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THE COLORADO PLATEAU: JOACHIMSTHAL REVISITED?

AN ANALYSIS OF THE LUNG CANCER PROBLEM IN URANIUM AND HARDROCK MINERS

by

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INTRODUCTION

There is no longer any significant debate concerning whether or not the inhalation of radon daughters in uranium and hardrock mining is associated with an excessively high incidence of lung cancer in the miners[1][2]. Among the items at issue are:

(a) type of cancer induced

(b) shape of the dose-effect curves

(c) correction for effect of cigarette smoking

(d) presence or absence of a "threshold"

(e) appropriate standards for uranium and hardrock mining.

An excellent set of hearings on the overall subject was conducted by the Joint Committee on Atomic Energy[3]. In spite of the quality of the presentations there, it is interesting that an enormous amount of confusion has been shed upon this subject. That the Joachimsthal tragedy has, in part at least, been repeated on the Colorado Plateau is regrettable, but it is past. What will indeed be difficult to understand will be a revisit to Joachimsthal in the future.

Dr. Carl Walske, of the Federal Radiation Council, recently requested us to re-study the findings in the JCAE Hearings concerning the uranium miners. It is the purpose of this report to present our analysis of this problem. We propose to address all the issues noted above.

I. THE INPUT DATA CONCERNING LUNG CANCER IN URANIUM AND HARDROCK MINERS

In FRC Report No. 8 (Preliminary Staff Report, May, 1967) are presented the potential input data for 49 cases of lung cancer among 1981 uranium miners who started mining before 1955[4]. Some debate occurred in the Epidemiologic-Statistical Subgroup as to which cases should or should not be included in a proper assessment of the problem.[5] Several important epidemiologic issues were properly and beautifully discussed by this group concerning case exclusion. Much of this centers around obtaining an appropriate "base" population estimate of expected lung cancers without exposure to radon daughters. This is excellent epidemiological thinking. However, the primary purpose of ascertainment that radon daughter exposure is related to excessive lung cancers is no longer an issue. Therefore, we must use the data for the remaining aspects of the problem listed in (a) through (e) above. For these purposes, we are not nearly so concerned about the precise estimates of expected lung cancers in non-exposed persons. Rather we are concerned about such issues as dose vs. effect, "thresholds", and types of cancer that are radiation-induced. As we shall show below, no material alteration in the substance of the conclusions would occur even if the "expected" incidence in non-exposed persons were twice that presented by the Epidemiologic Statistical Subgroup. Since this is true, we shall be able to use a larger fraction of the data pool than is in Table 4 of the Epidemiologic-Statistical Subgroup[5].

Next, this Subgroup indicated that the use of Death Certificate diagnosis did not materially alter the distribution of cases when contrasted with the results of careful clinico-pathologic study of autopsy or biopsy material. However, again because Death Certificate ascertainment was the basis for calculating expected incidence in non-exposed persons, they preferred to keep this requirement for inclusion of exposed cases. Again, because we shall show that even a doubling of "expected" incidence in non-exposed persons doesn't alter the picture, we shall utilize a larger fraction of the cases -- namely, those from death certification or clinico-pathologic study. However, we shall eliminate those cases where the careful clinico-pathologic study indicated the cancer not to be lung cancer, primary.

Next, the careful re-study of mining exposure led to the realization that some of the radon-daughter exposure was experienced in hardrock mining other than uranium mining. As a result, the low exposure categories tended to move up slightly when this additional exposure was taken into account. However, since similar corrections were not made for the base population, the Epidemiologic-Statistical Subgroup preferred to retain the case distribution based upon uranium mining exposure alone. We shall do this, but we shall also demonstrate that correction for the exposure due to hardrock mining would not materially alter any conclusions concerning dose-effect relationships, "thresholds", type of cancer induced by radiation, or appropriate guidelines for mine exposure to radon daughters.

Further, since it is well-known that a latency period exists before radiation-induced cancer becomes manifest, we too shall exclude cases of lung cancer occurring less than 5 years after the beginning of exposure.

TABLE 1

(Reproduced from Appendix A of FRC Report 8 (Preliminary). See Reference 4.)

49 CASES OF LUNG CANCER FOR POTENTIAL INCLUSION IN STUDY OCCURRING IN 1981 MINERS WHO BEGAN MINING BEFORE JULY 1955

FRC Case #	Exposure Category, WLM[4] (Uranium Exposure only)		Date of Death	Beginning of Mining	Exclusion Basis, if excluded
1	< 120 WLM	(A)	3-16-62	1951	Included
2	< 120 WLM	(A)	12-6-65	1950	Included
3	< 120 WLM	(A)	1-4-65	1954	Included
4	< 120 WLM	(A)	7-24-58	1955	→ Excluded, death only 3 yrs. later
5	120-359 WLM	(B)	10-21-65	1952	Included
6	120-359 WLM	(B)	9-20-62	1949	Included
7	120-359 WLM	(B)	3-1-64	1948	→ Excluded, Not primary lung cancer
8	120-359 WLM	(B)	2-22-65	1949	Included
9	120-359 WLM	(B)	12-22-62	1952	Included
10	120-359 WLM	(B)	5-2-64	1953	Included
11	120-359 WLM	(B)	Error in FRC (8)	1953	FRC 8 shows him dying 4 years before he quit mining. Included

TABLE 1 (contd)

FRC Case #	Exposure Category, WLM(4) (Uranium Exposure only)		Date of Death	Beginning of Mining	Exclusion Basis, if excluded
12	360-839 WLM	(C)	6-19-64	1954	Included
13	360-839 WLM	(C)	6-28-63	1951	Included
14	360-839 WLM	(C)	11-25-63	1950	Included
15	360-839 WLM	(C)	7-5-65	1952	Included
16	360-839 WLM	(C)	12-5-65	1952	Included
17	840-1799 WLM	(D)	4-12-64	1939	Included
18	840-1799 WLM	(D)	5-18-64	1945	Included
19	840-1799 WLM	(D)	9-15-63	1940	Included
20	840-1799 WLM	(D)	3-5-65	1940	Included
21	840-1799 WLM	(D)	12-9-65	1947	Included
22	840-1799 WLM	(D)	5-29-65	1955	Included
23	840-1799 WLM	(D)	10-31-61	1954	Included
24	840-1799 WLM	(D)	8-23-63	1952	Included
25	840-1799 WLM	(D)	12-29-60	1951	Included
26	840-1799 WLM	(D)	1-13-66	1952	Included
27	840-1799 WLM	(D)	6-15-60	1953	Included
28	1800-3719 WLM	(E)	2-14-56	1940	Included
29	1800-3719 WLM	(E)	11-19-56	1940	Included
30	1800-3719 WLM	(E)	10-20-62	1939	Included
31	1800-3719 WLM	(E)	5-4-63	1937	Included
32	1800-3719 WLM	(E)	8-15-64	1940	Included
33	1800-3719 WLM	(E)	12-23-63	1941	Included
34	1800-3719 WLM	(E)	2-5-61	1944	Included
35	1800-3719 WLM	(E)	3-23-63	1940	Included
36	1800-3719 WLM	(E)	6-29-65	1948	Included
37	1800-3719 WLM	(E)	1-14-61	1949	→ Excluded, Not primary lung cancer
38	> 3720 WLM	(F)	11-3-55	1925	Included
39	> 3720 WLM	(F)	2-14-57	1941	Included
40	> 3720 WLM	(F)	8-29-57	1945	→ Excluded, Not primary lung cancer
41	> 3720 WLM	(F)	5-22-65	1939	Included
42	> 3720 WLM	(F)	11-15-58	1949	Included
43	> 3720 WLM	(F)	12-25-60	1944	Included
44	> 3720 WLM	(F)	12-29-65	1940	Included

TABLE 1 (contd)

FRC Case #	Exposure Category, WLM[4] (Uranium Exposure only)		Date of Death	Beginning of Mining	Exclusion Basis, if excluded
45	> 3720 WLM	(F)	11-19-63	1954	Included
46	> 3720 WLM	(F)	5-4-59	1951	Included
47	> 3720 WLM	(F)	4-10-64	1950	Included
48	> 3720 WLM	(F)	2-20-66	1950	Included
49	> 3720 WLM	(F)	8-26-65	1950	Included

Note:
1. Wherever clinico-pathology corrected death certificate diagnosis, the former was used.
2. Cases are included, where either death certificate or clinico-pathology indicated primary lung cancer, subject to proviso (1).
3. Cases 2, 5, 15, 16, 21, 26, 44, 48, 49 died soon after the June 1965 cutoff date. (Av. few months). The correction of "expected" lung cancers for inclusion of these cases, purposely made generous, is described in text. It would appear impossible that any dose-category bias is thereby introduced.
4. Correction for hardrock mining radon-daughter exposure is described in text.

TABLE 2

45 CASES OF LUNG CANCER IN RADON-DAUGHTER EXPOSED URANIUM MINERS BY WLM EXPOSURE CATEGORY*

Exposure Category	Estimated Cumulative(WLM) Range	Median	No.of Miners in Base Population	No.of Cancers
A	< 120	< 60	383	3
B	120-359	240	421	6
C	360-839	600	496	5
D	840-1799	1320	400	11
E	1800-3719	2760	218	9
F	≥ 3720	~6000	63	11
TOTALS			1981	45

*Bases for inclusion thoroughly discussed in text plus footnotes to Table 1.

Lastly, there are several cases who died of lung cancer shortly after the cut-off date (June 1965) for the original formal analysis. The Epidemiologic-Statistical Subgroup excluded such cases because they wanted to check for complete ascertainment in this post-June 1965 period, as well as to check that the Death Certification was precisely like the other cases. However, for the purposes of this analysis, it is perfectly acceptable to include such cases, and increase the "expected" cancers generously to account for them.

In Table 1 are listed the 49 lung cancer cases available for potential inclusion. We shall exclude the following cases and provide the reason for exclusion.

Case 4: Excluded because death occurred 3 years after beginning of mining.

Case 7: Clinico-pathology diagnosis "Not primary lung cancer".

Case 37: Clinico-pathology diagnosis "Not primary lung cancer".

Case 40: Clinico-pathology diagnosis "Not primary lung cancer".

(Case 12, which the clinico-pathology group labelled mediastinal malignancy is included, since the Epidemiologic-Statistical Subgroup indicates that such a case is, by coding rules, properly a respiratory malignancy.)

With the exclusion of the four cases above, there remain 45 cases for analysis, and these are presented by uranium-exposure subgroup in Table 2.

We can now proceed with an analysis of these cases, addressing ourselves to the question (a) through (e) above.

II. ESTIMATION OF DOUBLING DOSES IN WLM FOR RADON-DAUGHTER INDUCED LUNG CANCER

The first task is to determine the overall estimation of doubling dose in WLM units for lung cancer induction by radon-daughters. Then the task will be to determine how the dose-effect curve appears. This latter can be translated into the question of whether the doubling dose in WLM is rising, falling, or remaining constant over a large span of dosages.

The first requirement is an estimation of the "expected" number of lung cancers in each exposure category, corrected for cigarette smoking and other possible variables. Such an estimation is provided in Table 8 of (p.1040), Reference 4, and is reproduced here:

TABLE 3

Exposure Category	"Expected" No. of Cancers 5-9 yrs.	> 10 yrs.	"Expected" Total for Persons 5 or more yrs. after start of mining
A	0.48	0.37	0.85
B	0.43	0.50	0.93
C	0.36	0.79	1.15
D	0.22	0.77	0.99
E	0.08	0.58	0.66
F	0.02	0.13	0.15

Two bases for increasing these estimates are to be considered:

(a) A few cases of lung cancer occurring after the June 1965 cut-off date are included in Table 2. These deaths occurred several months or so after the cut-off data. It is unimaginable that this should require more than a 10% correction in the "expected" cancer. But to be conservative, we shall give it a 20% correction.

(b) The Epidemiologic-Statistical Subgroup expressed concern that the cigarette smoking effect might be 20% or even 40% greater than they used in deriving the "expected" cases. Following our analysis, using (a) a 20% greater value than the "expected", we shall also do the analysis allowing a 100% greater "expected" value (much more than the 20-40% concern) and show that none of the conclusions concerning radiation-induction are substantively altered. Shown below are, therefore, the "expected" values, (a) Corrected by 20% and (b) corrected by 100%.

TABLE 4

CORRECTED LUNG CANCER EXPECTATIONS IN BASE POPULATION FOR THOSE 5 OR MORE YEARS AFTER BEGINNING OF EXPOSURE

Exposure Category	(a) Expected No.of Cancers Corrected by 20%	(b) Expected No.of Cancers Corrected by 100%
A	1.02	1.70
B	1.12	1.86
C	1.38	2.30
D	1.19	1.98
E	0.79	1.32
F	0.18	0.30
TOTAL GROUP	5.68	9.46

(a) Using the "Expectations" of Column (a)

The analysis starts with a consideration of the doubling dose in WLM for the entire group of miners (Categories A through F) and proceeds serially by elimination, successively, of the high exposure groups. The goal, of course, is to determine what is happening to the WLM doubling dose in the lower dosage categories - the region of relevance for setting standards for "safe" mining exposure.

The overall group of 1981 miners

45 lung cancers observed
5.68 lung cancers "expected"
39.32 excess lung cancers in miners

$\frac{39.32}{5.68}$ = 6.93 doubling doses is what the excess cases of lung cancer show.

Now, to calculate the Mean Radiation dose in WLM, we proceed as follows:

$$\text{Mean Dose} = \frac{(383)(60)+(421)(240)+(496)(600)+(400)(1320)+(218)(2760)+(63)(6000)}{1981}$$

or

$$\text{Mean Dose} = \frac{22980 + 101040 + 297600 + 528000 + 601680 + 378000}{1981} = \frac{1,929,300}{1981}$$

or

Mean Dose = 973.9 WLM

Therefore, one doubling dose = $\frac{973.9}{6.93}$ = 140.5 WLM

The group of miners, excluding group F, the highest exposure group

34 lung cancers observed (Groups A+B+C+D+E)
5.50 lung cancers "expected". Table 4(a)(Groups A+B+C+D+E)
28.50 excess lung cancers in Groups A through E, inclusive

$\frac{28.50}{5.50}$ = 5.18 doubling doses is what the excess cases of lung cancer show.

For Mean Radiation dose, we have, for 1918 miners in A through E, inclusive:

$$\text{Mean Dose} = \frac{(383)(60)+(421)(240)+(496)(600)+(400)(1320)+(218)(2760)}{1918}$$

or

$$\text{Mean Dose} = \frac{22980 + 101040 + 297600 + 528000 + 601680}{1918} = \frac{1551300}{1918}$$

or

Mean Dose = 808.8 WLM

Therefore, one doubling dose = $\frac{808.8}{5.18}$ = 156.1 WLM

The group of miners, excluding groups E+F, the two highest exposure groups

25 lung cancers observed (Groups A+B+C+D)
4.71 lung cancers "expected" Table 4(a) (Groups A+B+C+D)
20.29 excess lung cancers in Groups A through D, inclusive.

$\frac{20.29}{4.71}$ = 4.31 doubling doses is what the excess cases of lung cancer show.

Now, for 1700 miners,

$$\text{Mean Dose} = \frac{(383)(60)+(421)(240)+(496)(600)+(400)(1320)}{1700}$$

or

$$\text{Mean Dose} = \frac{22980 + 101040 + 297600 + 528000}{1700} = \frac{949620}{1700}$$

or

Mean Dose = 558.6 WLM

Therefore, one doubling dose = $\frac{558.6}{4.31}$ = 129.6 WLM

The group of miners, excluding groups D,E,F, the three highest exposure groups

14 lung cancers observed (Groups A+B+C)

3.52 lung cancers "expected" Table 4(a) (Groups A+B+C)

10.48 excess lung cancers in Groups A through C, inclusive.

$\frac{10.48}{3.52}$ = 2.98 doubling doses is what the excess cases of lung cancer show.

For mean radiation dose in 1300 miners,

$$\text{Mean Dose} = \frac{(383)(60)+(421)(240)+(496)(600)}{1300} =$$

or

$$\text{Mean Dose} = \frac{22980 + 101040 + 297600}{1300} = \frac{421620}{1300}$$

or

Mean Dose = 324.3 WLM

$$\text{Therefore, one doubling dose} = \frac{324.3}{2.98} = 108.8 \text{ WLM}$$

The group of miners, including A+B, the two lowest exposure categories

9 lung cancers observed (Groups A+B)

2.24 lung cancers "expected" Table 4(a) (Groups A+B)

6.76 excess lung cancers in Group A+B

$\frac{6.76}{2.24}$ = 3.02 doubling doses is what the excess cases of lung cancer show.

For mean radiation dose in 804 miners,

$$\text{Mean Dose} = \frac{(383)(60)+(421)(240)}{804} = \frac{22980 + 101040}{804} = \frac{124020}{804}$$

or

Mean Dose = 154.3 WLM

$$\text{Therefore, one doubling dose} = \frac{154.3}{3.02} = 51.1 \text{ WLM}$$

Group A alone, the lowest exposure category

3 lung cancers observed (Group A)

1.02 lung cancers "expected" Table 4(a) (Group A)

1.98 excess lung cancers in Group A.

$\frac{1.98}{1.02}$ = 1.94 doubling doses is what the excess cases of lung cancer suggest (small numbers preclude assurance)

For 383 miners, the radiation dose is as follows:

$$\text{Mean Dose} = \frac{22980}{383} = 60 \text{ WLM}$$

$$\text{Therefore, one doubling dose} = \frac{60}{1.98} = \underline{\underline{30.3 \text{ WLM}}}$$

We cannot assign too much assurance to this value since the total number of cancers (3) is so small as to have a high probable error. Of one thing we can be certain, the analysis of Group A alone, or Group A+B suggests the radiation risk is growing, if anything, not decreasing, in the low exposure categories. However, there is one correction that should be made for these lowest exposure categories before we seriously attempt to consider an increasing hazard at the lowest dosages. We shall now make this correction to the analysis.

In FRC 8 (Revised), account is taken of the fact that the lowest exposure categories deserve correction of WLM dose because of a contribution of (non-uranium) hardrock mining(6). This is important.

To take this into account, we shall triple the exposure for the lowest category (A), that is a change from 60 to 180 WLM, and we shall provide a 50% increase in dosage for category (B), that is a change from 240 to 360 WLM. The data of Reference 5 indicate these two categories are the only significant ones affected, and that our increases are very generous.

Recalculation of Group (A+B) crediting the hardrock mining exposure

9 lung cancers observed (Groups (A+B)
2.24 lung cancers "expected" Table 4(a) (Groups A+B)
6.76 excess lung cancers

$$\frac{6.76}{2.24} = 3.02 \text{ doubling doses.}$$

Mean radiation dose (including correction for hardrock mining),

$$\text{Mean Dose} = \frac{(3)(383)(60)+(1.5)(421)(240)}{804} = \frac{68940 + 151560}{804} = \frac{220500}{804}$$

or

Mean Dose = 274.3 WLM

$$\text{Therefore, one doubling dose} = \frac{274.3}{3.02} = \underline{\underline{90.8 \text{ WLM}}}$$

Summary of All Doubling Dose Estimates and the Question of "Thresholds"

Exposure Category	Exposure Mean WLM	Radiation Doubling Dose, Lung Cancer
A+B+C+D+E+F	973.9	140.5 WLM
A+B+C+D+E	808.8	156.1 WLM
A+B+C+D	558.6	129.6 WLM
A+B+C	324.3	108.8 WLM
A+B (corrected for Hardrock mining)	274.3	90.8 WLM

Inspection indicates that all the evidence points to radiation-induction of lung cancers, either with no trend in doubling dose, or if anything, a trend toward lower doubling doses at the low end of the dosage scale. Therefore, this is a confirmation of linear theory, or even possibly a demonstration that linear theory underestimates the risk at low total dosages.

Let us ask ourselves, in terms of doubling doses, what a so-called "threshold" means. If a "threshold" exists, this means that below such a "threshold" the radiation-cancer doubling dose must go to infinity. But the data above show that, with decreasing exposure dose, the doubling dose is decreasing, if anything - hardly a behavior of a function that is about to turn around and go to infinity! It is a strange phenomenon, indeed, to consider the "threshold hopers". No evidence whatever, for any form of cancer, has even suggested a threshold dose of radiation to be "safe" with respect to carcinogenesis in man. The claims of so-called "practical" or absolute thresholds are readily refuted[7][8]. In a public health problem of the gravity of setting radiation standards, and where the evidence indicates linearity (or an even greater than linear hazard at low doses) in a measurable region, one should shudder at the audacity of a man who announces, "Maybe, somehow, somewhere, someday, someone will show a threshold for some form of carcinogenesis". In this area of public health, the burden of proof is on whoever thinks there might be a threshold. The burden is not upon those who see no evidence for a threshold. Standards should never be set, counting upon mythical assistance to prevent damage to humans, particularly not for damage being the very destruction of human life. The Federal Radiation Council, in FRC 8, paid lip service to linearity and no threshold and then, in spite of warnings by Archer[9], Parker[10], Snyder[11], Morgan[12], and others, went ahead to set acceptable working levels that would double lung cancer for miners working 10 years. We shall return to this later.

(b) Estimation of Doubling Doses Using the "Expectation" of Lung Cancer in Table 4(b)

Table 4(b) provides a tabulation of "expected" lung cancer risks double that of the Epidemiology Group estimates. Thus cigarette smoking and any other biases are very generously over-compensated. Now let us see if this alters the picture for the behavior of the radiation-induced doubling dose for lung cancer.

The overall group of miners (A through F, inclusive)

45 lung cancers observed
9.46 lung cancers expected Table 4(b)
35.54 excess lung cancers

$$\frac{35.54}{9.46} = 3.76 \text{ doubling doses}$$

We have previously estimated mean dose = 973.9 WLM

$$\text{Therefore, one doubling dose} = \frac{973.9}{3.76} = \underline{\underline{259 \text{ WLM}}}$$

The group of miners (A through E) excluding the highest dose category

34 lung cancers observed (Groups A+B+C+D+E)
9.16 lung cancers expected Table 4(b)
24.84 excess lung cancers

$$\frac{24.84}{9.16} = 2.71 \text{ doubling doses}$$

We have previously estimated the radiation dose = 808.8 WLM

$$\text{Therefore, one doubling dose} = \frac{808.8}{2.71} = \underline{\underline{298.5 \text{ WLM}}}$$

The group of miners (A through D) excluding the 2 highest dose categories

25 lung cancers observed
7.84 lung cancers expected (Table 4(b)
17.16 excess lung cancers

$$\frac{17.16}{7.84} = 2.19 \text{ doubling doses.}$$

We have previously estimated the radiation dose = 558.6 WLM

Therefore, one doubling dose = $\frac{558.6}{2.19}$ = 255.0 WLM

The group of miners (A+B+C) - the three lowest dose categories

14 lung cancers observed (Groups A+B+C)
5.86 lung cancers "expected", Table 4(b)
8.14 excess lung cancers

$$\frac{8.14}{5.86} = 1.37 \text{ doubling doses.}$$

We have previously estimated the radiation dose = 324.3 WLM

Therefore, 1 doubling dose = $\frac{324.3}{1.37}$ = 236.7 WLM

The group of miners (A+B) - the two lowest dose categories

9 lung cancers observed (Groups A+B)
3.56 lung cancers "expected" Table 4(b)
5.44 excess lung cancers

$$\frac{5.44}{3.56} = 1.52 \text{ doubling doses.}$$

We have estimated the radiation dose above, including a generous correction for hardrock mining exposure, to be = 274.3 WLM

Therefore, 1 doubling dose = $\frac{274.3}{1.52}$ = 180.5 WLM

Now let us summarize all these calculations:

Exposure Category	Exposure Mean WLM	Radiation Doubling Dose, Lung Cancer
A+B+C+D+E+F	973.9	259.0 WLM
A+B+C+D+E	808.8	298.5 WLM
A+B+C+D	558.6	255.0 WLM
A+B+C	324.3	236.7 WLM
A+B (corrected for Hardrock mining)	274.3	180.5 WLM

Again, even with the exaggerated correction of Table 4(b) for cigarette smoking or other possible bias, the answer is the same - perfect agreement with linear theory (= constancy of doubling dose) over the entire range of doses, with the lowest dose category suggesting an increased hazard over linear theory, if anything. Recall again, so-called "threshold" theory would require doubling dose to trend toward infinity in the low dose categories. Inspection of the actual trend readily shows the absurd nature of such "threshold hoping".

Morgan, reading from the FRC Advisory Committee Report ("Radiation Exposure to Uranium Miners", August 1968) quotes, "At each level of radiation exposure, including the level equal to and less than 120 working level months, in the uranium mines a significant excess of respiratory cancer has now been observed among the white miners. Two exposure levels are now significant for the first time".(13)

Archer has predicted this in the JCAE Hearings based upon his analysis of the then existing data(14).

In the analysis of this report, based upon data available by 1967, we concluded that everything pointed unmistakably to a clear-cut association of respiratory cancer for the lowest two working levels. While for rigorous epidemiological purposes, cases were properly excluded by the Epidemiologic-Statistical Subgroup, and thus making absolute proof difficult for the lowest categories, our analysis demonstrates clearly that sufficient data were available to allow this conclusion in 1967 - certainly more than adequate for considerations involving the health of the miners.

There are times when epidemiologic data can be over-restrictively interpreted. For rigor, this restrictive approach is beautiful. For protecting lives, there is no loss if the data are pressed fully for what they soundly can reveal. It appears there are already too many persons involved in standard-setting who demand seeing every possible coffin before they are galvanized into action.

III. THE TRUE DOUBLING DOSE FOR LUNG CANCER INDUCTION BY RADON DAUGHTERS

All the analyses above are based upon observed lung cancers in miners who are 5 or more years beyond the inception of their mining experience, with many of them less than 10 years since inception. Clearly we are still early in the latency period for many of them. Following Archer's general models, which assume a mean of 20 years from first exposure to appearance of lung cancer[5], we can feel highly confident that the 45 cases observed would have been considerably higher if these studies had been conducted at an interval longer than that concluded in June 1965. To be conservative, and not over-estimate the situation, it is doubtful that anyone would argue that "at full bloom", 1.5 times as many cases would have been observed in this study conducted at a later time.

(45)(1.5) = 67.5 cases would have been observed.

Now let us estimate the doubling doses, using Table 4(a) "expected" values and Table 4(b) "expected" values.

	Conservative Calculation	Exaggerated Calculation
	Table 4(a) "expected"	Table 4(b) "expected"
Category:	A+B+C+D+E+F	A+B+C+D+E+F
Mean Dose	973.9 WLM	973.9 WLM
Observed	67.5	67.5
Expected	5.68	9.46
Excess Cancers	61.82 cases	58.04
Doubling Doses	$\frac{61.82}{5.68} = 10.88$	$\frac{58.04}{9.46} = 6.13$
One Doubling Dose	$= \frac{973.9}{10.8} = \underline{\underline{90.2\text{ WLM}}}$	$= \frac{973.9}{6.13} = \underline{\underline{154.6\text{ WLM}}}$

For the sake of conservatism, we shall choose a final value midway between these, or 122.4 WLM. We fully expect, as data accumulate, the true value will lie below this value, and from every evidence, this doubling dose will hold all the way down to the lowest dose categories. Nor should this value surprise anyone, since Archer suggested the doubling dose to lie between 100-400 WLM with "a high probability it lies at the lower limit of this range"[14]. We agree!

IV. THE TYPES OF LUNG CANCER INDUCED BY RADON DAUGHTER EXPOSURE

Saccomano and co-workers discovered that some 57% of the lung cancers among United States uranium miners were of the small cell undifferentiated variety, many referred to as of "oat cell" variety. Among non-miners, small cell undifferentiated cancers were estimated rarely to exceed 20% of all lung cancers.[15] These appear to be quite firm, reliable data.

However, in the absence of a quantitative interpretation of these important findings, a lore has arisen which holds the remarkable view that radiation induces a specific histologic type of lung cancer. So widespread has this fiction become that Miller[16] and Storer[17] have attempted to use it to raise doubts about the induction of lung cancer by radiation in the Hiroshima-Nagasaki survivors. No more grave error could be committed in this area of human radiation biology.

Let us approach this problem by consideration of the 45 cases of lung cancer evaluated above, and let us use the "expected" lung cancers from Table 4(a). Using Saccomano's estimates:

"Observed" = (0.57)(45) = 25.7 small cell, undifferentiated lung cancers.
"Observed" = (0.43)(45) = 19.3 bronchiogenic cancers.

"Expected" = (0.20)(5.68) = 1.14 small cell, undifferentiated lung cancers.
(0.80)(5.68) = 4.54 bronchiogenic cancers.

Therefore, for Bronchiogenic Cancer:

19.3 cases "observed" bronchiogenic cancers
4.54 cases "expected" bronchiogenic cancers
14.76 cases, excess bronchiogenic cancers

We doubt that even the most hardened biometrician would require formal statistics to prove that bronchiogenic cancer, from these data, is radiation-induced. It clearly is!

$\frac{14.76}{4.54}$ = 3.25 doubling doses.

Mean radiation dose = 973.9 WLM

So, 1 doubling dose for Bronchiogenic Cancer = $\frac{973.9}{3.25}$ = 299.7 WLM

For Small Cell, Undifferentiated Cancer:

25.7 cases "observed" small cell, undifferentiated cancers
1.14 cases "expected" small cell, undifferentiated cancers
24.56 cases, excess small cell, undifferentiated cancers

Obviously, such cancers are also radiation-induced.

$\frac{24.56}{1.14}$ = 21.54 doubling doses.

Mean radiation dose = 973.9 WLM

So, 1 doubling dose for Small Cell, Undifferentiated Cancer

= $\frac{973.9}{21.54}$ = 45.2 WLM

These analyses prove that two types of cancer are induced by exposure to radon daughters in uranium miners, namely bronchiogenic cancer and small cell, undifferentiated cancer. The six-fold lower doubling dose for small cell cancer induction than for bronchiogenic cancer is, in all probability, not a real difference in susceptibility to cancer induction, but rather is a reflection of the distribution of the radon daughter irradiation - with the "small cells" receiving much more radiation than those cells which give rise to the bronchiogenic cancers. Too little is known of the behavior of the radon daughters to pin this down, but it seems a far more likely explanation than a difference in intrinsic susceptibility to radiation-induced cancer.

In any event, both bronchiogenic lung cancer and small cell, undifferentiated cancer are clearly radiation-induced. It would be helpful if the fiction of a specific radiation-induced type of lung cancer would die now, before it can cause further confusion and, thereby, damage to human lives.

V. THE IMPLICATIONS OF THE NEW FRC GUIDELINES FOR URANIUM AND HARDROCK MINING EXPOSURE TO RADON DAUGHTERS

After elegant testimony by Archer[14], Parker[9], and Snyder[11], as well as others, in the important JCAE Hearings, the Federal Radiation Council came up with the astounding conclusion that:

"a higher than expected incidence of lung cancer is demonstrated when the cumulative exposures are more than about 1000 WLM. The degree of risk at lower levels of cumulative exposure cannot be determined from currently available epidemiologic data".[6]

There would appear to exist no rational way to explain these statements. The same data were available then to the Federal Radiation Council as are available to us now for the analyses completed above. Our analyses showed clearly that radiation-induction appears to have an essentially constant doubling dose (agreement with linear theory) down to the lowest two dosage categories. The deviation, if significant, in the low dose categories was in the direction of a higher risk of cancer induction; not lower. (See entire analysis in preceding sections). So there was clear-cut evidence available for radiation induction way, way below the 1000 WLM spoken of by the FRC. But Snyder did do an analysis and did point out that there was no reason to believe that effects upon the miners did not extend down to the lowest dose range[11]. The words of Snyder at that Hearing are so beautiful and so relevant on this issue that they must be quoted here[11]: (Snyder) "However, one may wonder why it is considered so undesirable to use a conservative criterion where human life is in question. Surely if the linear hypothesis is conservative and is not in conflict with the data that are available, this is a point in its favor. When human life is in the balance, it would seem that conservatism in safeguarding those lives has much to commend it".

Eloquent, scientifically sound words, in the best public health tradition! Who was listening?

VI. JOACHIMSTHAL REVISITED? THE VERY SERIOUS PROBABLE CONSEQUENCES OF THE NEW FRC GUIDELINES FOR URANIUM MINING

That we, in the United States, have repeated much of the tragedy of Joachimsthal and Schneeburg in the period from 1940 through 1967 is indeed regrettable. But human errors do occur, and it is best to forgive those that are past. However, if we go forward with a new generation of miners and repeat the Joachimsthal experience again, this will be absolutely inexcusable.

As we shall show below, it is our contention that the revised FRC Guidelines for uranium mining exposure to radon daughters (12 WLM per year) has a dangerously high probability of a needless repetition of the Joachimsthal tragedy (Even the more recent 3.6 WLM per year of the Labor Department is high).[18]

The hazards in the FRC Guidelines are in two parts:

(a) A mis-estimation by the FRC of the meaning of a doubling of the lung cancer risk in comparison with the risk of a fatal accident in mining. The FRC error is ten-fold.

(b) A far more serious possibility that resides in the lack of appreciation of the significance of the fact that both bronchiogenic and small cell undifferentiated cancer are radiation-induced. This possibility, as we shall show, can have the most dire consequences, and of itself should certainly lead to a drastic lowering of the Mining Guidelines.

We shall consider (a) and (b) serially now.

(a) The FRC Mis-estimation of the Lung Cancer Risk vs Fatal Accidents

In FRC 8 (Preliminary, May 1967) (Paragraph 3.35), the FRC presents "a general perspective on the magnitude of the lung cancer risk for a stated occupational exposure can be gained by comparing it to the risk of a fatal accident in the same occupation". The FRC goes on to estimate that:

(a) For 1000 men working 10 years, there will be 20 deaths from fatal accidents.

(b) For 1000 men exposed to an average of 2 x the lung cancer risk over a 10-year period, they would be expected to incur 2 lung cancers.

(c) The FRC states, "It appears that a lung cancer risk twice expected would be about one-tenth the risk of a fatal accident".

Concerning:

(a) We do not disagree about the 20 deaths from accidents.

(b) We disagree violently about how the FRC estimates the meaning of doubling the lung cancer risk.

(c) The final FRC estimate is erroneous by at least a factor of 10.

In order to demonstrate the FRC error we need to go through a few simple calculations.

Let us start with a group of 1000 men at age 20 years who enter the occupation of uranium mining de novo.

Let these men work 10 years at FRC Guidelines, during which they would accumulate one doubling dose of radon daughters. (FRC Guidelines allow

120 WLM; our estimate is that this is more than one doubling dose, but for consistency with the FRC "perspective" we shall accept this as one doubling dose).

Further, we shall assume no cancers at all during the ten-year period of mine exposure, from age 20 to age 30 years. However, by age 40 years, we shall assume (approximately following Archer) that lung cancers occur, and that between 40-50 years of age, the rate is $\frac{1}{2}$ that expected at full effect of the radiation.

Between 50 and 70 years, we shall assume that the full effect of the radiation is experienced each year. Thus, between 50 and 70 years, one doubling dose will produce a number of additional cancers equal to the spontaneously occurring number.

First we need data concerning the spontaneous occurrence rate for lung cancers for the age span 40-70 years. From Hammond's data, we calculate the following expectancies for smokers of 10-19 cigarettes/day[19]. (The miners average $\cong$ 13/day. (Ref. 5, p. 1277)

Age (Males)	Lung Cancers/100,000/year
45 yrs.	24
50 yrs.	65
55 yrs.	106
60 yrs.	147
65 yrs.	183
70 yrs.	208

Next, we need to know how many men survive to be at risk at each age from 40 to 70 years. Using the U.S. Vital Statistics for 1966, we have calculated the number of men surviving at various ages, starting with 100,000 men at age 20 years[20]. These are listed below.

Survivors at Various Ages

starting with 100,000 men at age 20 yrs. (U.S.Males)

Age	Survivors at Specified Ages
at 24 yrs.	99,000
at 29 yrs.	98,069
at 34 yrs.	96,990
at 39 yrs.	95,535
at 44 yrs.	93,270
at 49 yrs.	89,749
at 54 yrs.	84,256
at 59 yrs.	76,155
at 64 yrs.	65,402
at 69 yrs.	51,344
at 74 yrs.	35,522
at 79 yrs.	20,398

Now to calculate the lung cancers, starting to occur at age 40 years in our miners exposed to one doubling dose.

40-50 yr.decade 10 years

$\sim$ 91.5% have survived to be at risk

$\frac{1}{2}$ of full effect occurs in this decade (0.5 doubling)

24/100,000 is the spontaneous rate of lung cancer

$$\therefore (0.915)(0.5) \times \frac{24}{100000} \times 1000 \times 10 = \frac{109800}{100000} = 1.1 \text{ cases}$$

50-60 yr.decade 10 years

$\sim$ 80.2% have survived to be at risk

Full effect occurs in this decade (doubling dose)

106/100,000 is the spontaneous rate of lung cancer

$$\therefore (0.802) \times \frac{106}{100000} \times 1000 \times 10 = 8.5 \text{ cases}$$

60-70 yr.decade 10 years

$\sim$ 58.4% have survived to be at risk

Full effect occurs in this decade (doubling dose)

183/100,000 is the spontaneous rate of lung cancer

$$\therefore (0.584) \times \frac{183}{100000} \times 1000 \times 10 = 10.7 \text{ cases}$$

Thus, if we neglect radiation-induced cancers beyond 70 years (not a negligible number), we can add up 1.1 + 8.5 + 10.7 = 20.3 cases of lung cancer per 1000 men mining uranium at one doubling dose accumulated over a 10-year period.

For 1000 men:
- Thus, fatal accidents in 10 years = 20 deaths
- Lung cancer, from 10 years of mining = 20.3 deaths.

Therefore, these two sources of death are equal. To be sure the radiation-induced lung cancers occur later in life, but the number equals the accidental death number, rather than being 0.1 as high, as claimed by FRC 8.

(b) The Serious Implications of The Two Types of Cancers Induced by Radon Daughters

In Section IV it was demonstrated that Saccomanno's finding of a different proportion of bronchiogenic versus small cell cancer in uranium miners compared with non-miners was extremely important. First, the use of his evidence allowed a demonstration that both bronchiogenic and small cell cancer are radiation-induced. Second, the use of his data allowed a comparison of doubling doses for the two forms of lung cancer. These were:

299.7 WLM for bronchiogenic cancer
45.2 WLM for small cell, undifferentiated cancer.

We indicated there that we believed it far more likely that different dosages to the relevant tissues accounted for the difference in apparent doubling dose, rather than a different intrinsic susceptibility to cancer induction. We shall now treat this issue in extenso, for it has major implications for the uranium miners.

Recently we presented three major laws of radiation-carcinogenesis in man[21]. The second of those three laws states:

"All forms of cancer show closely similar doubling doses and closely similar increases in incidence per rad".

We shall now demonstrate, in practise, how useful these laws can be in understanding a problem such as radon-daughter exposure.

Now, we have an apparent 6.6-fold higher doubling dose for bronchiogenic cancer than for small cell cancer (299.7/45.2). We shall use Law 2, and state:

"The doubling dose for bronchiogenic cancer equals that for small cell cancer". How, then shall we explain the 6.6-fold apparent difference? We shall accomplish this by consideration of dosage to the relevant target tissues.

Before going ahead, we shall refer to Section III, where in discussing the "true" doubling dose, we pointed out that the 45 cases in 1981 miners do not represent the full effect because of latency, and that an estimate of 67.5 cases for 1981 miners is not an overestimate of the true value.

Further, we shall use the data for all 1981 miners because we have seen that doubling doses estimated for the overall group understate the problem rather than overstating it. So, we have the following parameters:

Categories: A+B+C+D+E+F
No. of miners: 1981
Mean Dose: 973.9 WLM units
"Observed": 67.5 Lung cancers (all types) (corrected for latency)
"Expected": 5.68 Lung cancers (all types) Table 4(a)
Excess: 61.82 Lung cancers (all types)

Overall Doubling Doses: $\frac{61.82}{5.68}$ = 10.88 doubling doses.

From Saccomanno[15], we have:

In "spontaneous" lung cancers (including cigarette smoking)

80% bronchiogenic
20% small cell, undifferentiated

In uranium miner lung cancers

43% bronchiogenic
57% small cell, undifferentiated.

What we do not know is the size of the two domains, (a) that which gives rise to bronchiogenic cancer and (b) that which gives rise to small cell, undifferentiated cancer.

Let us suppose there are no other domains exposed, and that the full dose 973.9 WLM is distributed between these two domains.

Let the total mass of both domains be arbitrarily set at unity.

Let A be the fractional mass of the "bronchiogenic" domain.

Let B be the fractional mass of the "small cell" domain.

Let the total WLM be distributed in some manner (to be calculated) between A and B.

Now,

(I) $A + B \equiv 1$

(II) Dosage can be expressed in the units:

$$\frac{(WLM)_A}{A} \quad \text{and} \quad \frac{(WLM)_B}{B}$$

(III) Let D ≡ the identical doubling dosage for cancer induction in both domains.

Utilizing our input parameters, we have

For bronchiogenic cancers, (0.43)(67.5) = 29.0 "observed"
(0.80)(5.68) = 4.54 "expected"
Excess = 24.46 cases
Doubling doses = $\frac{24.46}{4.54}$ = 5.39

(IV) So $\left[\frac{(WLM)_A}{A}\right] = (5.39)\ (D)$

For small cell cancers, (0.57)(67.5) = 38.5 "observed"
(0.20)(5.68) = 1.14 "expected"
Excess = 36.36 cases
Doubling doses = $\frac{36.36}{1.14}$ = 31.89

(V) So, $\left[\frac{(WLM)_B}{B}\right] = (31.89)(D)$

Therefore,

(VI) $$\frac{\left[\frac{(WLM)_A}{A}\right]}{\left[\frac{(WLM)_B}{B}\right]} = \frac{(5.39)(D)}{(31.89)(D)}$$

or, eliminating D, we have

(VII) $$\left[\frac{(WLM)_B}{B}\right] = \left(\frac{31.89}{5.39}\right)\left[\frac{(WLM)_A}{A}\right] = (5.92)\left[\frac{(WLM)_A}{A}\right]$$

We have arrived then at the knowledge that the dose in (WLM) per unit mass of domain is 5.92 times as high in the small cell domain as in the bronchiogenic domain. But we still do not know A or B, so we cannot know how to apportion the total WLM into $(WLM)_A$ and $(WLM)_B$. Within these data, we cannot ascertain A and B. Instead we shall consider the implications of 3 possibilities of the size of these domains.

(a) $A = B$ (of course $A + B \equiv 1$)

(b) $A = 9\ (B)$, which means $B = 0.1$, $A = 0.9$

(c) $B = 9\ (A)$, which means $B = 0.9$, $A = 0.1$

Now we can proceed to calculations of D for these 3 possibilities.

(a) Calculation of "D", where A = B = 0.5

$$\text{Overall Dose} = \frac{\text{Overall WLM}}{1.0}$$

$$\text{Bronchiogenic Domain Dose} = \frac{(WLM)_A}{A} = \frac{(WLM)_A}{0.5}$$

$$\text{Small Cell Domain Dose} = \frac{(WLM)_B}{B} = \frac{(WLM)_B}{0.5}$$

But from (VII), we have

$$\left[\frac{(WLM)_B}{B}\right] = (5.92)\left[\frac{(WLM)_A}{A}\right]$$

Substituting A = B = 0.5, we have

$$\frac{(WLM)_B}{0.5} = (5.92)\ \frac{(WLM)_A}{0.5}$$

or

$$(WLM)_B = 5.92\ (WLM)_A.$$

But,

$$\text{Total WLM} = (WLM)_A + (WLM)_B$$

So, substituting, $973.9 = (WLM)_A + (5.92)(WLM)_A$

$$\text{or } (6.92)(WLM)_A = 973.9$$

$$(WLM)_A = \frac{973.9}{6.92} = 140.7 \text{ WLM units}$$

$$(WLM)_B = 973.9\text{-}140.7 = 833.2 \text{ WLM units}$$

Therefore, $\frac{(WLM)_A}{A} = \frac{140.7}{0.5} = 281.4$ WLM units/unit mass of domain

$$\frac{(WLM)_B}{B} = \frac{833.2}{0.5} = 1666.4 \text{ WLM units/unit mass of domain}$$

We now can calculate "D", the doubling dose, either from the bronchiogenic or the small cell data. Since we have assumed a single value of D for both domains, we must get the same answer, if all the arithmetic is correct above.

For bronchiogenic cancer data, we have 5.39 doubling doses.

Therefore:

$$\frac{281.4}{5.39} = D = \underline{52.2 \text{ WLM units/unit}} \text{ mass}$$

For the small cell cancer data, we have 31.89 doubling doses.

Therefore:

$$\frac{1666.4}{31.89} = D = \underline{52.3 \text{ WLM units/unit}} \text{ mass}$$

We can say D = 52.2 WLM units/unit mass in either domain.

Note: According to the assignment of A=B=0.5, 833.2 WLM units are in the small cell domain and 140.7 WLM units are in the bronchiogenic domain. This accounts for the smaller excess cancers in the bronchiogenic domain than in the small cell domain, even though D is identical in both domains.

(b) Calculation of "D", where A = 9 B (A =0.9;B -0.1)

$$\text{Overall Dose} = \frac{\text{Overall WLM}}{1.0}$$

$$\text{B ronchiogenicDomain Dose} = \frac{(WLM)_A}{A} = \frac{(WLM)_A}{0.9}$$

$$\text{Small Cell Domain Dose} = \frac{(WLM)_B}{B} = \frac{(WLM)_B}{0.1}$$

But from (VII), we have

$$\left[\frac{(WLM)_B}{B}\right] = (5.92)\left[\frac{(WLM)_A}{A}\right]$$

Substituting A = 0.9, B = 0.1, we have

$$\frac{(WLM)_B}{0.1} = (5.92)\frac{(WLM)_A}{0.9}$$

or

$$(WLM)_B = \frac{(5.92)}{9}(WLM)_A = (0.66)(WLM)_A$$

B ut,

$$\text{Total WLM} = (WLM)_A + (WLM)_B$$

$$973.9 = (WLM)_A + (0.66)(WLM)_A$$

or $1.66\,(WLM)_A = 973.9$

$$(WLM)_A = \frac{973.9}{1.66} = 586.7 \text{ WLM units}$$

$$(WLM)_B = 973.9 - 586.7 = 387.2 \text{ WLM units}$$

Therefore,
$$\left[\frac{(WLM)_A}{A}\right] = \frac{586.7}{0.9} = 651.9 \text{ WLM units/unit mass}$$

$$\left[\frac{(WLM)_B}{B}\right] = \frac{387.2}{0.1} = 3872.0 \text{ WLM units/unit mass}$$

Now to calculate "D" for both domains:

For bronchiogenic cancer data, we have 5.39 doubling doses

Therefore:

$$\frac{651.9}{5.39} = D = 120.9 \text{ WLM units/unit mass}$$

For small cell cancer data, we have 31.89 doubling doses

Therefore,

$$\frac{3872.0}{31.89} = D = 121.4 \text{ WLM units/unit mass}$$

Say D = 121.2 WLM units/unit mass in either domain.

Note: According to this assignment A=0.9 and B=0.1, more WLM units (586.7) are in A domain than in B domain (387.2). But because of the larger mass of A (9xB), the dose per unit mass is still much lower in A than in B, which accounts for the smaller number of excess cancers in the bronchiogenic domain than in small cell domain. D, again, is identical in both domains.

It is important to note that if A = 9 B in domain size, the doubling dose, D, of 121.2 WLM units/unit mass is much higher than D = 52.2 WLM units/unit mass, where A = B. So, the true sensitivity of lung tissue for radiation-carcinogenesis is very strongly dependent on domain sizes.

(c) Calculation of "D" where B = 9(A) (A=0.1; B=0.9)

$$\text{Overall Dose} = \frac{\text{Overall WLM}}{1.0}$$

$$\text{Bronchiogenic Domain Dose} = \frac{(WLM)_A}{A} = \frac{(WLM)_A}{0.1}$$

$$\text{Small Cell Domain Dose} = \frac{(WLM)_B}{B} = \frac{(WLM)_B}{0.9}$$

But from (VII), we have

$$\left[\frac{(WLM)_B}{B}\right] = (5.92)\left[\frac{(WLM)_A}{A}\right]$$

Substituting A = 0.1, B = 0.9, we have

$$\left[\frac{(WLM)_B}{0.9}\right] = (5.92)\left[\frac{(WLM)_A}{0.1}\right]$$

or

$$(WLM)_B = (9)(5.92)(WLM)_A$$

$$(WLM)_B = (53.28)\ (WLM)_A$$

But,

$$\text{Total} \quad WLM = (WLM)_A + (WLM)_B$$

$$973.9 = (WLM)_A + (53.28)(WLM)_A$$

or $$54.28\,(WLM)_A = 973.9$$

$$(WLM)_A = \frac{973.9}{54.28} = 17.9 \text{ WLM units}$$

$$(WLM)_B = 973.9 - 17.9 = 956.0 \text{ WLM units}$$

Therefore,

$$\left[\frac{(WLM)_A}{A}\right] = \frac{17.9}{0.1} = 179 \text{ WLM units/unit mass}$$

$$\left[\frac{(WLM)_B}{B}\right] = \frac{956.0}{9.9} = 1062.2 \text{ WLM units/unit mass}$$

Now to calculate "D" for both domains:

For bronchiogenic cancer data, we have 5.39 doubling doses

Therefore,

$$\frac{179}{5.39} = D = 33.2 \text{ WLM units/unit mass}$$

For small cell cancer data, we have 31.89 doubling doses

Therefore,

$$\frac{1062.2}{31.89} = D = 33.3 \text{ WLM units/unit mass}$$

So, we can say D = 33.3 WLM units/unit mass

Note: How very low the true doubling dose for radiation-induction of cancer is if we assume the bronchiogenic domain mass (A) to be 1/9 as large as the small cell domain mass (B). And, we simply don't know the size of these two domains, so this low a doubling dose is quite possibly the correct one!

Summary

Domain Size		Doubling Dose, D, for Lung Cancer
A=0.9	B=0.1	121.2 WLM units/unit mass
A=0.5	B=0.5	52.2 WLM units/unit mass
A=0.1	B=0.9	33.3 WLM units/unit mass

The doubling dose is highly dependent on assumed A and B, neither of which we know. Worse yet, the implications are vastly different, even beyond the D value itself, for the three different situations. Let us turn to such implications now.

(c) Some Possible Serious Surprises in the Future of Uranium Miner Lung Cancer

We shall now explore the implications of the assumed tissue domain sizes and D values for what may happen in the uranium mines. The factors which determine, in a particular person, in a particular mine, in respect to humidity in the mine, in respect to dust composition in the mine, - what the distribution of radon daughters will be into the two domains are so poorly known that we can say they are unknown. As we shall see below, if a change in these factors occurred in a particular mine, or if we consider the possibility of miner to miner variation, the implications can be drastic.

Let us consider serially, the effect of a different distribution of WLM into the two domains from what currently seems to be the average for uranium miners studied thus far. We shall explore the implications of equal distribution of total WLM into the two domains.

Start with case (b), where A=9B (A = 0.9; B = 0.1) D = 121.2 WLM

In the calculations above, for these domain sizes, we have

$$(WLM)_A = 586.7 \text{ WLM units}$$

$$(WLM)_B = 387.2 \text{ WLM units}$$

Let us suppose, either because of miner variation, or condition differences in the mines, that a shift in distribution occurred to

$$(WLM)_A = (WLM)_B = \tfrac{1}{2}\,(973.9) = 487 \text{ WLM units}$$

Bronchiogenic Domain Dose becomes $= \frac{(WLM)_A}{A} = \frac{487}{0.9} = 541$ WLM units/unit mass

Small Cell Domain Dose becomes $= \frac{(WLM)_B}{B} = \frac{487}{0.1} = 4870$ WLM units/unit mass

For bronchiogenic cancer, excess = $\frac{541}{121.2}$ = 4.46 doubling doses

Since expected = 4.54 cancers (See above III)

The Excess = (4.54)(4.46) = 20.25 cases

Total bronchiogenic cancers = Spontaneous + Radiation-Induced

= 4.54 + 20.25 = 24.79 cases

For small cell cancer, excess = $\frac{4870}{121.2}$ = 40.18 doubling doses

Since expected = 1.14 cancers

Excess cases = (1.14)(40.18) = 45.81

Total small cell cancers = Spontaneous + Radiation-Induced

= 1.14 + 45.81 = 46.95 cases

Total Cancers, both types = 24.79 + 46.95 = 71.74 cases

This is to be compared with 67.5 for the <u>existing</u> dose distribution.

Therefore, the shift in dosage distribution is <u>not</u> serious, since there will be only a $\frac{71.74}{67.5}$ = 1.06-fold increase in cancer incidence.

<u>Now try case (a), where A=B (A = 0.5; B = 0.5)</u> D = 52.2 WLM

In the calculations above, for these domain sizes, we have

$(\text{WLM})_A$ = 140.7 WLM units

$(\text{WLM})_B$ = 833.2 WLM units

Let us now suppose a shift in distribution were to occur, so that

$(\text{WLM})_A$ = $(\text{WLM})_B$ = 487 WLM units

Bronchiogenic Domain Dose becomes $\frac{487}{0.5}$ = 973.9 WLM units/unit mass

Small Cell Domain Dose becomes $\frac{487}{0.5}$ = 973.9 WLM units/unit mass

For bronchiogenic cancer, excess = $\frac{973.9}{52.2}$ = 18.7 doubling doses

Since expected = 4.54 cancers

The Excess = (4.54)(18.7) = 84.9 cancers

Total bronchiogenic cancers = Spontaneous + Radiation-Induced

= 4.54 + 84.9 = 89.44 cases

For small cell cancers, excess = $\frac{973.9}{52.2}$ = 18.7 doubling doses also

Since expected = 1.14 cases

Excess = (1.14)(18.7) = 21.3 cancers

Total small cancers = 1.14 + 21.3 = 22.44 cases

Total Cancers, both types = 89.44 + 22.44 = 111.88 cases

So, $\frac{111.88}{67.5}$ = 1.66-fold increase in cancers

Lastly, try case (c), where B=9A (A = 0.1; B = 0.9) D = 33.3 WLM

In the calculations previously, for these domain sizes, we have

$(WLM)_A$ = 17.9 WLM units

$(WLM)_B$ = 956.0 WLM units

Let us now suppose, either because of miner variations or mining condition change, a shift occurred to

$(WLM)_A$ = $(WLM)_B$ = 487 WLM units

Bronchiogenic Domain Dose becomes $\frac{487}{0.1}$ = 4870 WLM units/unit mass

Small Cell Domain Dose becomes $\frac{487}{0.9}$ = 541.1 WLM units/unit mass

For bronchiogenic cancers, excess = $\frac{4870}{33.3}$ = 146.2 doubling doses

Since expected = 4.54 cancers

The Excess = (454)(146.2) = 651.2 cancers

Total Cancers = Spontaneous + Radiation-Induced

= 4.54 + 651.2 = 655.74

For small cell cancers, excess = $\frac{541.1}{33.3}$ = 16.2 doubling doses.

Since expected = 1.14 cancers

Excess = (1.14)(16.2) = 18.5 cancers

Total small cancers = Spontaneous + Radiation-Induced

= 1.14 + 18.5 = 19.64 cancers

Total Cancers, both types = 655.74 + 19.64 = 675.4 cases

$\frac{675.4}{67.5}$ = a 10-fold increase in number of cancers

Thus, with this assumed size of domains (A=0.1 and B=0.9) and with a shift in distribution of burden to equal amounts in each domain, a 10-fold increase in cancers could occur over whatever value is calculated from past experience for any exposure level. And we do not know that these domain sizes are not the true ones.

Thus, even with the grudging FRC lowering of guidelines in 1967 to 12 WLM/year, and even with more recent Labor Department reduction to 3.6 WLM/year, this still means 36 WLM in a 10 year mining period of exposure. If the domain sizes are as indicated, and either for certain miners or mine conditions, the distribution of burden ever became equal in the two domains, there could be a 10-fold increase in total cancer incidence over what anyone might have thought possible. And this would indeed represent Joachimsthal revisited.

There may be those who say this is not at all reasonable since Joachimsthal had 30-150 WLM concentrations of radon-daughters. But Joachimsthal also 30-70% of all miners die of lung cancer(4). Since some miners must have died of heart disease and other causes, the 30-70% deaths due to lung cancer can, for all practical purposes, represent massive overkill. It just might not have been possible to have more lung cancers because the supply of candidates ran out! Furthermore, no one knows that the conditions in Joachimsthal mines were at all similar to those in USA uranium mines, and how those condition differences might affect burden distributions into the two domains.

These calculations should put those involved in setting standards on notice concerning what a treacherous problem this radon-daughter situation is in our primitive knowledge of the domain sizes and factors that may shift burden. Allowed levels of 12 WLM/year or 4 WLM/year may, with further experience, prove far from conservative. This problem deserves sober reconsideration with a possible view toward appreciable further lowering of the allowable level of radon-daughters to avoid revisiting Joachimsthal.

REFERENCES

1. Wagoner, J. K., Archer, V. E., Carroll, B. E., Holaday, O. A., and Lawrence, P. A. "Cancer Mortality Patterns Among U.S. Uranium Miners and Millers, 1950 through 1962". J. Nat. Cancer Inst. 32, 787-801, 1964.

2. Wagoner, J. K., Archer, V. E., Lundin, F. E., Jr., Holaday, D. A., and Lloyd, J. W. "Radiation as the Cause of Lung Cancer Among Uranium Miners". New Engl. J. Med. 273, 181-188, 1965.

3. Joint Committee on Atomic Energy. "Radiation Exposure of Uranium Miners" Parts I and II. 90th Congress, 1st Session, May 9 through Aug. 10, 1967.

4. Staff Report of the Federal Radiation Council. "Guidance for the Control of Radiation Hazards in Uranium Mining". (Preliminary) Report No. 8, May, 1967. (appears as Appendix 8 in Reference 3, pp 1017-1080 (Part II), 1967.)

5. Gardner, J. W., Secretary of HEW. "Report on a Review and Evaluation of the P.H.S. Epidemiological Study" August 1967 (Including Findings of the Epidemiological-Statistical Subgroup.) (appears as Appendix 21 in Reference 3, pp 1261-1277) This is a superb source of important information and analysis.

6. Staff Report of the Federal Radiation Council. "Guidance for the Control of Radiation Hazards in Uranium Mining" (Revised) Report No. 8, September 1967. (appears as Appendix 25 in Reference 3, pp 1289-1352, Part II, 1967.)

7. Gofman, J. W. and Tamplin, A. R. "Studies of Radium-Exposed Humans: The Fallacy Underlying a Major Foundation of NCRP, ICRP, and AEC Guidelines for Radiation Exposure to the Population-at-Large". Supplement to Testimony presented before the Sub-Committee on Air and Water Pollution, Committee on Public Works, United States Senate, 91st Congress, November 18, 1969. Also submitted to Science. GT-103-69

8. Gofman, J. W. and Tamplin, A. R. "Studies of Radium-Exposed Humans II. Further Refutation of the R. D. Evans' Claims that "The Linear, Non-Threshold Model of Human Radiation Carcinogenesis is Incorrect". Submitted to Dr. Paul Tompkins for the Review of Federation Council Guidelines (Dec. 26, 1969). GT-105-69

9. Parker, H. M. "Critique of the Ur anium Mining Hazards Testimony" in Reference 3, Appendix 20, pp 1241-1250, Part II, 1967.

10. Archer, V. E. "Comments of Dr. Victor E. Archer on Uranium Mining Hazards Testimony" in Reference 3, Appendix 20, pp 1254-1256, Part II, 1967.

11. Snyder, W. S. "The Bases of Standards for Radiation Protection: A Comparison of the Threshold Hypothesis and the Linear Hypothesis for the Dose-Effect Relation" in Reference 3, Appendix 20, pp 1256-1260, Part II, 1967.

12. Morgan, K. Z. "Maximum Permissible Exposure of Miners in the United States to Radon and Its Daughters" in Reference 3, Appendix 19, 1216-1222, Part II, 1967.

13. Morgan, K. Z. "Supplemental Statement on the Proper Working Level of Radon and Its Daughter Products in the Uranium Mines of the USA." (Supplement to Testimony Nov. 20, 1968, Department of Labor Hearings, Washington, D.C.)

14. Archer, V. E. "Initial Statement by Dr. Victor E. Archer to Round Table of JCAE Hearings on Uranium Mining Radiation Safety Standards" in Reference 3, Appendix 19, pp 1208-1211, Part II, 1967.

15. Saccomanno, G., Archer, V. E., Saunders, R. P., James, L. A., and Beckler, P. A. "Lung Cancer of Uranium Miners on the Colorado Plateau". Health Physics 10, 1195-1201, 1964.

16. Miller, R. W. "Delayed Effects in Atomic-Bomb Survivors". Science 166, 569-574, 1969.

17. Storer, J. Memorandum from John Storer to John Totter "Comments on manuscript "Low-Dose Radiation, Chromosomes, and Cancer". November 10, 1969. (A Memorandum widely circulated by DBM-AEC).

18. Wirtz, W.W., Secretary of Labor. "Radiation Standards for Mining. Amendment for November 9, 1967". In Reference 3, Appendix 29, p. 1368, Part II, 1967.

19. Hammond, E. C. "Smoking in Relation to the Death Rates of 1 Million Men and Women" in Haenszel, W., editor "Epidemiologic Approaches to the Study of Cancer and Other Diseases", Bethesda, U.S. Public Health Service, National Cancer Institute Monograph 19, pp 127-204, January 1966. Reproduced in "The Health Consequences of Smoking: A Public Health Service Review, 1967", pp 134-135. Public Health Service Publication No. 1696, Revised January, 1968.

20. Deaths for 258 Selected Causes by Age, Race and Sex, 1966. Table 1-25 Vital Statistics of the United States, 1966, Vol II - Mortality, Part A. U. S. Department of Health, Education and Welfare, Public Health Service.

21. Gofman, J. W. and Tamplin, A. R. "Federal Radiation Council Guidelines for Radiation-Exposure of the Population-at-Large -- Protection or Disaster?" Testimony presented before The Subcommittee on Air and Water Pollution, Committee on Public Works, United States Senate, 91st Congress, November 18, 1969. GT-102-69