighted average lifetime risk factors. The UNSCEAR report uses absolute risk, or the number of expected cancer cases that will result from exposure of a given population. The BEIR III report uses both estimated relative risk, which is the ratio of incidence in an exposed population to the incidence in a control population, and absolute risks.

The American Cancer Society (ACS, 1983) indicates that about half of all diagnosed cancer cases are fatal. Thus, the numbers in Table 1 can be multiplied by 2 to estimate total incidence (injury and illness

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*Skin cancers are largely ignored in this presentation.

Table 1. Estimates of cancer mortality from exposure to low-level low-LET radiation

Source	Additional[a] fatal cancers estimated to occur in 1 million people after exposure to 0.5 rem of radiation[b]
BEIR, 1980, absolute-risk model	38-83
BEIR, 1980, relative-risk model	113-250
ICRP, 1977	50
UNSCEAR, 1977	40-90

[a]Additional means above the normal cancer mortality.

[b]All three groups estimated cancer mortality from radiation-induced cancers. The 0.5 rem level of radiation is the annual dose limit for the public.

in addition to fatalities but not skin cancers). These cancers would be in addition to those normally expected in a population. According to the American Cancer Society, the individual risk of getting cancer for any member in the population is about 1 chance in 4. The cure rate for these cancers ranges from 90% to 5%, depending on the type of cancer. As medical practices for the detection and treatment of cancers improve, the fatality rate, but not the incidence, may decrease.

The values given in Table 1 are the best estimates that can be provided by national and international experts in radiation biology and protection. Press releases have publicized radiation effects studies in which authors have indicated that the risk is much higher than represented by the estimates given in Table 1. Examples of this are that recent epidemiological studies on workers from the Portsmouth Naval Shipyards and the Hanford facility indicate a greater risk may exist for radiation exposure than reported in the past. It should be noted, however, that the National Academy of Sciences (NAS, 1980) did take these and other widely publicized studies into account in setting risk estimators.

Recent re-calculations of doses received in the Hiroshima and Nagasaki atomic bomb explosions raise questions about the present understanding of the relative effectiveness of the gamma and neutron radiation in producing health effects. It seems premature to base conclusions on the results obtained to date. No offsite or onsite neutron doses are associated with the radiation doses from phosphate mining.

There have been no direct measurements of increased cancer for low-level radiation exposures (1-5 rem or 0.01-0.05 Sv). Data exist only for much higher exposures (typically 100 rem or 1 Sv and above). Risks at lower doses have been estimated by assuming that the same dose/health effects relationship applies to low doses as to high doses, and then extrapolating from data taken at higher dose levels to low-dose levels.

Organ risk estimators have been developed for radiation exposure of organs. Risk factors for selected organ doses averaged over both age and sex are listed in Table 2. An estimate of the probability of injury to the individual as a result of a particular exposure can be obtained by multiplying the estimated dose by the appropriate risk factor.

The estimates of risk factors depend on the type of cancer involved; the quality factor (QF) which is determined by the nature of the radiation - low linear energy transfer (LET) radiations such radiations as X- and gamma-rays and beta particles or high-LET radiations such as neutrons, and alpha particles protons; the assumption of dose response model applicable such as linear (effect = a constant times dose) or linear-quadratic (effect = a constant times dose plus a second constant times dose squared); the assumption of absolute-risk or relative-risk-model; the variations of sensitivity with age and sex; single acute exposure or chronic exposure; and other factors. Usually the estimates are made for low-LET radiations, conservatively assuming a linear dose response curve, assuming the absolute risk model obtains, and giving population results averaged for typical and sex distributions, Table 2 shows variations in estimated mortalities with these variables.

Table 2. Radiation induced cancer mortality for selected organs from single acute exposure

Exposure	Type of cancer	Model		Lifetime risk of mortality[a] excess mortalities per 10^6 persons per rad (or rem)		Based on low or high LET radiation	Reference/page
		Dose response[b]	Risk model[c]	Rad	Rem		
Whole body	All	LQ	Abs	77	77	Low	NAS, 1980/145,209
		L	Abs	167	167	Low	NAS, 1980/145,210
		LQ	Rel	226	226	Low	NAS, 1980/145,209
		L	Rel	501	501	Low	NAS, 1980/145,210
		L	Abs	75-175	75-175	Low	UNSCEAR, 1977/414
		L	Abs	100	100	Low	ICRP, 1977/12
Whole body	Leukemia	LQ	--	23	23	Low	NAS, 1980/203
		L		∿20	∿20	Low	UNSCEAR, 1977/377
Epithelium of lung	Lung	L		900	90×10^{-6}	High	NAS, 1980; USNRC, 1983
Lung	Lung	L		20	20	Low	ICRP, 1977/11
		L		25	25	Low	UNSCEAR, 1977/399
Endosteal bone	Bone sarcoma	L		27	1.3	High	NAS, 1980/417
Bone (volume)	Bone sarcoma	L		40-200	2-5	High	NAS, 1980/414
	Bone sarcoma	L		2-5	2-5	Low	UNSCEAR, 1977/400
Liver	Liver	-		300	15	High	NAS, 1980/375

[a]Except for lung, a quality factor of 20 has been assumed for high-LET radiations.

[b]LQ = linear-quadratic model; L = linear model.

[c]Abs = absolute risk model; Rel = relative risk model.

No cumulative risk factor for lung cancer from exposure to high linear energy transfer (LET) radiation was presented in BEIR III; instead, a set of age-dependent risk rates and latent periods was given. These risk rates and latent periods were used with life table data to calculate the lifetime cumulative risk factor shown in Table 2 for the lung from gamma rays and inhaled alpha particles, such as Rn-222 emits.

The risk of lung cancer from inhalation of radon progeny is a special case. Some risk estimators for mortality from lung cancer resulting from one working level month* (WLM) of radon progeny are listed in Table 3. The range of values shown in the table is a factor of 5. For phosphate mining, radon and its daughters are probably the radionuclides of greatest concern.

Probable health effects from radon progeny exposure do not appear until after age 35 or 40 (NAS, 1980; Harley and Pasternack, 1981). The conversion from rads to rems (grays to sieverts) for radon progeny, if used, is based on assuming the QF and for high-LET radiations to low-LET radiations to be 10, Based on data from humans exposed by uranium mining, as well as from other sources, the QF is found to be between 8 and 15 for radon progeny (NAS, 1980).

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*1 WLM - 1 Working Level Month. One WL is now defined as any combination of radon daughters in 1 liter of air that will result in the ultimate emission of 1.3 x 10^5 MeV of potential alpha particle energy. Historically 1 WL was based on calculation of the potential alpha energy of short-lived daughters in equilibrium with 100 pCi (10^{-10}Ci) of radon, 1 WLM is the exposure at 1 WL for 170 hours.

Table 3. Life risk estimates of lung cancer mortality from 1 WLM of radon progeny

Source	Number of additional fatal lung cancers expected in 1 million people exposed to 1 WLM of radon progeny
Evans et al. (1981)	100
UNSCEAR (1977)	200-450
USNRC (1980)	360
BEIR III (1980)[a]	560

[a]BEIR III quotes a value of 930 (deaths/lifetime)/10^6 person-rad for lung. Using the mean of the BEIR range, 0.6 rads/WLM, we converted this to 560 (deaths/lifetime)/10^6 person-WLM.

2.2 GENETIC EFFECTS

Genetic effects are estimated to all subsequent generations as a result of an annual exposure at a particular radiation level. The risk factor used to estimate the total of all genetic effects was taken from BEIR III (NAS, 1980) to be from 60 to 1100 total cases of genetic disorders per 1,000,000 live-born offspring for each 1 rem (0.01 Sv) of dose from low-LET radiation and from 180 to 3300 total cases of genetic disorder per 1,000,000 live-born offspring for each 1 rem of high-LET radiation. The dose involved here is the calculated germ cell, which is based on the gonadal dose of the exposed individuals, their age and sex distribution, probabilities of having children, and adjustment factors of 0.82 and 0.18 for male and female exposures, respectively, to account for the relative mutational sensitivities of precursors of sperm or egg cells.

3. DISCUSSION

The risk factors given above do not take into account age grouping or sex, but instead represent average population risk estimators. For planning purposes, average estimated risks appear to be acceptable; however, for site-specific risk analyses, age- and sex-specific risk factors should be used in conjunction with demographic data for the site. For risk from radon progeny, Harley and Pasternack (1981) provide an example of risks to age groups and use of mortality tables to examine lifetime risks from continuous exposure. By using the BEIR III age-specific risk factors, one can conduct site-specific analyses for the population present in the area.

The risks from exposure to 0.5 rem (5 mSv) per year whole body can be compared with other risks commonly encountered in life from the data given in Tables 4 and 5. The risks of cancer from other common agents and the risks of other types of injuries are approximately the same as the risk from radiation. To put these values in perspective, note that Table 6 indicates that for the U. S. population the lifetime cancer risk (other than skin cancer) is about one in four and the mortality from cancer about one in seven. The current ratio of mortality to cancer incidence is about one in two which with early detection and treatment might be reduced to one in three.

Another manner of looking at risk from radiation is that the induction of cancer results in a life shortening that would not take place otherwise. When evaluated by the same method, average background radiation (about 0.1 rem/year) results in an estimated life shortening of 8 days. Estimators for comparison of life shortening expected from various activities are listed in Table 7.

Table 4. Risk comparison data — individual increased chance of death caused by selected activities[a]

Activity	Risk of death[b]
Smoking 1 pack of cigarettes (cancer, heart disease)	1.5×10^{-5}
Drinking one-half liter of wine (cirrhosis of the liver)	1×10^{-6}
Chest x-ray in good hospital (cancer)	1×10^{-6}
Traveling 10 miles by bicycle (accident)	1×10^{-6}
Traveling 1000 miles by car (accident)	1×10^{-6}
Traveling 3000 miles by jet (accident, cancer)	3.5×10^{-6}
Eating 10 tablespoons of peanut butter (liver cancer)	2×10^{-7}
Eating 10 charcoal broiled steaks (cancer)	1×10^{-7}
Exposure to 0.5 rem/year of radiation	6×10^{-5}

[a]Adapted from USNRC (1977).

[b]Probabilities are expressed in exponential notation; they can be converted to expression of chance by taking the numerical value in front of the multiplication sign (X) as "chances" and writing a one (1) followed by the number of zeros given in the exponent (i.e., 1.5×10^{-5} becomes 1.5 chances in 100,000).

Table 5. U. S. average individual risk of death in one year due to selected causes[a]

Cause	Annual risk of death
Motor vehicle	2.5×10^{-4}
Accidental fall	1×10^{-4}
Fires	4×10^{-5}
Drowning	3×10^{-5}
Air travel	1×10^{-5}
Electrocution	6×10^{-6}
Lightning	5×10^{-7}
Tornadoes	4×10^{-7}
Natural radiation (0.1 rem/year whole body)	1.2×10^{-5}
Exposure to 0.5 rem/year of radiation	6×10^{-5}

[a]Adapted from Wilson (1979).

Table 6. Cancer incidence and mortality in the United States

Events	Estimated for U S. in 1983	Approximate lifetime cancer risk[a]
New skin cancers (non-melanoma)	400,000[b]	0.127 ≃ 1/8
Other new cancers	855,000[b]	0.27 ≃ 1/4
Mortalities	440,000[b]	0.14 ≃ 1/7
Possible reduction in mortalities with early diagnosis and treatment	145,000[b]	
Mortalities with early diagnosis and treatment	295,000	0.094 ≃ 1/10
Mortalities/Other cancers	0.52 ≃ 1/2	
Mortalities with early detection and treatment/Other cancers	0.35 ≃ 1/3	

[a]Calculated as (estimated value for U.S. in 1983) x (70-year average lifespan) ÷ (U. S. population of 220,000,000).

[b]From ACS, 1983.

Table 7. Estimated loss of life expectancy from health risks[a]

Health risk	Estimates of days of life expectancy lost (average)
Smoking 20 cigarettes/day	2370 (6.5 years)
Overweight (by 20%)	985 (2.7 years)
All accidents combined	435 (1.2 years)
Auto accidents	200
Alcohol consumption (U.S. average)	130
Home accidents	95
Drowning	41
Natural background radiation	8
Medical diagnostic x-rays (U.S. average)	6
All catastrophes (earthquake, etc.)	3.5
1 rem occupational radiation dose (industry average for the higher dose job categories is 0.65 rem/year)	1
0.5 rem/year for 30 years	15

[a]Adapted from Cohen and Lee (1979).

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