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AN EVALUATION OF MILHAM'S ANALYSIS
OF HANFORD DEATHS

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FOLDER 2.3 MANCUSO PROJECT (MORALITY DATA)
CORRESPONDENCE FOR 1971-1975

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INTRODUCTION

Dr. Samuel Milham, Jr., M.D., Washington State Department of Social and Health Services, Health Services Division, is studying occupational mortality patterns in Washington State. He has studied the occupational mortality in the nuclear industry (Hanford Works in Richland) and he feels that the findings of this study support the hypothesis that higher incidence of cancer deaths among Hanford employees are attributed to external radiation exposure.

The purpose of our study is to evaluate Dr. Milham's findings and to analyze the available data on Dr. Milham's Hanford study population and see if our findings agree with Dr. Milham's findings. Utilizing the Hanford study population data base, we will first compare mortality rates not only to Dr. Milham's results but also to Washington State and United States mortality rates. The second major task will be to investigate the possible relationship between cancer deaths and radiation exposure.

STUDY POPULATION DESCRIPTION

Dr. Milham identified the study population by examining all death records for the three counties around Richland, Washington, (Benton, Franklin and Yakima), filed in the years 1950-1973. Records of men whose occupation statement listed Hanford, Atomic Energy Commission or an AEC contractor were considered those of Hanford employees. In all, 843 such records were identified but two of these had to be omitted from the study when it was determined they had not worked at Hanford. A brief review of Dr. Milham's methodology is given in Appendix A.

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Some characteristics of the study population are shown in Table I. The study population is all male and the race distribution is 832 Whites, 5 Negroes, 3 Indians, and 1 Mexican. Information as to whether an autopsy was performed was available on 831 individuals and 28.3% of these were autopsied.

Distribution of age at death broken down into 10 year intervals shows that 36.8% of the study population died when they were 65 years old or older. The distribution of the year of death shows that 57.9% of the study population died during the nine-year time period 1965 through 1973 whereas only 42.1% died during the 15-year time period 1950 through 1964. Over 72% of the group worked at Hanford for 10 years or longer and over 50% of the study population started to work at Hanford during the years 1943-1945. This indicates the uniqueness of the group in that many of them started to work at Hanford at the start of the project and worked on the project until they died.

The nuclear industry has many unique occupations which are difficult to classify using standard occupation codes. However, by utilizing broad occupation classes it is possible to look at the occupation distribution of the study population. Approximately 17% of the study population are professional and managers, 7% clerical, 24% craftsmen, 30% operatives, 7% laborers and service workers, and 15% are protective service workers.

One very important point should be made regarding the study population. The point being that the 841 Hanford deaths which occurred in the three Washington Counties is only a fraction of the total number of Hanford deaths which occurred in the United States for the same time period. The AEC Health and Mortality Study has death certificates for 3,486 male Hanford employees who died at ages 20+ during the years 1943-1972.

Problems in Analysis

The point of major interest in this study is whether or not there is anything about the Hanford deaths which suggests that exposure to radiation has played a role in causing some of them. Since we do not have information concerning the number and age distribution of the base population from which these deaths occurred (in fact we do not even have all the deaths-- just those occurring in three Washington counties), we have no way of assessing if the number of deaths observed is excessive. Instead we must determine if there is anything unusual about the distribution of deaths among various causes. In particular we will attempt to determine if the proportion of deaths due to cancer is in any way excessive since this cause is thought by many to be associated with radiation exposure.

The approach used by both Milham and Sanders was to compare the observed Hanford cause of death distribution with that found in the State of Washington over the years 1950-1971. That is, the age specific proportions for various causes of death were applied to the number of deaths in each age group of the Hanford deaths to determine the number of deaths from a given cause that would be expected if the Washington rates prevailed. The observed and expected number of deaths are then compared and tested for statistical significance. (See Appendix A for more detail.)

This method has the potential to establish that the cause of death distribution for the Hanford deaths is different from the distribution for the state of Washington (or any other base of comparison which is chosen), but it leaves much to be desired as a method of establishing that radiation is causing excess cancer deaths. First, looking at proportional mortality can be deceptive. An excessive proportion of cancer deaths may, for example,

represent a deficiency of cardiovascular deaths. Second, the Hanford population differs in many respects other than exposure to radiation from the population of the total state of Washington (and probably from any other base that one could find). Listed below are a number of differences which could effect the cause of death distribution.

1. All the deaths in the study are those of persons who were once employed at Hanford. Employed persons are known to have somewhat different death patterns than non-employed.
2. Most of these deaths are of those who came to work on a special project in the 1940's. The type of person who would choose to participate in such an undertaking very likely differs somewhat from the average Washingtonian. For one thing, a pre-employment physical was required screening out the obviously ill.
3. Hanford provides yearly physicals for its workers, possibly leading to better than average health care. One can imagine a number of ways this might effect proportional mortality. For example, early detection and subsequent treatment of high blood pressure could prevent some cardiovascular deaths.
4. Hanford employees live in a dry, desert, small city environment -- quite different from the moist, forested, urban environment of the Puget Sound Region.
5. Cause of death classification as recorded on death certificates may be slightly different from that of the state as a whole.
6. We are examining only those deaths which occurred in three counties in the state of Washington representing only 841 out of a total of 3486. Health factors could have played a role in persons leaving or staying in the Hanford area.

7. Some of these workers may have been exposed to other occupational hazards (chemicals, for example).

Fortunately, there is an alternative approach made possible by the fact that we have information on the external and internal doses of radiation received by those in our study. This information permits us to relate the cause of death distribution to the dose received avoiding many of the difficulties noted above. It is still possible of course, that those receiving high doses differ from the remainder in ways other than the dose received, but the differences are probably not as great as when an outside population is used for comparison.

In the next two sections we describe the results of the two methods of analysis discussed above.

Comparison of the Hanford Deaths With Vital Statistics for the United States and for Washington

As a first step in our analysis, we felt it was of interest to establish if the Hanford cause of death distribution differs in any way from an outside comparison population. This was Milham's approach, and since one purpose of this work is to evaluate Milham's findings, we should at least determine if he is on sound grounds in concluding that the Hanford cause of death distribution is significantly different from that of the state of Washington as a whole, regardless of whether he is correct in attributing such a difference to exposure from radiation.

Our main basis of comparison is the United States as a whole, primarily because of the availability of reliable vital statistics for specific years, age groups, and types of cancer. We also used data from the state of Washington for comparing broad cause classifications, but year and age specific rates were not available to us for specific types of cancer. We

had access to Milham's data for Washington deaths only as proportional mortality pooled over the years 1950-1971. Since cancer rates have been increasing over time,⁽⁷⁾ and since the Hanford deaths are not uniformly distributed over the considered time interval (see Table I), we felt it was important to consider the year of death as well as the age of death. We did not feel that Washington data necessarily provided a better basis of comparison than data for the U.S. as a whole. The majority of Washington's population lives in the Puget Sound area. It has already been noted that this area differs from Hanford with respect to climate, population density, and probably many other factors. Further a comparison of U.S. and Washington proportional mortality does not reveal much difference in proportional mortality for the various cancer types.

The source of our U.S. vital statistics are shown below. Data for white males only were used.

Source of Vital Statistics for Comparing
Hanford Deaths With the U.S.

<u>Source</u>	<u>Year(s) of Data</u>	<u>Years of Hanford Deaths This Data Was Compared With</u>
<u>End Results and Mortality Trends in Cancer</u> (3)	1950	1950-1952
" " "	1955	1953-1957
<u>Cancer in the United States</u> (6)	1959-61	1958-1961
<u>Vital Statistics of the U.S.</u> (12)	1962	1962-1963
" " "	1966	1964-1967
" " "	1969	1968-1970
<u>Monthly Vital Statistics Report</u> (8)	1972	1971-1973

The last source did not contain sex or race specific rates. To obtain this estimate, the overall proportion for 1972 was multiplied by the ratio of the 1969 proportions for white males and for total deaths.

The source of our Washington data were the Washington Vital Statistics Summary's (13). The table below gives the years available to us and the years of Hanford deaths with which comparison was made. Data for all males was used since this was all that was available. (Only about 4% of Washington's deaths are non-whites).

Source of Vital Statistics for
Comparing Hanford Deaths With Washington

<u>Source</u>	<u>Year of Data</u>	<u>Years of Hanford Deaths This Data Was Compared With</u>
Washington Vital Statistics Summary	1951	1950-1954
"	1958	1955-1959
"	1962	1960-1963
"	1964	1964-1965
"	1968	1966-1968
"	1969	1969
"	1970	1970
"	1971	1971-1972
"	1973	1973

To calculate expected values using either U.S. or Washington data, the age-year of death specific proportions (for the U.S. or Washington) were multiplied by the number of Hanford deaths in the particular age-year category. These numbers were then summed over years to obtain the expected deaths for each age group, and then over ages to obtain the total number of expected deaths.

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The results of these calculations using U.S. Statistics are presented in Table II for each ten year age group along with the observed Hanford deaths in each category.* The cancer categories are those given in the Vital Statistics of the U.S. volumes. Table III presents a summary of these same calculations for the total group and for those under and over 65 years of age. In the over 65 group genital and urinary cancers were pooled, and leukemia and lymphatic cancers were pooled. This was done to obtain high enough expected values to make the use of chi-square tests valid. The expressions $(\text{Observed}-\text{Expected})^2/\text{Expected}$ are also presented so that it can be seen which categories are making the greatest contribution to the total chi-square. The chi-square statistic is the sum of these expressions.

For each of the tables, a total chi-square for all 12 (10 for the over 65 group) categories was calculated. This total chi-square was then partitioned into three independent chi-squares testing the following hypotheses.

1. (Major categories) The distribution of deaths into cancer, cardiovascular, and all other causes is the same for Hanford deaths as for the U.S. as a whole.
2. (Within Cancer) The distribution of cancer deaths into specific types of cancer is the same for Hanford deaths as for the U.S. as for the U.S. as a whole.
3. (Within Cardiovascular) The distribution of cardiovascular deaths into heart disease, cerebrovascular and other is the same for Hanford deaths as for the U.S. as a whole.
4. (Total) The distribution of deaths into the 12 (10) categories in Table III (those not in parentheses) is the same for Hanford deaths as for the U.S. as a whole.

*A detailed cause of death breakdown for the Hanford deaths is presented in Appendix B.

The results of the chi-square tests are presented in Table IV. The observed cancer deaths for the under 65 group are somewhat in excess of those expected (115 vs. 100.4) but this difference is significant only at the .10 level. It is seen that the largest individual contribution to the total chi-square for this age group is for cancers of the digestive system. If we examine specific types of cancer within this category we obtain the following results for the under 65 group.

Cancer Type	Observed Deaths	Expected Deaths	χ^2	Level of Significance
Stomach	6	6.02	.00	N.S.
Colon	14	7.85	4.82	.05 ←
Rectum	2	3.59		N.S.
Pancreas	13	5.62	9.69	.005 ←

Cancer of the colon and pancreas show significant excesses for this age group. These cancers were also examined for the total group and for those over 65. Only cancer of the pancreas in the total group showed a significant excess (at the .005 level) with 18 observed deaths versus 8.1 expected. 18 vs 8.1

The within cancer chi-square for the over 65 group also reaches significance at the .10 level. Examining the contributions of individual cancer types to this statistic, we find that buccal cancer with an individual chi-square of 7.78 yields by far the largest value. Since the expected value for this cancer type is less than five, it is not valid to use the chi-square statistic to test this cancer type individually. However, Poisson tables can be appropriately used to obtain a valid test (see Guenther p. 55).⁽⁵⁾ This test reveals that the buccal cancer excess is significant at the .02 level.

Table V presents the observed and expected deaths based on Washington data for three age groups and for the total group. The causes selected are those for which data is available for the particular age group. Chi-square

tests were calculated for each age group. Although none of the results are significant, we note that the chi-square value for cancer alone is quite high in the 45-64 age group. If cancer alone is tested for significance in this age group, with all other causes grouped together we obtain a chi-square of 4.32 which is significant at the .05 level.

In summary, we can say that our data suggest that Hanford has a higher proportion of cancer deaths for those under 65 than the U.S. as a whole or than the state of Washington as a whole. More data would be required to establish this firmly. There definitely appear to be excess cancers of the pancreas and very likely excess cancers of the colon in the under 65 group as well as excess buccal cancers in the over 65 group.

Comparison with Milham's Findings

Our study included 841 of the 842 deaths originally analyzed by Milham. Milham claimed that his excess of cancers in the under 65 group is significant at the .025 level, and if his test statistics were correctly calculated he would obtain significance at the .01 level.* The primary reason for the discrepancy between his conclusions and ours is the difference in expected frequencies. We used U.S. data and took the year of death into account while Milham used Washington data pooled for the years 1950-1971. It is our belief that it is taking the year of death into account rather than the use of the U.S. as a base that is primarily responsible for the different results. We calculated the expected deaths for all cancer using Washington data (again taking year of death into account) and obtained 155.5 as compared with 157.8

*The correct statistic for testing the agreement of a single cause is the sum of the expressions $(\text{Observed}-\text{Expected})^2/\text{Expected}$ for the cause of interest and for all other causes combined. When the cause of interest is relatively rare (such as a specific cancer type), the second term is negligible and Milham's use of a single term is an appropriate approximation. However, when considering a more common cause, such as all cancer, both terms need to be included.

using U.S. data. By contrast Milham obtained 148 expected cancer deaths.

Milham also claimed a significant excess for a number of specific types of cancer. These are presented in Table VI along with a comparison of his and our expected and observed values. Many of our expected values are higher than Milham's, causing the significance of cancer of the tongue (buccal) and lung to disappear. In addition there are a few discrepancies in the observed cancer deaths. After careful review with the Hanford Environmental Health Foundation, we determined that Milham had one too few cancers in each of the categories lung, bone, and prostate cancer, while he had two too many deaths from leukemia and one extra death from aplastic anemia (non-cancer). In addition, there were a few errors in age classification including two tongue cancers and one cancer of the colon misclassified into the 20-64 age group. Correction of these errors eliminates the significance of aplastic anemia and cancer of the tongue. The age classification errors also contribute to the claimed significance of excess cancers in the 20-64 age group.

Milham's statistical tests are sometimes invalid. The chi-square statistic with one degree of freedom is appropriate for testing only when the expected frequencies are at least five (see Cochran⁽²⁾). In many instances this condition is not met. It is still possible to perform a valid test by using a Poisson approximation to the binomial distribution (Guenther⁽⁵⁾ p. 55). In Table VI we redid Milham's tests using his observed and expected values to obtain the correct significance levels. In every case the level of significance is increased (making the result less significant), but with the exception of aplastic anemia in the 20+ group, all results remain significant at least at the .05 level. Thus, it is the method of calculating

expected frequencies rather than statistical technique which primarily accounts for the discrepancies between Milham's and our conclusions.

We did not calculate expected frequencies for cancer of the bone (these cancers are included in our "other" category), aplastic anemia, or amyotrophic lateral sclerosis (non-cancers). We did recalculate the levels of significance using Milham's expected frequencies with our observed deaths and a correct statistical test. The excess of bone cancers and of amyotrophic lateral sclerosis remain significant and it seems unlikely that recalculation of the expected frequencies to take year of death into account would substantially alter these findings. With respect to amyotrophic lateral sclerosis, it must be noted that this cause was singled out for testing precisely because it appeared excessive. In any population of deaths there is likely to be some cause which will show a cluster of excess deaths with many possible explanations for such clusters.

Milham later redid his calculations, eliminating those who died in 1972 and 1973 (with obvious loss of information), and considering the year of death in calculating his expected frequencies. He also added a few cases who died in other parts of Washington. Since we do not have data on these additional deaths and since we do not have access to the detailed data from which his expected frequencies were calculated, it is impossible to completely evaluate these later calculations. He again did his statistical tests incorrectly, and since his errors included rounding off the expected frequencies to the nearest integer, we cannot redo his tests correctly. However, it appears that we will be left with the same valid excesses as before except that amyotrophic lateral sclerosis is no longer significant (3 of the 6 deaths occurred in 1972 and 1973).

Finally we note that in this section we are evaluating only whether Milham is correct in concluding that the Hanford deaths have a cause of death distribution which is different from that of the state of Washington. As we have discussed earlier, this does not establish that radiation is the cause of any significant differences. To gain further insight into this question we turn to a consideration of our information on radiation exposure and its relation to cause of death.

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EXTERNAL RADIATION EXPOSURE

Radiation exposure information is based on radiation exposure records maintained by personnel dosimetry. Rems of whole body penetrating radiation are accumulated over the years to determine the total occupational exposure. Prior to 1972 at Hanford, whole body penetrating radiation is interpreted as the combined exposure from gamma, 35% X-rays, fast neutrons, slow neutrons and tritium. The rem is the unit of radiation exposure and as used here includes only ionizing radiation which is able to reach critical organs of the body.

The National Council on Radiation Protection and Measurements (NCRP), since its founding, has recommended maximum permissible limits for radiation exposure received by individuals in the course of their occupation. The NCRP recommendations for occupational exposure to whole body penetrating radiation are:

1. The accumulated whole body penetrating exposure shall not exceed 5 rems multiplied by the number of years beyond age 18.
2. The whole body penetrating exposure in any calendar quarter shall not exceed 3 rems.

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Total External Dose Related to Cause of Death

Information on the total external dose in rems is available for 811 of the Hanford deaths. Various percentiles of the dose distribution are as follows:

<u>Percentile</u>	<u>Dose in Rems</u>	<u>Percentile</u>	<u>Dose in Rems</u>	<u>Percentile</u>	<u>Dose in Rems</u>
5	.00	40	.65	75	2.24
10	.05	45	.80	80	2.8
15	.12	50	1.00	85	4.3
20	.24	55	1.2	90	6.60
25	.32	60	1.4	95	20.0
30	.46	65	1.6	100	52.0
35	.56	70	1.9		

The distribution is highly skewed to the right, in fact, exponential in shape. None of the doses are particularly high at least relative to the standards noted above.

For the purposes of examining the relationship of dose to other variables, we have divided the deaths into five dose groups with cut points corresponding to the 25th, 50th, 75th, and 90th percentiles.

Dose Group 1	dose < .32R
Dose Group 2	.32 R ≤ dose < 1.00R
Dose Group 3	1.00R ≤ dose < 2.24R
Dose Group 4	2.24R ≤ dose < 6.60R
Dose Group 5	6.60R ≤ dose

It would be desirable to separately examine individuals with doses much higher than required by dose group 5, but there are not enough of these to make such an analysis feasible.

Table VII shows the relationship of dose to cause of death (cancer, cardiovascular, and other). It is seen that the percent of deaths due to cancer increases with dose showing a particularly striking jump between

doses 4 and 5. Pooling the four lowest dose groups, we have a cancer percent of 19.7 versus 33.3 for the highest group. That the difference should be observed primarily in the top group is probably not too surprising since none of the doses in the lower groups are particularly high.

It would be unwise to draw any conclusions before examining the relationship of dose to other factors which are related to cancer incidence and which may account for some of the dose-cancer relationship observed above.

Tables VIII and IX present the relationship of dose to age and year of death, respectively. It is seen that the age group 55-64 has an unusually high dose distribution while those over 75 are on the low side. Since cancer incidence is relatively high and low in the same respective age groups, age could well account for at least a part of the observed cancer-dose relation. Year of death also shows a strong relationship to dose. Only 2.5% of the deaths in the highest dose group occurred before 1950 compared with 36.6% in the lowest dose group. Nearly 52% of the deaths in the highest dose group occurred in 1970 or after compared with about 20% of those below the median. Since the incidence of cancer between 1950 and 1954 is particularly low (9.1%), this relationship could also effect our conclusions about dose and the cancer proportion.

The first thing that was done in order to reduce bias due to the difference in age distribution was to calculate an age adjusted cancer percent for each age group. That is, for each dose the age-dose specific cancer proportion was multiplied by the total number of Hanford deaths in

the particular age group. These quantities were summed over age and then divided by the grand total of deaths. The resulting percent can be interpreted as the cancer percent that would be observed in the total group of deaths if it had experienced the age specific rates for the particular dose group of interest. This is the direct method of age adjusting and is described in Spiegelman⁽¹⁰⁾ (pp. 67-69).

The age adjusted percents are 17.3, 19.1, 21.9, 20.8, and 30.7 for dose groups 1, 2, 3, 4, and 5, respectively. Thus this adjustment slightly lessens, but certainly does not eliminate, the effect of dose on the cancer percent.

The second thing that was done to remove age-year of death biases was to limit our more detailed analysis to the age group 45-74 and to those deaths occurring 1960 and after. The cancer proportion does not vary much over these age and year intervals. Further, one really does not lose much information by limiting the group in this way. In making comparisons regarding the dose groupings of primary interest, it is the size of the smallest group, dose group 5, which primarily effects validity and power of the statistical tests. In dose group 5, 71 of the original 81 are in the age group 45-74 and died 1960 or after.

In the table below are presented the crude cancer percents for each dose group for ages 45-74, year of death 1960-1973. These are then age adjusted (for the age groups 45-54, 55-64, 65-74). Also presented are data for dose groups 1-4 pooled versus dose group 5. This pooled data is adjusted for both age (as above) and year of death (for the groups 1960-1969 and 1970-1973).

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Percent Dying from Cancer for Various Dose Groups for
Those With Age at Death 45-74, Year of Death 1960-1973

Dose Group	1	2	3	4	5
Crude Cancer %	17.4	21.9	23.6	22.1	36.6
Age Adjusted Cancer %	18.1	22.3	23.5	21.0	36.8
Dose Group		1-4	5		
Crude Cancer %		21.7	36.6		
Age-Year Adjusted Cancer %		21.9	37.3		

We still see a slight increase in the cancer percent over doses 1-4 with quite a jump as we move to dose 5. Note that age-year adjustment makes very little difference within this group due to the uniformity of the cancer percent over this age-year of death range.

Tables X and XI summarize the observed dose-cancer relationship. Results including all five dose groups are given for each 10-year age group and for the total group. The numbers for those dying at age 45-54 are too small to be very meaningful. The 55-64 age group shows a slightly higher cancer percent in all dose groups than the 65-74 age group with the largest difference in dose group 4 (30.6% vs 16.0%). The three age groups were pooled for the purpose of performing a statistical test.

We wish to test the null hypothesis that the cancer proportion is independent of dose versus the alternative that cancer increases with dose. A possible test is, of course, the chi-square test, but this test does not take into account the ordered nature of the dose groups and thus is not particularly sensitive to the kind of differences in which we are interested.

An alternative is a test for linear trend in proportions described in Snedecor and Cochran⁽⁹⁾ (pp. 246-248). The procedure essentially involves performing a linear regression of the proportions on scores assigned to the dose groups and then testing the significance of the regression coefficient b . The method may, of course, be sensitive to the scores assigned. Two sets of scores were used; the first were simply the numbers 1, 2, 3, 4 and 5, while the second were the median doses for the 5 groups (.09, .64, 1.49, 3.39, and 20.63, respectively). In both cases the results were highly significant. With the simple scores we have $z = 2.41$, significant at the .01 level, and with the median dose scores we have $z = 2.80$, significant at the .005 level. Significance levels are based on a one-tailed test.

Table XI presents comparisons for the pooled dose groups 1-4 versus dose group 5. In addition to individual age groups, this comparison is shown for the two year of death groups 1960-1969 and 1970-1974. The most striking observation regarding these age-year of death specific tables is the low cancer percent for the top dose group age 55-64 in deaths occurring 1970 and after. No ready explanation comes to mind for this observation. However, the fairly high cancer percent (30.6) observed for this age group for dose group 4 when considering all years of death 1960-1973 suggested that we examine this next highest dose group. In doing so we found that 35.0% of the 20 in dose group 4, age 55-64, year of death 1970-1973 had died from cancer. It could well be that the result observed for this age-year of death group is a fluke which is partially a result of the somewhat arbitrary cutpoint of 6.6 rems and partially a result of the small numbers involved. We cannot, however, rule out the possibility that we are looking at a real phenomena whose explanation escapes us.

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A Yates corrected chi-square was calculated for all tables with a sufficient number of deaths to make such a test valid. Of greatest interest is the chi-square for the total group which has a value of 6.75 and thus is significant at the .01 level.

We next examined the relationship of dose and specific types of cancer, again limiting ourselves to those with age 45-74 and year of death 1960-1974. In this group (including deaths from all causes) there are 13.5% with doses over 6.6 (dose group 5) and 62.0% with doses 1.00 and greater (dose groups 3, 4, and 5). (For the total group these percents would be 10% and 50%, but they are altered for the limited group.) For each type of cancer, we examine the percent of deaths over 6.6, and over 1.00 and then test whether these percents are greater than 13.5 and 62.0, respectively. Tables of the binomial distribution⁽¹¹⁾ were used to yield an exact test. Results are presented in Table XII. In only two cases was statistical significance (at .05 or less) obtained; for lymphatic cancers (only for the percent with doses over 6.6), and for respiratory cancer where 27.1% had doses over 6.1 and 79.2% had doses over 1.00. In fact, out of 26 cancer deaths occurring in the top dose group, 13 were due to lung cancer. A relationship of dose with cancer of the pancreas and cancer of the colon is suggested, but does not reach statistical significance. It is perhaps interesting to note that 3 out of 5 of the buccal cancers in the over 65 age group had doses below 1.00 suggesting that the excess observed in comparison to U.S. data is unlikely to be radiation related.

The relationship of dose to aplastic anemia and amyotrophic lateral sclerosis is also examined since Milham showed an interest in these causes.

The one death from aplastic anemia had a dose of 0.0. Of the six deaths from amyotrophic lateral sclerosis, one had a dose of 20.28, 4 had a dose between 1 and 2, and one had a dose of 0.0. Although 5 out of 6 had doses over the median, this result is not statistically significant.

As a further verification of the cancer-dose relation, the U.S. vital statistics data was used to calculate the expected cancer deaths for the top dose group only. These calculations show a statistically significant excess for cancer (26 observed vs 16.5 expected) and specifically for respiratory cancer (13 observed vs 6.1 expected).

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Other Measures of Radiation Dose

In addition to the total external dose, we also had available information on the dose received each year for those in our study. The analysis of this more detailed information was limited to those with age at death 45-74 and year of death 1960-1973. The additional measures of dose which we considered were the maximum dose received in a single year, the average yearly dose (the total external dose divided by the number of years for which dose information was available), and the number of years for which we had dose information. For each of these variables we looked at the top 13.5% (71 individuals) since that was the percent in our top dose group for total external dose. When a category was split by selecting exactly 71 individuals, we chose the smallest number which did not involve splitting a category. Table XIII shows the agreement of these new variables with total external dose with respect to division into the top 13.5% and bottom 86.5%. Dose maximum agrees quite well with total dose with 68 deaths falling in the top category for both. Eight deaths fell in the top total dose group but not in the top group for dose maximum, while seven showed disagreement in the reverse direction. Dose average also agrees quite well with total dose with 62 deaths falling in the top category for both. Nine deaths fell in the top total dose group but not in the top group for dose average, and nine also showed disagreement in the reverse direction. In contrast, the number of years does not give the same information as total dose. Only 15 deaths are in the top category for both variables with a total of 102 showing disagreement.

Table XIV relates the percent dying from cancer to the three variables defined above. Recall that the percents for low and high total dose were 20.7 and 35.2, respectively. The results for dose maximum and dose average are quite similar to those for total dose -- hardly surprising in view of the agreement of these variables with total dose. The percents for low and high number of years are 21.9 and 29.5, a somewhat smaller difference.

There is obviously much more that might be done with this more detailed information but this has limited us to this very brief consideration. It would be interesting, for example, to examine the interval between the year of maximum exposure (or the first year with a large exposure) and the year of death.

Finally, there were eight deaths with recorded internal exposure to radiation. All but one of these were in dose group 6 with respect to total external exposure. Two of the eight died of cancer, one of lung cancer and one of cancer of the brain. Only six of the eight fall within the 45-74 age group (all eight died after 1960), including both cancer deaths. The numbers involved are obviously too small to draw any firm conclusions.

Occupation and Dose

Examination of the occupations of those in our high dose group (for those aged 45-74 with year of death 1960 or later) revealed that 61 out of 77 were either craftsmen or operatives. In addition, there were five radiation workers, classified as clerical with just one or two in each of the additional categories given in table 1. It occurred to us that this relationship of dose and occupation could bias our results. Cancer of the lung has been reported to be more prevalent among the less educated.⁽⁶⁾ Possibly, then, socioeconomic factors at least partially account for our observed relationship of cancer and dose. To minimize such a possibility we have repeated our analysis but this time we have included only those classified as craftsmen and operatives. We have again restricted the analysis to those with age at death 45-74 and year of death 1960-1973.

The number in each dose group and the percent dying from cancer for this new group are presented below.

	<u>Dose Group</u>					<u>Total</u>
	1	2	3	4	5	
Number in Group	27	37	68	40	56	228
Percent Dying from Cancer	14.8	10.8	22.1	28.6	40.0	25.3

A chi-square test reveals that the relationship of dose and cancer percent is significant at the .01 level. If we compare dose groups 1-4 with the top group, we have cancer percents of 20.4 and 40.0 respectively, a difference which is significant at the .001 level. Adjusting these percents for age and year of death changes these percents to 21.2 and 39.4 for the low and high dose groups, respectively, so that it seems highly unlikely that the observed difference can be accounted for by

discrepancies in age and year of death.

There are 23 lung cancers in the group, 12 of which are in dose group 5. The percentages for deaths from lung cancer are then 5.1 and 20.0 for the low and high dose groups, respectively. This difference is significant at the .005 level. Numbers are too small to say much about other specific types of cancer. There are six deaths from cancer of the pancreas with three falling in the top dose group, and six deaths from cancer of the colon only one of which is in the top dose group.

As an alternative form of analysis, we calculated the cancer deaths that would be expected for both the low and high dose groups using U.S. Vital Statistics and taking age and year of death into account. For the low dose group we would expect 37.3 cancer deaths and we observed 37. However, for the high dose group we would expect 12.8 cancer deaths and we observed 24. The observed and expected deaths from respiratory cancer are 7.1 and 13.4, respectively, for the low dose group and 1.2 and 4.9 for the high dose group. The differences in observed and expected deaths for the high dose group are significant at the .005 level for both cancer and lung cancer.

The five radiation monitors were not included in the above analysis. Four of the five fall in the high dose group with two of the four dying from cancer.

In addition to looking at all craftsmen and operatives, we examined those particular occupations which are unique to the nuclear industry. These include radiation monitors, utility operators, chemical operators, power operators, reactor workers and metal workers. All of these categories, with the exception of power operators and metal workers, had unusually high dose levels (40% or more in dose group 5). The only

other categories with very high doses were the millwrights and steamfitters. Since there may have been individuals in these groups who worked in non-nuclear areas, they were not included in this particular analysis.

For the group described above, 19 out of 61 or 31.1% of the low dose group died of cancer, while 17 out of 46 or 37.0% of the high dose group died of cancer, a result which just misses statistical significance ($\chi^2 = 3.78$) at the .05 level. Even within this very limited group, the low dose group is made up primarily of power operators and metal workers while the high dose group is made up primarily of utility, chemical and reactor operators. We cannot ignore the possibility that there are factors other than exposure to radiation which distinguish these specific occupations and which possibly explain the observed difference in the proportion dying from cancer. In fact, the cancer percent for all metal workers and power operators is just 13.8% while for the remainder of the group - it is 40.6%. Within this remainder (primarily utility, chemical and reactor operators), there is no evident relationship between the total external dose and cancer as a cause of death (but 38 out of 54 were in dose group 5 while only one person had a dose less than 1.0 rem). This suggests either that it is something other than radiation that is causing the deaths, or that nearly everyone in the high exposure occupations received a threshold dose and beyond this it doesn't make much difference.

CONCLUSIONS

We have established that there is a relationship between cancer as a cause of death and the total external dose of radiation received. The relationship is particularly pronounced for lung cancer. This does not, of course, in itself imply that radiation is the cause of the observed excess cancer deaths. We have attempted to minimize the effects of possible biasing factors by restricting our final analysis to operatives and craftsmen with age at death 45-74 and year of death 1960-1973. However, it is still possible that there are subtle biases operating that distinguish those in the very specific occupations where high doses are received and those that make up the remainder of the craftsmen and operatives. There may be other occupational hazards connected with these occupations or perhaps there are distinguishing features that lead a person to select (or be selected for) these occupations.

There are certain problems associated with basing our analysis on the total external dose as a measure of radiation exposure. This measure obviously does not tell us the manner in which a person has received his exposure. A given dose may represent two or three years of very high exposure or twenty years of moderate exposure. These two situations may be quite different in terms of their effect on an individual's health. It would seem, too, that the more years of exposure a total dose represents the more possible exposure situations it could represent. This could be a factor in the lack of dose relation for the deaths 1970 and after in the 55-64 age group since many of those people had worked for 20 or more years.

Another problem with the total external dose is that to some extent it is a function of the length of time a person has worked at Hanford. If environmental or occupational factors other than radiation are responsible

for excess cancers, those with high total doses would on the average have been exposed to these factors longer than those with low doses. There is a possibility then that some other factor may account at least partially for the observed dose cancer relationship. Possibly the reason the relationship does not show up in the 25-34 deaths 1970 and after is that nearly all of them are long term Hanford workers regardless of dose.

A finding which may be another indication of the inadequacy of the use of total external dose is that examination of the very high doses (those 20 years and above) does not show a cancer proportion any greater than we find when the group with doses 6.6 rads and above are considered. This finding may suggest some direct dose or it may indicate that it is a radiation related factor rather than radiation itself which is causing excess deaths.

A careful look at the detailed year by year dose data could help to resolve some of the questions raised above. For the time being radiation must certainly be placed high on the list of suspects in considering possible explanations for the observed relationship.

TABLE I

Description of Hanford Study Population

Observed Deaths Due To All Causes By Race

	<u>Race</u>				Total
	<u>Caucasian</u>	<u>Neuro</u>	<u>Indian</u>	<u>Mexican</u>	
Number	832	5	3	1	841
Percent	98.9	0.6	0.4	0.1	100

Observed Deaths Due To All Causes By Autopsy Information

	<u>Autopsied</u>		
	<u>No</u>	<u>Yes</u>	<u>Total</u>
Number	596	235	831*
Percent	71.7	28.3	100

*10 Missing

Observed Deaths Due To All Causes By Age

	<u>Age</u>							Total
	<u>20-24</u>	<u>25-34</u>	<u>35-44</u>	<u>45-54</u>	<u>55-64</u>	<u>65-74</u>	<u>75-84</u>	
Number	4	21	66	163	289	121	79	841
Percent	.4	2.5	6.5	19.4	34.4	26.3	9.4	100

Observed Deaths Due To All Causes By Year Of Death

	<u>Year Of Death</u>					Total
	<u>50-54</u>	<u>55-59</u>	<u>60-64</u>	<u>65-69</u>	<u>70-74</u>	
Number	69	110	178	232	252	841
Percent	7.8	13.1	21.2	27.6	30.3	100

Observed Deaths Due To All Causes by Number Of Years Worked At Hanford

	<u>Number Of Years Worked At Hanford</u>						Total
	<u>0-4</u>	<u>5-9</u>	<u>10-14</u>	<u>15-19</u>	<u>20-24</u>	<u>25-29</u>	
Number	54	123	204	206	145	52	784*
Percent	6.9	15.7	26.0	26.3	18.5	6.6	100

*57 Missing

TABLE 1. (Cont'd)

Observed Deaths Due To All Causes By First Year Worked At Hartford

	<u>First Year Worked At Hartford</u>			
	<u>43-45</u>	<u>46-50</u>	<u>51</u>	<u>Total</u>
Number	424	226	153	803 ^a
Percent	52.8	28.1	19.1	100

*38 Missing

Observed Deaths Due To All Causes By Occupation

<u>Occupation</u>	<u>Number</u>	<u>Percent</u>
Professional and Technical	81	10.36
Managers and Administrators	50	6.38
Clerical	57	7.29
Craftsmen	190	24.30
Operatives	169	21.61
Transport Equipment Operatives	67	8.57
Laborers	8	1.02
Service Workers	40	5.08
Protective Service Workers	111	14.50
TOTAL	782 ^a	100.00

*59 Missing

1. Alphabetical Index of Industries and Occupations, Bureau of Census, U.S. Department of Commerce, June 1971.

TABLE

A Comparison of Observed and Expected Deaths by Cause* for All Deaths, for Those Dying Under 65 Years of Age and Those Dying Over 65 Years of Age (Expected Deaths are Calculated Using Age-Year-Cause Specific Death Rates for U.S. White Males)

Cause	All Ages		Under 65 Years		Over 65 Years	
	Observed Deaths	Expected Deaths	Observed Deaths	Expected Deaths	Observed Deaths	Expected Deaths
Cancer						
Bladder Cancer	9	8.7	3	3.7	6	5.0
Digestive Cancer	42	48.7	30	28.9	12	19.8
Respiratory Cancer	88	72.3	35	35.7	53	36.5
Soft Tissue Cancer	10	12.4	7	8.7	3	3.7
Uterine Cancer	3	0.1	2	0.1	1	0.0
Vaginal Cancer	2	10.2	1	10.2	1	10.2
Leukemia Cancer	4	0.4	2	0.2	2	0.2
Other Lymphatic Cancer	13	8.4	13	5.7	0	2.7
Cancer Total	(177)	187.8	(175)	100.6	(155)	87.6
Heart Disease	366	365.6	200	242.6	166	122.2
Cerebrovascular	50	50.2	20	20.2	30	30.0
Other Cardiovascular	29	22.8	12	11.3	17	11.5
Cardiovascular Total	(445)	438.6	(232)	274.1	(213)	163.7
All Other Causes	273	280.2	185	171.6	88	108.6
TOTAL	801	866	592	599	451	559
				10.67		300
						11,779

* The causes of death codes are the same as those given in Table

**The Chi-square is the (Observed Deaths-Expected Deaths)²/Expected Deaths

TABLE IV.

Results of Statistical Tests for the Comparison
of Observed and Expected Deaths as Calculated in Table

	<u>Chi-Square</u>	<u>Degrees of Freedom</u>	<u>Level of Significance</u>
<u>All Deaths</u>			
1. Major Categories	4.01	2	N.S.*
2. Within Cancer	3.13	7	N.S.
3. Within Cardiovascular	1.37	2	N.S.
4. TOTAL	8.85	11	N.S.
<u>Under 65 Years</u>			
1. Major Categories	4.73	2	.10
2. Within Cancer	4.33	7	N.S.
3. Within Cardiovascular	.70	2	N.S.
4. TOTAL	10.41	11	N.S.
<u>Over 65 Years</u>			
1. Major Categories	.74	2	N.S.
2. Within Cancer	10.09	5	.10
3. Within Cardiovascular	1.28	2	N.S.
4. TOTAL	11.79	9	N.S.

*N.S. means not significant at the 10% level

TABLE V.

A Comparison of Observed and Expected Deaths by Cause
for All Deaths and for Three Age Groups
(Expected Deaths are Calculated Using Age-
Year - Cause Specific Rates for Washington Males.)

Cause	Code	All Ages			Under 45 Years		
		Observed Deaths	Expected Deaths	χ^2	Observed Deaths	Expected Deaths	χ^2
Cancer	140-209	174	156.5	2.20	9	9.4	.02
Heart Disease	300-398,402, 404,410-429	350	354.7	.30	22	16.5	1.82
Cerebrovascular	430-439	58	62.9	.39			
Accidents	1800-1949				22	25.3	.69
II Other Causes		253	266.9	2.10	27	27.8	.02
TOTAL		841	841	5.03**	80	80	2.55**

Cause	Code	45-64 Years			Over 65 Years		
		Observed Deaths	Expected Deaths	χ^2	Observed Deaths	Expected Deaths	χ^2
Cancer	140-209	105	88.9	3.28	59	57.2	.06
Heart Disease	300-398,402, 404,410-429	207	200.7	.72	137	138.9	.03
Cerebrovascular	430-439	22	28.4	1.45	31	34.5	.008
Accidents	1800-1949	26	29.9	.50			
Other Causes		91	104.6	1.70	79	78.4	.005
TOTAL		452	452	7.21**	309	309	.10**

The Chi-Square is the $(\text{Observed Deaths} - \text{Expected Deaths})^2 / \text{Expected Deaths}$

None of the chi square values reach significance at the .10 level.

TABLE I.

A Comparison of Milham's Significant Results With Our Calculations

Type of Cancer	Age Group	Significance Level		Observed Frequencies		Expected Frequencies		New Level of Significance**
		Milham's (Using χ^2)	Significance Level	Milham's	Ours	Milham's	Ours	
All Cancers	20+	.05	.05	173	174	145.3	137.3	N.S.
	20-64	.005	.07	113	113	93.3	100.4	.10
Tongue	20+	.005	.03	1	6			
	20-64	.001	.007	3	3			
Mouth & Pharynx	50+	.001	.005	3	3			
	20+			6	3	2.78	5.46	N.S.
Succal	20-54			3	3	2.24	3.92	N.S.
	50+			3	5	.74	1.54	.03
Colon	20-64	.005	.005	13	14	5.68	7.65	.05
	20+	.01	.01	13	18	9.65	6.33	.005
Pancreas	20-64	.005	.005	13	13	5.65	3.32	.005
	20+	.01	.05	54	55	47.4	59.2	N.S.
Lung	20+	.02	.05	3	4	.31		.01
	20+	.05	.01	2	1	.45		N.S.
Aplastic Anemia	20+	.001	.02	2	1	.19		N.S.
	20-64	.001	.001	3	3			
Atrophic Lateral Sclerosis	20+	.001	.001	5	5	.33		.001
	20-64	.001	.025	3	3	.66		.025
Lateral Sclerosis	20-64	.001	.001	3	3	.21		.001
	65+			3	3			

* This significance level was obtained using Milham's observed and expected frequencies

** This level was obtained using our observed and expected frequencies with an appropriate test.

TABLE VII.

Total External Dose Related to Cause of Death

Dose in Rems	Dose Group					Total
	1	2	3	4	5	
0		.32-	1.00-	2.23-	6.60	
Percent Dying from:						
Cancer	16.8	19.7	23.2	21.8	33.3	171
Cardiovascular	53.0	62.1	53.7	46.7	44.4	435
Other	31.2	18.7	23.2	32.0	22.2	205
Number in Dose Group	202	203	203	122	81	811

TABLE VIII.

Total External Dose Related to Age at Death

Percent with Dose Above	Age at Death							
	20	25	35	45	55	65	75	85
1.00 Rems (Median)	0	36.8	49.1	50.6	61.4	46.8	25.9	34.3
2 Rems (75th Percentile)	0	25.3	30.2	21.9	33.2	21.3	9.7	34.3
6.60 Rems (90th Percentile)	0	15.8	9.4	6.3	14.6	9.3	1.4	0
Number in Age Group	4	19	53	160	210	215	72	7

TABLE IX.

Total External Dose Related to Year of Death

Dose in Rems	Dose Group				
	1	2	3	4	5
0		.32-	1.00-	2.23-	6.60-
Percent with Year of Death					
1950-1959	35.6	28.6	31.4	6.5	2.5
1960-1969	45.6	31.8	51.3	51.6	45.6
1970-1973	15.8	19.7	37.4	41.8	51.9
Number in Dose Group	202	203	203	122	81

TABLE X.

Age-Specific Percent of Cancer Deaths for Five Dose Groups Including Those with Age of Death 45-74, Year of Death 1960-1973

<u>Dose in Rad</u>	<u>Dose Group</u>					<u>All Dose Levels</u>
	1 0-	2 1.33-	3 1.00-	4 2.23-	5 6.00-	
<u>Age 45-54 Years</u>						
Number in Group	18	23	34	21	9	98
Percent Dying from Cancer	30.8	14.3	26.5	9.5	44.4	22.4
<u>Age 55-64 Years</u>						
Number in Group	26	35	74	49	41	225
Percent Dying from Cancer	15.4	25.7	23.0	30.5	36.6	26.7
<u>Age 65-74 Years</u>						
Number in Group	47	58	53	25	21	204
Percent Dying from Cancer	14.9	22.4	22.6	10.0	33.3	21.1
<u>Total Group Age 45-74 Years</u>						
Number in Group	89	114	161	95	71	527
Percent Dying from Cancer	17.4	21.9	23.6	22.1	36.6	23.7

Age and Year of Death-Specific Percent of Cancer Deaths for Two Base Groups Including Those with Age of Death 45-74, Year of Death 1960-1973

Base Group	Year of Death 1960-1969			Year of Death 1970-1973			Total Year of Death 1960-1973		
	T-4	0-5.6	6.5+	T-4	0-5.6	5.6+	T-4	0-5.6	5.6+
Total Base in Rems	114	19	133	70	22	92	184	41	225
Age 45-54 Years	22.8	62.5	27.7	27.1	22.7	24.9	24.5	35.5	25.7
			$\chi^2=5.91^*$			$\chi^2=.02$			$\chi^2=1.94$
Number in Group	55	7	62	24	3	27	89	9	98
Percent Dying from Cancer	15.5	33.8	18.3	33.2	31.7	36.3	20.2	44.4	22.4
Age 45-74 Years	113	7	120	70	14	84	188	21	209
Number in Group	113	7	120	70	14	84	188	21	209
Percent Dying from Cancer	19.5	28.6	20.0	20.0	35.7	22.6	19.7	33.8	21.1
			$\chi^2=7.86^{**}$			$\chi^2=.38$			$\chi^2=1.37$
Total Group	227	32	259	154	39	193	456	71	527
Age 45-74 Years	20.2	63.8	22.5	24.4	30.8	25.6	21.7	35.6	23.7
Number in Group	202	32	234	154	39	193	456	71	527
Percent Dying from Cancer	20.2	63.8	22.5	24.4	30.8	25.6	21.7	35.6	23.7
			$\chi^2=7.86^{**}$			$\chi^2=.38$			$\chi^2=6.75^{**}$

The χ^2 statistic is a Yates corrected chi-square with one degree of freedom. It was calculated only when the numbers involved were large enough to make its use valid.

*Significant at the .025 level.

**Significant at the .01 level.

TABLE XII.

Distribution of Total External Base for Specific Cancer Types for Those with Age at Death 45-74, Year of Death 1960-1973.

	<u>Percent with Base</u>		<u>Number In Group</u>
	<u>≥1.00</u>	<u>≥ 6.5</u>	
Total Group	62.3	18.5	525
Buccal Cancer	28.5	14.3	7
Digestive Cancer	71.4	11.4	35
Respiratory Cancer	79.2*	27.1*	48
Genital Cancer	60.0	0.0	5
Urinary Cancer	40.0	20.0	5
Leukemia	0.0	0.0	2
Other Lymphatic	66.7	55.5*	9
Cancer of the Colon	83.3	8.3	12
Cancer of the Pancreas	59.2	73.1	13
Cancer of the Bone	25.0	0.0	4

Tables of the "Binomial" Distribution were used to test the hypothesis that the observed percents are consistent with the percents for the total group.

* Significant at the .01 level.

TABLE XIII

Agreement of Total External Exposure and Maximum Yearly Dose, Average Yearly Dose, and Number of Years with Dose Information, Ages 45-74, Year of Death 1950-1973.

		Maximum Yearly Dose			Average Yearly Dose			Number of Years with Dose Information		
		<1.49R	1.49R-1	Total	<.35R	.35R-	Total	<25	25+	Total
Total External Dose	<6.6R	439	7	446	437	9	446	400	46	446
	6.6R+	8	63	71	9	62	71	56	15	71
	TOTAL	447	70	517	446	71	517	456	61	517

TABLE XIV

Percent Dying from Cancer Related to Maximum Yearly Dose, Average Yearly Dose, and Number of Years with Dose Information, Ages 45-74, Year of Death 1950-1973.

	Maximum Yearly Dose			Average Yearly Dose			Number of Years with Dose Information		
	<1.49R	1.49R-1	Total	<.35R	.35R-	Total	<25	25+	Total
Number in Group	447	70	517	446	71	517	456	61	517
Percent Dying from Cancer	21.0	34.3	22.8	20.7	38.0	22.8	21.9	28.5	22.8
	$\chi^2 = 5.31^*$			$\chi^2 = 9.02^{**}$			$\chi^2 = 1.35$		

The chi-square statistic is a Yates corrected chi-square with 2 degree of freedom

* Significant at the .025 level.

** Significant at the .005 level.

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APPENDIX A

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APPENDIX A.

BRIEF REVIEW OF DR. MILHAM'S METHODOLOGY

Dr. Milham's first step in studying occupational mortality patterns in Washington State, was to search the death records of all male residents, age 20 plus, dying in the years 1950-1971. The occupational statement was abstracted and coded, based on the U.S. Census Bureau occupational code. This information along with age at death and cause of death was filed on magnetic tape for 307,828 records. The age at death and cause of death information was utilized to calculate the proportion of deaths due to various causes by age for Washington State male residents. His second step in the study was to examine all death records for the three counties around Richland, Washington (Benton, Franklin and Yakima), filed in the years 1950-1973. Records of men whose occupation statement listed Hanford, Atomic Energy Commission or an A.E.C. contractor were considered those of Hanford employees. In all, 843 such records were identified and tabulated by cause of death and age at death.

Expected number of deaths for Hanford employees were derived by using a proportionate mortality approach. Total deaths for Washington state during the years 1950-1973 and the cause of death to be examined are counted by 5 year age groups for the entire file, and the proportion of deaths due to the examined cause is calculated in each age class. The proportion is then multiplied by the total Hanford deaths in each age class to get the expected deaths due to that cause in each age class in Hanford employees. Observed deaths for that cause are tabulated by age, and observed and expected deaths are summed over age and compared using a chi-squared test.

Dr. Milham discussed his work with Dr. Barker S. Sanders and decided to analyze Hanford deaths for the years 1950 through 1971 which corresponds to the same years as his proportionate mortality statistics. Dr. Milham's second

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analysis is based on Hanford white males dying anywhere in the State of Washington during the years 1950 through 1971.

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APPENDIX B

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APPENDIX B

DETAILED LIST OF HANFORD STUDY POPULATION BY CAUSE OF DEATH
(EIGHTH REVISION INTERNATIONAL CLASSIFICATION OF DISEASES)

<u>Number of Deaths</u>	<u>Cause of Death</u>
	I. INFECTIVE AND PARASITIC DISEASES (000-136)
	Poliomyelitis and other enterovirus diseases of central nervous system (040-046)
1	040 Acute paralytic poliomyelitis specified as bulbar
	Other viral diseases (070-079)
1	070 Infectious hepatitis
	II. NEOPLASMS (140-239)
	Malignant neoplasm of buccal cavity and pharynx (140-149)
4	141 Malignant neoplasm of tongue
1	145 Malignant neoplasm of other and unspecified parts of mouth
1	146 Malignant neoplasm of oropharynx
1	147 Malignant neoplasm of nasopharynx
1	148 Malignant neoplasm of hypopharynx
	Malignant neoplasm of digestive organs and peritoneum (150-159)
3	150 Malignant neoplasm of esophagus
9	151 Malignant neoplasm of stomach
1	152 Malignant neoplasm of small intestine, including duodenum
16	153 Malignant neoplasm of large intestine, except rectum
4	154 Malignant neoplasm of rectum and rectosigmoid junction
2	155 Malignant neoplasm of liver and intrahepatic bile ducts, specified as primary
18	157 Malignant neoplasm of pancreas
	Malignant neoplasm of respiratory system (160-163)
1	161 Malignant neoplasm of larynx
55	162 Malignant neoplasm of trachea, bronchus, and lung

Number of
Deaths

Cause of Death

Malignant neoplasm of bone, connective tissue, skin, and breast (170-174)

4	170	Malignant neoplasm of bone
1	171	Malignant neoplasm of connective and other soft tissue
2	172	Malignant melanoma of skin
1	173	Other malignant neoplasm of skin
1	174	Malignant neoplasm of breast

Malignant neoplasm of genitourinary organs (180-189)

10	185	Malignant neoplasm of prostate
2	188	Malignant neoplasm of bladder
7	189	Malignant neoplasm of other and unspecified urinary organs

Malignant neoplasm of other and unspecified sites (190-199)

7	191	Malignant neoplasm of brain
3	197	Secondary malignant neoplasm of respiratory and digestive systems
1	198	Other secondary malignant neoplasm
2	199	Malignant neoplasm without specification of site

Neoplasms of lymphatic and hematopoietic tissue (200-209)

5	200	Lymphosarcoma and reticulum-cell sarcoma
3	201	Hodgkin's disease
4	203	Multiple myeloma
1	204	Lymphatic leukemia
2	205	Myeloid leukemia
1	206	Monocytic leukemia
1	209	Myelofibrosis

Benign neoplasms (210-228)

2	211	Benign neoplasm of other parts of digestive system
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Neoplasm of unspecified nature (230-239)

0	238	Neoplasm of unspecified nature of other genito-urinary organs
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III. ENDOCRINE, NUTRITIONAL, AND METABOLIC DISEASES (240-279)

Diseases of thyroid gland (240-246)

1	244	Myxedema
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Diseases of other endocrine glands (250-258)

9	250	Diabetes mellitus
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Number of
Deaths

Cause of Death

	Other metabolic diseases (270-279)
2	272 Congenital disorders of lipid metabolism
1	276 Amyloidosis
1	279 Other and unspecified metabolic diseases
	IV. DISEASES OF THE BLOOD AND BLOOD-FORMING ORGANS (280-289)
1	284 Aplastic anemia
1	289 Other diseases of blood and blood-forming organs
	V. MENTAL DISORDERS (290-315)
	Neuroses; personality disorders, and other nonpsychotic mental disorders (300-309)
1	303 Alcoholism
1	309 Mental disorders not specified as psychotic associated with physical conditions
	VI. DISEASES OF THE NERVOUS SYSTEM AND SENSE ORGANS (320-389)
	Hereditary and familial diseases of nervous system (330-333)
1	331 Hereditary diseases of the striatopallidal system
	Other diseases of central nervous system (340-349)
1	342 Paralysis agitans
6	348 Motor neurone disease
	VII. DISEASES OF THE CIRCULATORY SYSTEM (390-458)
	Chronic rheumatic heart disease (393-398)
3	394 Diseases of mitral valve
3	395 Diseases of aortic valve
2	396 Diseases of mitral and aortic valves
1	397 Diseases of other endocardial structures
	Hypertensive disease (400-404)
2	400 Malignant hypertension
4	401 Essential benign hypertension
4	402 Hypertensive heart disease
2	403 Hypertensive renal disease

Number of
DeathsCause of Death

	Ischemic heart disease (410-414)
282	410 Acute myocardial infarction
1	411 Other acute and subacute forms of ischemic heart disease
48	412 Chronic ischemic heart disease
	Other forms of heart disease (420-429)
1	420 Acute pericarditis, nonrheumatic
2	424 Chronic disease of endocardium
1	426 Pulmonary heart disease
18	427 Symptomatic heart disease
1	428 Other myocardial insufficiency
1	429 Ill-defined heart disease
	Cerebrovascular disease (430-438)
3	430 Subarachnoid hemorrhage
19	431 Cerebral hemorrhage
2	432 Occlusion of precerebral arteries
13	433 Cerebral thrombosis
13	436 Acute but ill-defined cerebrovascular disease
8	437 Generalized ischemic cerebrovascular disease
	Diseases of arteries, arterioles, and capillaries (440-448)
6	440 Arteriosclerosis
12	441 Aortic aneurysm (nonsyphilitic)
1	442 Other aneurysm
1	445 Gangrene
	Diseases of veins and lymphatics, and other diseases of circulatory system (450-458)
4	450 Pulmonary embolism and infarction
	VIII. DISEASES OF THE RESPIRATORY SYSTEM (460-519)
	Influenza (470-474)
1	470 Influenza, unqualified
	Pneumonia (480-486)
1	481 Pneumococcal pneumonia
2	486 Pneumonia, unspecified

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Number of
DeathsCause of Death

	Bronchitis, emphysema, and asthma (490-493)
3	491 Chronic bronchitis
18	492 Emphysema
2	493 Asthma
	Other diseases of respiratory system (510-519)
1	512 Spontaneous pneumothorax
1	513 Abscess of lung
1	514 Pulmonary congestion and hypostasis
1	517 Other chronic interstitial pneumonia
1	518 Bronchiectasis
2	519 Other diseases of respiratory system
	IX. DISEASES OF THE DIGESTIVE SYSTEM (520-577)
	Diseases of oral cavity, salivary glands, and jaws (520-529)
1	520 Disorders of tooth development and eruption
	Diseases of esophagus, stomach, and duodenum (530-537)
1	530 Diseases of esophagus
2	531 Ulcer of stomach
2	532 Ulcer of duodenum
2	533 Peptic ulcer, site unspecified
	Hernia of abdominal cavity (550-553)
1	551 Other hernia of abdominal cavity without mention of obstruction
	Other diseases of intestine and peritoneum (560-569)
1	560 Intestinal obstruction without mention of hernia
1	561 Gastroenteritis and colitis, except ulcerative, of non infectious origin
1	569 Other diseases of intestines and peritoneum
	Diseases of liver, gallbladder, and pancreas (570-577)
16	571 Cirrhosis of liver
1	573 Other diseases of liver
2	574 Cholelithiasis
2	577 Diseases of pancreas

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Number of
DeathsCause of Death

	X.	DISEASES OF THE GENITOURINARY SYSTEM (580-629)
		Nephritis and nephrosis (580-584)
1		580 Acute nephritis
5		582 Chronic nephritis
		Other diseases of urinary system (590-599)
1		590 Infections of kidney
		Diseases of male genital organs (600-607)
2		602 Other diseases of prostate
	XI.	COMPLICATIONS OF PREGNANCY, CHILDBIRTH, AND THE PUERPERIUM (630-678)
		Complications of the puerperium (670-678)
1		673 Puerperal pulmonary embolism
	XII.	DISEASES OF THE SKIN AND SUBCUTANEOUS TISSUE (680-686)
		Other inflammatory conditions of skin and subcutaneous tissue (690-698)
1		695 Erythematous conditions
	XIII.	DISEASES OF THE MUSCULOSKELETAL SYSTEM AND CONNECTIVE TISSUE (710-738)
		Arthritis and rheumatism, except rheumatic fever (710-718)
1		716 Polymyositis and dermatomyositis
		Other diseases of musculoskeletal system (730-738)
1		733 Other diseases of muscle, tendon, and fascia
2		734 Diffuse diseases of connective tissue
	XVI.	SYMPTOMS AND ILL-DEFINED CONDITIONS (780-796)
		Symptoms referable to systems or organs (780-789)
4		782 Symptoms referable to cardiovascular and lymphatic system

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Number of
DeathsCause of Death

Senility and ill-defined diseases (790-796)

1	792	Uremia
1	796	Other ill-defined and unknown causes of morbidity and mortality

E XVII. ACCIDENTS, POISONINGS, AND VIOLENCE (EXTERNAL CAUSE)
(E800-E999)

Railway accidents (E800-E807)

1	E801	Railway accident involving collision with other object
4	E803	Railway accident involving explosion, fire, burning
1	E805	Hit by rolling stock

Motor vehicle traffic accidents (E810-E819)

2	E810	Motor vehicle traffic accident involving collision with train
1	E811	Motor vehicle traffic accident involving collision with street car
5	E812	Motor vehicle traffic accident involving collision with another motor vehicle
1	E813	Motor vehicle traffic accident involving collision with other vehicle
1	E814	Motor vehicle traffic accident involving collision with pedestrian
7	E816	Noncollision motor vehicle traffic accident due to loss of control
1	E818	Other noncollision motor vehicle traffic accident
7	E819	Motor vehicle traffic accident of unspecified nature

Water transport accidents (E830-E838)

2	E830	Accident to watercraft causing submersion
1	E832	Other accidental submersion or drowning in water transport

Air and space transport accidents

5	E841	Accident to powered aircraft, other and unspecified
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Accidental poisoning by gases and vapors (E870-E877)

1	E873	Accidental poisoning by motor vehicle exhaust gas
1	E875	Accidental poisoning by other carbon monoxide

Accidental falls (E880-E887)

1	E880	Fall on or from stairs or steps
2	E887	Other and unspecified fall

Number of
DeathsCause of Death

	Accidents caused by fires and flames (E890-E899)
1	E890 Accident caused by conflagration in private dwelling
	Other accidents (E910-E929)
1	E913 Accidental mechanical suffocation
5	E922 Accident caused by firearm missiles
1	E923 Accident caused by explosive material
1	E925 Accident caused by electric current
1	E929 Other and unspecified accidents
	Surgical and medical complications and misadventures (E930-E936)
1	E930 Complications and misadventures in operative therapeutic procedures
	Suicide and self-inflicted injury (E950-E959)
5	E952 Suicide and self-inflicted poisoning by other gases
25	E955 Suicide and self-inflicted injury by firearms and explosives
1	E958 Suicide and self-inflicted injury by other and unspecified means
	Homicide and injury purposely inflicted by other persons (E960-E969)
1	E966 Assault by cutting and piercing instruments
	Injury undetermined whether accidentally or purposely inflicted (E980-E989)
1	E980 Poisoning by solid or liquid substances, undetermined whether accidentally or purposely inflicted
1	E985 Injury by firearms and explosives, undetermined whether accidentally or purposely inflicted
1	E986 Injury by cutting and piercing instruments, undetermined whether accidentally or purposely inflicted
1	E988 Injury by other and unspecified means, undetermined whether accidentally or purposely inflicted