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Uranium Mill Tailings and Radon

Lewis A. Hanchey

Prepared by Sandia National Laboratories, Albuquerque, New Mexico 87185
and Livermore, California 94550 for the United States Department
of Energy under Contract DE-AC04-76DP00789

Printed January 1981

Sandia National Laboratories

SF 2900-Q(3-80)

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SAND80-2142
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URANIUM MILL TAILINGS AND RADON

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ABSTRACT

The major health hazard from uranium mill tailings is presumed to be respiratory cancer resulting from the inhalation of radon daughter products. A review of studies on inhalation of radon and its daughters indicates that the hazard from the tailings is extremely small. If the assumptions used in the studies are correct, one or two people per year in the U.S. may develop cancer as a result of radon exhaled from all the Uranium Mill Tailings Remedial Action Program sites. The remedial action should reduce the hazard from the tailings by a factor of about 100.

URANIUM MILL TAILINGS AND RADON

Introduction

Sandia National Laboratories is assisting the Department of Energy in the Uranium Mill Tailings Remedial Action Program (UMTRAP). The purpose of UMTRAP is to implement the provisions of Title I of Public Law 95-604, "Uranium Mill Tailings Radiation Control Act of 1978." Among other things, the act provides for remedial action to prevent or minimize radon diffusion into the environment at designated inactive uranium mill tailings sites.

The objectives of this report are: (1) to assist UMTRAP personnel in gaining a perspective of the potential hazards from radon which is being exhaled from uranium mill tailings, and (2) to provide related information which may be useful when dealing with other organizations and the public.

Radon Hazard

The major health hazard from uranium mill tailings is presumed (by EPA and DOE) to be respiratory cancer which may result from inhalation of radon daughter products. The solid radon daughters are much more easily retained in the lungs than is radon gas; their inhalation may result in potentially significant alpha radiation doses to the respiratory system. The radon flux from uncovered tailings at UMTRAP sites can be hundreds of times greater than that from typical soils. Hence, as the radon from the tailings disperses and decays, the air concentrations of radon daughter products beyond the site are increased above normal background levels. However, dispersion is usually rapid, and except for areas in proximity to a tailings site the concentrations are typically only fractionally above background levels. Information in the Ford, Bacon and Davis Utah engineering assessments[1] of the sites indicate that usually within one mile of the tailings radon concentrations are down to background levels.

Working Level Concept

Exposure to radon daughter products is usually expressed in terms of working level months (WLM). One working level (WL) is defined as any combination of short-lived radon daughters (Po 218 or RaA, Pb 214 or RaB, Bi 214 or RaC, and Po 214 or RaC') in one liter of air leading to total emission of 1.3×10^5 MeV of alpha energy. One WLM is defined as exposure to one WL for 170 hours (the number of working hours in a month.)* The short-lived radon daughters can approach secular equilibrium whenever there is no opportunity for separation from the source radon. Such a situation

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*The Environmental Protection Agency does not use this relationship in evaluating exposure of the general population because of the difference in the amount of air breathed by the average person as compared to a man performing hard labor.

can exist outdoors during a temperature inversion and indoors in an unventilated structure. If equilibrium exists, 100 pCi/liter of radon is equivalent to one WL. Radon daughter concentrations (RDC) are usually assumed to be 50 percent of equilibrium (100 pCi/liter of radon results in 0.5 WL) if actual measurements are not available. The 50 percent equilibrium condition appears to be characteristic of residences which normally have about one air change per hour.

If 50 percent equilibrium and continuous (not just working hours) exposure are assumed, the following approximate relationships exist:

1 pCi/liter radon = 0.005 WL
0.005 WL = 0.25 WLM/year.

The radiation dose to the lung is the important factor in estimating the risk. The uncertain but commonly used relationship is:

1 WLM = 5 rem (lung dose).

Risk Estimate

Evidence that respiratory cancer can result from exposure to radon has been determined from studies of uranium and other underground miners who were exposed to high WLs for varying lengths of time. The studies revealed that miners exposed to more than 100 WLMs experienced significantly higher rates of respiratory cancer than would have been expected without such exposure. The data are inconclusive as to the effect at lower exposures. The approach used to establish an estimate of risk assumes that the dose response curve is linear, i.e., the same cancer rate per unit exposure observed at high exposures occurs at all levels of exposure down to and including background. The major effort in establishing risk estimates for radon and other radioactive hazards was performed by the National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation (BEIR). The BEIR committee in their 1972 report on "The Effects on Population of Exposure to Low Levels of Ionizing Radiation"[2] emphasized that the assumption of linearity could overestimate or, conceivably, underestimate the actual hazard at low exposures. Because of numerous factors which differ between miner and general population exposure, there is uncertainty about the applicability of the miner data to the general population.[3] However, it seems generally agreed that the miner data and the assumption of linearity provide the best available basis for developing an estimate of risk from radon exposure, in spite of the many uncertainties.

In the 1972 BEIR report it was indicated that the best estimate of risk appeared to be one lung cancer per year for every 10^6 person-rem exposure. However, it was also stated that, because additional cancers could develop in the miners being studied, in the final analysis the absolute risk could approach 2 cases/10^6 person-rem-year. The miners did develop additional cancers, and in 1976 an ad hoc committee of the BEIR Committee presented an estimate of 2 lung cancer cases/10^6 person-rem-year (10 cases/10^6 person-WLM-year) for use in evaluating the risk from radon exposure.[4] This appears to be the most recent authoritative statement on this hazard and is the risk estimate used by the EPA in their Draft Environmental Impact Statement on uranium mill tailings.[5]

Ford, Bacon, and Davis Utah used an estimate of 6 cancers/10^6 person-WLM-year in their Phase II-Title I engineering assessments of the UMTRAP sites. This estimate, which was derived from information presented in the 1972 BEIR report, has been superseded by the 1976 BEIR estimate. It should be noted that the number of health effects or cancers predicted by FBDU in reference 1 and EPA in reference 4 does not exactly differ by the 6:10 ratio of the risk estimates because their models for predicting cancer are not the same.

Hazard Perspective

Several quotes from the 1972 BEIR report help place their risk estimates in perspective:

> "Given the estimates for genetic and somatic risk, the question arises as to how this information can be used as a basis for radiation protection guidance. Logically the guidance or standards should be related to risk. Whether we regard a risk as acceptable or not depends on how avoidable it is, and, to the extent not avoidable, how it compares with the risks of alternative options and those normally accepted by society."

"It is not within the scope of this Committee to propose numerical limits of radiation exposure. It is apparent that sound decisions require technical, economic and sociological considerations of a complex nature."

"The public must be protected from radiation but not to the extent that the degree of protection provided results in the substitution of a worse hazard for the radiation avoided. Additionally, there should not be attempted the reduction of small risk even further at the cost of large sums of money that spent otherwise would clearly produce greater benefit."

"It is emphasized that the risk estimates lack precision but do indicate that the mean dose both to the population and to each individual must be kept as low as practicable."

The EPA also recognizes the uncertainty of the risk estimates used in setting standards, as the following extracts from the "EPA Policy Statement on Relationship Between Radiation Dose and Effect" (41 FR 28409) indicate.

"Although much is known about radiation dose-effect relationships at high levels of dose, a great deal of uncertainty exists when high level dose-effect relationships are extrapolated to lower levels of dose, particularly when given at low dose rates."

"It is the present policy of the Environmental Protection Agency to assume a linear, nonthreshold relationship between the magnitude of radiation dose received at environmental levels of exposure and ill health...."

"In adopting this general policy, the Agency recognizes the inherent uncertainties that exist in estimating health impact at the low levels of exposure and exposure rates expected to be present in the environment due to human activities, and that at these levels, the actual health impact will not be distinguishable from natural occurrences of ill health, either statistically or in the forms of ill health present."

"It is to be emphasized that this policy has been established for the purpose of estimating the potential human health impact of agency actions regarding radiation protection, and that such estimates do not necessarily constitute identifiable health consequences."

Uncertainties

What are believed to be some of the more significant uncertainties relative to the data on and analysis of the radon hazard are discussed below.

- The actual WL exposure is not known for many of the mining groups studied. This is particularly true for the higher exposure levels which occurred before there was concern over radon. The individuals performing the studies believe their estimated exposure levels are probably on the high side--meaning the risk per unit exposure could be higher than indicated.[2,6,7]

- The best data available on U. S. uranium miners indicate that in the 1950's and 1960's exposure levels of tens or even hundreds of WL were not uncommon, though the duration of exposure was generally short. Exposure rates of 100 to 200 WLM per year were apparently common. There may be a significant difference between the effect of exposure at these high rates and that of exposure at much lower rates.[2,3,6] The rate from normal background radon appears to be on the order of 10 WLM per lifetime.

- The data on U. S. uranium miners do not project a linear dose-response curve as per the assumption used in establishing the risk estimate. Data were inconclusive regarding effects below 120 WLM.* Exposure in the 120 to 360 WLM range resulted in a cancer risk per unit exposure that was significantly higher than that in the 360 to 1800 WLM range. The risk did begin to increase above 1800 WLM. The data suggest low exposures possibly could be more effective than high ones in inducing cancers.[4,6,7]

- The WLM, which is a measure of the alpha energy in inhaled air, may not accurately reflect the dose to the respiratory system. The fraction of radon daughters which are attached or unattached to aerosols and the particle size distribution of aerosols are significant factors in determining dose. Unattached RaA is particularly significant because it readily deposits in the upper respiratory tract. Other factors which can affect dose include ventilation, humidity, and chemical composition of aerosols. Variations in these factors can cause an order of magnitude change in estimated dose.[2,3,8,9]

- The miners were exposed to high levels of dust and were, in most cases, heavy smokers. The dust and smoke may have affected lung clearance and acted as cancer promoting agents.[3,7] Thus, the miners may have been more susceptible than the general public to cancer initiation by radon daughters.

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*The earlier statement that data were inconclusive as to effects below 100 WLM took account of non-U.S. sources.

- Most cancers in the miners were of the small-cell anaplastic type. If it is assumed that radon induced cancers will be of that type and that the chances of developing such a cancer are proportional to radon exposure, background radon would be expected to induce a certain number of small-cell anaplastic cancers in a given population group. However, one Norwegian study found that the total number of such cancers in a non-smoking population group was smaller than would have been expected even if background radon were assumed to be the only possible cause of such cancer.[2,9,10]

- Uranium mill workers have not experienced an increased risk of lung cancer. The BEIR report suggested this may have been the result of good ventilation.[2,6] (While the mill ventilation may have been much better than that in the mines, it is hardly conceivable that the mill workers would not have experienced exposure levels considerably above background and above the levels that would be experienced by anyone currently residing in proximity to the UMTRAP sites.)

Absolute and Relative Risk

The absolute risk is the excess of risk due to irradiation. It is expressed as the number of excess cancers per unit of time in an exposed population of given size per unit of dose. It is based on the assumption that the risk is directly proportional to the dose received. The estimated risk discussed thus far in this report is an absolute risk.

The relative risk is the ratio between the risk in the irradiated population and that in the nonirradiated population. It is expressed in terms of the percent increase in the cancer rate per year per rem. For example, the EPA estimates the relative risk for lung cancer to be a 0.6 percent increase in cases per year per rem.[5] The use of relative risk is appropriate if the risk due to radiation increases in proportion to natural risk. Between 1950 and 1976 the incidence of lung cancer among U.S. males increased by a factor of 3.3. Hence, the relative risk concept would have predicted a 3.3 times higher risk from a lung dose of one rem in 1976 than it would have predicted in 1950. Factors affecting the chances of developing cancer include age, sex, race, where a person lives, and life-style. Any or all of these factors can be considered in a relative risk model--again, if it is believed there is a correlation between radiation risk and natural risk.

The cancer rate in the areas where the study group miners lived is low in comparison to the average rate in the U.S. In those parts of the country where the natural risk is higher than that it is in the mining areas, a relative risk model will predict more cancers than will an absolute risk model. Hence, in most parts of the U.S., relative risk estimates of numbers of cancers are higher than those predicted using absolute risk.

Among population groups which were exposed to high levels of radiation to the lungs, there were periods of years between the exposure and the appearance of significant increases in the number of clinically detectable cancers. This interval is called the latent period. The cancer incidence rate remained elevated for many years and then began to diminish. The period during which the incidence rate remains at the undiminshed level is known as a plateau. In the 1972 BEIR report, a latent period of 15 years and a plateau of either 30 years or a lifetime were suggested.[2]

Several points should be kept in mind in order to understand the significance of the risk estimates:

- Radiation induced cancers are indistinguishable from those occurring naturally.

- The actual cause of cancer (of any kind) is not known. Evidence of radiation induced cancer is statistical, not medical.

- All people are exposed to natural and man-made sources of radiation and some to occupational sources, but only a small percentage ever develop what are postulated to be radiation induced cancers.

- In using absolute or relative risk estimates, it appears appropriate to consider a latent period and plateau. However, this does not mean radiation induced cancers could not occur before or after the plateau period.

Radon Exposure and Risk

Estimates of the risk from exposure to various levels of radon were calculated (Table 1). These were derived from EPA estimates in reference 5. The EPA analysis considers the following factors and assumptions:

- Continuous exposure to one WL results in 27 WLM per year rather than 50 WLM. This is based on the fact that, on the average, a member of the general population breathes a smaller volume of air than does a working miner.

- Children breathe more air in relation to lung mass than do adults and, hence, receive higher doses from exposure to any given WL.

- Ten-year latent period.

- Lifetime plateau.

- Age distribution and mortality rates are considered.

Table 1
Estimated Lifetime Cancer Risk from Exposure to Radon

Radon Concentration (Pci/l)	WL	Lifetime Chance of Cancer (Percent)	Comments
0.3	0.0015	0.11	Average outdoor background in U.S.[11] ICRP MPC for general population.[12]
0.6	0.003	0.21	Outdoor background in Salt Lake City.[1]
0.8	0.004	0.28	Average indoor background in U.S.[5] Outdoor background in Grand Junction.[1]
1.0	0.005	0.35	ICRP MPC for controlled offsite population.[12]
1.2	0.006	0.42	Average outdoor background at 19 UMTRAP sites.[1]
1.4	0.007	0.50	Average indoor background in Norway.[10] Average indoor background in Grand Junction.[13]
2.0	0.01	0.71	Surgeon General's Grand Junction Guideline for no action (0.01 WL above background).[14]
3.0	0.015	1.1	EPA Interim Offsite Cleanup Standard - including background.[13]
3.2	0.016	1.1	Four times Grand Junction's outdoor background.*
4.8	0.024	1.7	Four times the 19 UMTRAP site average outdoor background.*
10	0.05	3.5	Surgeon General's Grand Junction Guideline for required action (0.05 WL above background).[14] ICRP MPC for occupational exposure.[12]
67**	0.33**	2.1**	Maximum permissible exposure for U.S. miners - set by Department of Labor.

*The EPA indicates indoor WL may be four times outdoor WL.[15]
**Calculations based on occupational exposure age 25 to 55 rather than continuous lifetime exposure.

The EPA estimates are similar to those made by FBDU, in reference 1, but this is fortuitous. The EPA analysis is more refined, and some of their assumptions increase while other decrease their estimates in comparison with those by FBDU. The EPA estimates appear reasonable, and it seems desirable for Sandia to be consistent with EPA.

It has been estimated that background radon may be responsible for about 10 percent of lung cancer deaths.[5,10] The EPA indicated that the U.S. death rate from lung cancer in 1970 was 2.9 percent.[5] On the basis of data from references 16 and 17, it appears that by 1976 the rate had risen to 4.6 percent. The estimates of lifetime chance of cancer shown in Table 1 are reasonably consistent with an assumption of radon causing 10 percent of the lung cancer deaths. This places the table estimates in perspective; however, it should be noted that:

- Background radon levels vary widely, and the actual average background level in the U.S. is not accurately known.

- The validity of the estimates is dependent on how applicable the data on miners are to the general population.

In Table 2 the estimated risk from the Salt Lake City (SLC) tailings are presented in terms of deaths per year per 100,000 people and lifetime chance of fatal cancer. The estimates for the

Table 2

Estimated Risks - Exposure to Radon
From SLC Tailings and from Normal Background Radon

Source of Exposure	Location	Estimated Deaths/Year Per 100,000 People	Estimated Lifetime Chance of Fatal Cancer (Percent)
SLC Tailings (Current Condition)	Edge of Pile (0.05 Mile)	41	3
	SLC (Average)	0.22	0.015
SLC Tailings (Covered in Place)*	Edge of Pile (0.05 Mile)	0.41	0.03
	SLC (Average)	0.0022	0.00015
Normal Background Radon	SLC Outdoors	3	0.2
	US Outdoors (Average)	1.3	0.1
	US Indoors (Average)	3	0.2

*Three meters of soil is assumed to reduce the radon flux and hazard by a factor of about 99 percent - based on EPA half-value layer of 0.5 meters for typical western soil.[5]

tailings in their current condition are taken from the EPA DEIS.[5] It is estimated that covering the tailings in-place would reduce the radon hazard by a factor of about 100. Table 2 compares the hazard from the tailings with that from normal background radon (as calculated for Table 1).

The EPA has estimated the total number of people that would develop fatal cancers due to radon emissions from all of the UMTRAP tailings piles. Their estimate using the absolute risk model is 1.7 people per year.[5] Their model considered radon disperson patterns and population distributions in evaluating the risk to the total U. S. population.

Table 3 presents some death rate statistics for several familiar hazards faced by people in the U. S. and in Utah and SLC. The information in Table 3 is not directly comparable with the estimates in Table 2 because the estimates do not take into consideration age considerations that are reflected by the statistical data. Hence, the tailings hazard estimates in Table 3 are useful only for a "ballpark" comparison with other data. It is, however, interesting to note that the hazard from the SLC tailings appears to be "in the same ballpark" as being struck by lightning.

Table 3

Death Rate Statistics

Cause of Death	Population Group	Actual Deaths/Year Per 100,000 People	Percent of Total Deaths From this Cause	Year of Data
Lung Cancer	US Males	63	7	1976
Motor Vehicle	US	22	2.5	1976
	Utah	29.2	4.9	1978
	SLC	19.4	--	1978
Falls	US	6.6	7.4	1976
	Utah	8.1	1.3	1978
Lightning	US	0.04	0.004	1976
	Utah	0.1	0.013	1978
SLC Tailings (Current Condition)	SLC	0.22 (Est.)	0.015*	--
SLC Tailings (Covered in Place)	SLC	0.0022 (Est.)	0.00015*	--

*Estimated lifetime chance of fatal cancer

Standards for Radon Exposure

The International Commission on Radiological Protection (ICRP) maximum permissible concentration (MPC) for the general population--0.33 pCi/liter[12]--would be applicable to the radon exhaled from the UMTRAP piles. This MPC is in addition to background and does not consider whether an individual is indoors or outdoors. It should be noted that the MPC is essentially the same as the estimated average outdoor background exposure. The proposed EPA criteria for disposal of the UMTRAP tailings would allow the flux from the disposal site to be about double what EPA postulates to be the average flux from soil in the U.S. Although the EPA criteria would appear to be consistent with the ICRP guidelines, there are two problems:

- The soil in the western U.S. where the tailings disposal sites will be located may well exhale a higher radon flux, independent of the tailings, than the EPA criteria allow.

- Only people living on top of the disposal site would experience the higher but acceptable MPC; offsite exposure levels would diminish rapidly with distance.

The ICRP MPC of 1 pCi/liter for controlled offsite populations[12] would probably be applicable to the UMTRAP offsite cleanup program. The EPA interim cleanup standard of 0.015 WL appears to be reasonably compatible with the ICRP level if indeed the 0.007 WL for in-door background in Grand Junction is correct. However, variations in background and difficulties in accurately determining the WL in structures will create problems.

Cancer Data

It can be noted in Table 1 that background levels of radon in the areas where the UMTRAP sites are located are significantly higher than the average background levels in the U.S. Total external background radiation levels around the sites are also significantly above the U.S. average.[1,11] However, it is interesting that data on cancer rates in the U.S. show that the rates for both respiratory cancer and the total of all types of cancers are significantly lower around the sites than for the overall U.S. Figure 1 shows the rate for all cancers for white males by state for the period 1950-1969[18] as a function of the total (terrestial and cosmic) background radiation.*

In the 1972 BEIR report it was estimated that radiation of 100 mrem/year might cause about one percent of all cancer deaths.[2] The fact that the cancer rate is inversely proportional to radiation

*Total external background radiation in the U.S. is estimated to average 84 mrem/year: terrestial, 40 mrem/year; cosmic, 44 mrem/year.[11]

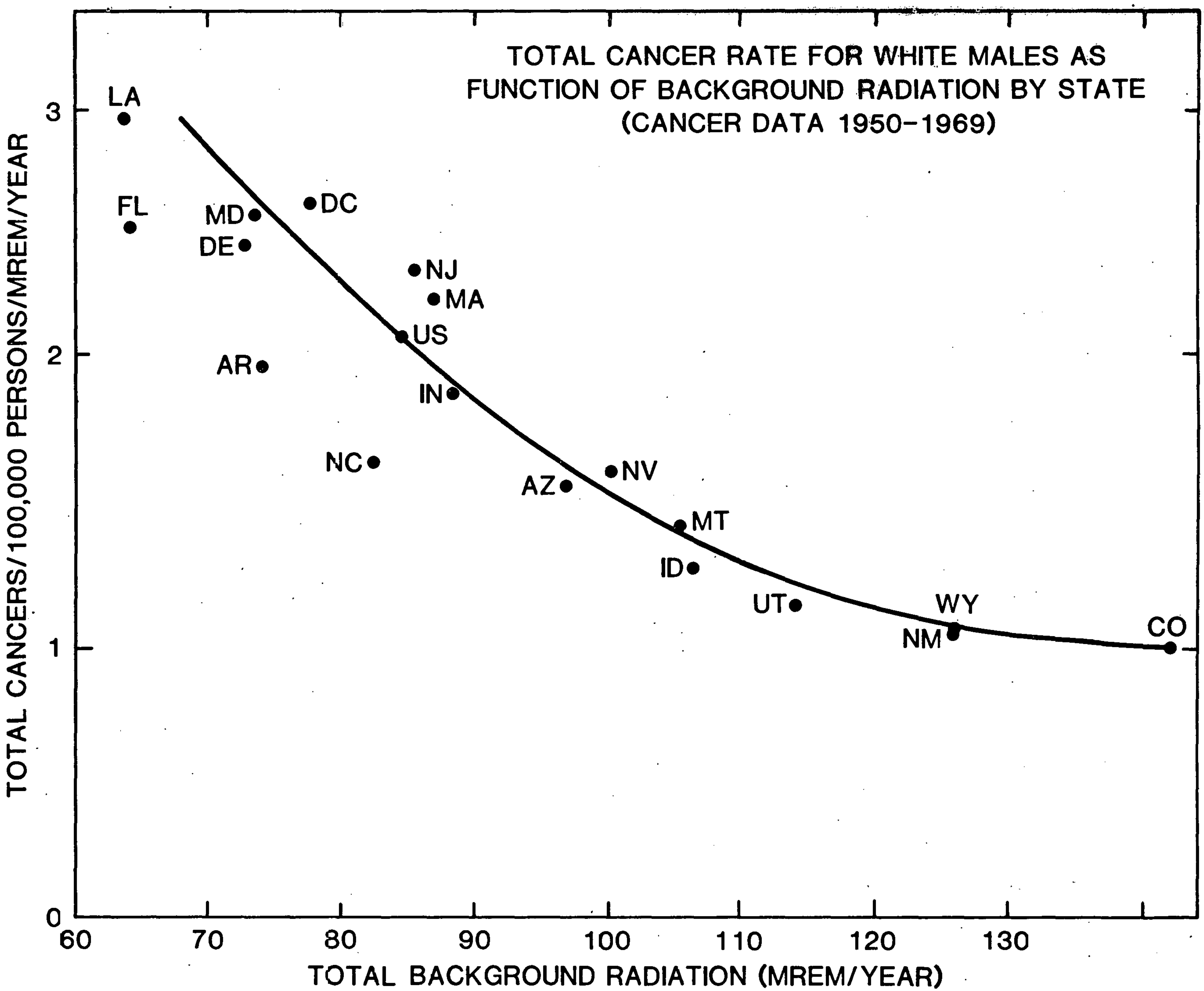
TOTAL CANCER RATE FOR WHITE MALES AS
FUNCTION OF BACKGROUND RADIATION BY STATE
(CANCER DATA 1950-1969)
TOTAL CANCERS/100,000 PERSONS/MREM/YEAR
TOTAL BACKGROUND RADIATION (MREM/YEAR)
0
1
2
3
60
70
80
90
100
110
120
130
LA
FL
MD
DE
DC
NJ
MA
US
AR
IN
NC
AZ
NV
MT
ID
UT
WY
NM
CO

Table 4

White Male Cancer Rates (Per 100,000)

Data from 1950-1969[18]

Location	Respiratory Cancer	All Cancer
US	37.98	174.04
Colorado	28.29	144.19
Gunnison Co. (Gunnison)	23.2	127.4
La Plata Co. (Durango)	28.2	130.3
Mesa Co. (Grand Junction)	28.3	139.8
New Mexico	24.71	136.30
San Juan Co. (Shiprock)	29.0	114.8
Utah	21.98	133.14
Salt Lake Co. (SLC)	26.2	142.6
Wyoming	26.73	138.98
Fremont Co. (Riverton)	25.2	138.01

levels is interesting but, because radiation is estimated to cause only this small percentage of cancer deaths, is statistically insignificant.

Table 4 lists the total cancer and respiratory cancer rates for the U. S. and for several counties where UMTRAP sites are located.[18] As can be observed, the rates in these counties are comparable to the rates in their respective states and much below the U.S. rate; hence, the higher levels of radon exposure in those counties does not result in correspondingly higher cancer rates. While these data definitely do not prove that low exposure to radon is not cancer inducing, it does seem reasonable to conclude that someone concerned about cancer would be better off living near an UMTRAP site than in some other part of the country where radon levels are much lower.

Smoking and Cancer

The following information gives some perspective on the relation between cancer and smoking.

- Male smokers are 1.7 times more likely to develop lung cancer than Male nonsmokers.[17]

- Males who smoke two or more packs of cigarettes a day are twice as likely as male nonsmokers to develop lung cancer.[17]

- Smoking is believed to be a cocarcinogen with radon in causing lung cancer in uranium miners, i.e. smoking promotes but does not actually initiate the cancer.[19]

The data on U.S. uranium miners was broken into several ranges of WLM exposure:

Less than 120 WLM
120-359
360-839
840-1799
1800-3719
>3720

No excess cancers were observed in the less than 120 WLM group; one cancer was observed versus 1.81 expected. In the 120-359 group there were 12 observed cancers with only 2.57 expected. All 12 of these had smoked for an average of 40 years (the range was from 25 to 50 years). Two had stopped smoking for periods of 1 and 14 years before death.[6]

Summary and Conclusions

Estimates of the hazard from radon are based on cancer rates of underground uranium miners who experienced large doses of radiation at very high dose rates. The validity of linear extrapolation of the miner data to low dose levels in the general population is uncertain; however, such an approach appears to be the best available for estimating potential hazards of the radon from the UMTRAP sites. If the assumptions used in estimating the hazard are correct, radon appears to constitute an extremely small hazard: a person in SLC has about the same chance of being killed by lightning as of developing cancer from inhaling tailings radon, and one or two people per year in the U.S. may develop cancer as a result of the radon exhaled from all the UMTRAP sites. The fact that cancer rates in the western U.S., where natural background radiation is the highest in the country, are much lower than the national average is not supportive of a conclusion that low doses of radiation should be a major health concern.

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4540 M. L. Kramm
4541 L. W. Scully
4541 M. D. DeWitte
4541 P. D. O'Brien
4542 J. W. McKiernan
4542 D. J. Hosterman
4542 H. L. Rarrick
4542 L. A. Hanchey (10)
8266 E. A. Aas
3141 T. L. Werner (5)
3151 W. L. Garner (3)
for DOE/TIC
3154-3 R. P. Campbell (25)
(DOE/TIC)

Org.	Bldg.	Name	Rec'd by *	Org.	Bldg.	Name	Rec'd by *