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AN EVALUATION OF MILHAM'S ANALYSIS  
OF HANFORD DEATHS

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FOLDER 2.3 MANCUSO PROJECT  
(MORALITY DATA) # 1 JAN. 16, 1976 -  
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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 occupational mortality in the nuclear industry (Hanford Works in Richland) and found that his results support the hypothesis of a higher incidence of cancer deaths among Hanford employees. He attributes the increase to external radiation exposure.

The purpose of this study is to evaluate Dr. Milham's findings by analyzing data on Dr. Milham's Hanford study population. Using this data base, we compare proportional mortality, not only with Dr. Milham's results, but also with Washington State and United States proportional mortality.

## 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. It is possible that some Hanford deaths were missed due to lack of information on the death certificates. In all, 843 such records were identified, but two were excluded 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 1. The study population is all male and the race distribution is 832 Caucasians, five Negroes, three Indians, and one Mexican. Information as to whether an autopsy was performed was available on 831 individuals; 28.3% of these individuals were autopsied.

The age at death distribution (by 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. Many of the group, then, began work at Hanford at the start of the project and stayed in the area until they died.

Occupations within the nuclear industry are sometimes unique and are difficult to classify using standard occupation codes. However, by utilizing broad occupation categories<sup>(1)</sup> it is possible to look at the overall occupational distribution of the study population. Approximately 17% of the study population are professionals and managers, 7% clerical workers, 24% craftsmen, 22% <sup>ops</sup> operatives, 7% laborers and service workers, and 15% protective service workers.

It is important to note that the 841 Hanford deaths in the three Washington counties are only a fraction (24%) of the total former Hanford worker deaths which have 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. Because many of these 3,486 deaths may be of relatively short-term employees, our 841 deaths probably constitute a more substantial proportion of long-term Hanford employees.

#### METHOD OF ANALYSIS

In order to evaluate Milham's findings, we attempt<sup>ed</sup> to establish <sup>whether</sup> ~~if~~ the Hanford cause-of-death distribution differs in any significant way from an outside comparison population. Milham compared the observed Hanford cause-of-death distribution to that found in the State of Washington over the years 1950-1971. He used the age-specific proportions for various causes of death in Washington State and applied these to the number of Hanford deaths in each age group to determine an expected number of deaths. The observed and expected number of deaths were then compared and tested for statistical significance. (See Appendix A for more detail).

Our own approach is similar. Since we do not know the number and age distribution of the base population from which the deaths occurred, we cannot assess whether the number of deaths is excessive, but must instead determine if there is anything unusual about the distribution of deaths among various causes. That is, we are limited to proportional mortality, a method which can be deceptive since an excessive proportion of cancer deaths may represent a deficiency of deaths from other causes (7, pp. 59-60).

Potentially, Milham's method can establish that the cause-of-death distribution for Hanford deaths is different from the distribution for the State of Washington, but it cannot establish that radiation is causing excess cancer deaths. In addition to the problems with proportional mortality noted above, the Hanford population differs in many respects

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other than radiation exposure from the population of the total State of Washington. Listed below are a number of differences which could effect the cause-of-death distribution in the study population.

1. All deaths in the study are of persons who were once employed at Hanford. Employed persons are known to have somewhat different death patterns than nonemployed. (11)
2. Most of these deaths are of those who came to work on a special secret project in the 1940's. The characteristics of a person who would participate in such an undertaking very likely differ from the average Washingtonian. A pre-employment physical was required screening out the obviously ill, possibly eliminating potential deaths from acute causes.
3. Hanford contractors provide yearly physical examinations for their workers, possibly preventing or postponing some deaths. This could effect proportional mortality since some causes may be more affected than others.
4. Hanford employees live in a dry, desert, small city environment which differs from the moist, forested, urban environment of the Puget Sound Region in western Washington.
5. Practices in cause-of-death classification may be slightly different in the three county area under study than those of the State as a whole.
6. The deaths under study, that is those which occurred in the three Washington counties, represent only 841 out of a total of 3,486 Hanford deaths. Health factors could have played a role in or be correlated to the migration of employees from the Hanford area.

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7. Some workers may have been exposed consistently to occupational hazards (chemicals, for example) other than radiation.

Even though the conclusions which may be drawn from a comparison of the study population with the State of Washington are limited, we nevertheless proceed with this approach to determine if Milham is correct in concluding that the Hanford cause-of-death distribution is significantly different from that of the State of Washington, regardless of whether he is correct in attributing such a difference to radiation exposure.

#### CHOICE OF COMPARISON POPULATION

Our main basis of comparison is the United States as a whole, primarily because reliable vital statistics for specific years, age groups, and types of cancer are available. We also use data from the State of Washington to compare broad cause classifications, but year and age-specific rates were not available 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,<sup>(9)</sup> and since the Hanford deaths are not uniformly distributed over the considered time interval (see Table 1D), it is important to consider the year of death as well as the age at death.

Washington data do not necessarily provide a better basis of comparison than data for the U.S. since the majority of Washington's population lives in the Puget Sound area. We have already noted that this area differs from Hanford in climate, population density, and probably many other factors. Further, U.S. and Washington proportional mortality rates do not differ substantially for the various cancer types.

All deaths in Benton, Franklin, and Yakima counties might seem a logical comparison population. However, since this would be a comparison of Hanford workers with non-Hanford workers (primarily farmers and businessmen) in the three counties, and since reliable, detailed county data *are* very difficult to obtain, it is questionable whether such a comparison is worth the effort involved. It is worth noting, however, that the age-adjusted rate for all cancers, 1950-1969, white males, is significantly lower than that for the U.S. in both Benton and Yakima counties. Cancer of the colon and rectum is significantly lower for Yakima County, but otherwise age-adjusted rates for white males in the three counties are not significantly different from the U.S. for any major cancer type.<sup>(8)</sup>

The sources of our U.S. vital statistics are shown in Table 2. Data for white males only are used.

TABLE 2. Sources of Vital Statistics for Comparing Hanford Deaths With U.S. Deaths

<u>Source</u>	<u>Year(s) of Data</u>	<u>Years of Hanford Deaths Used in Comparison</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 (Pooled)	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> (10)	1972	1971-1973

The Monthly Vital Statistics Report (10) does not contain sex or race specific rates. We estimated the specific rate for white males by multiplying

by the ratio of the 1969 proportions for white males and for total deaths by the overall proportion for 1972.

The source of our Washington data is the Washington Vital Statistics Summary's.<sup>(13)</sup> Table 3 gives the years of data available to us and the years of Hanford deaths with which comparison is made. Rates for all males are used since these were all that were available. (Only about 4% of Washington's deaths are non-whites).

TABLE 3. Source of Vital Statistics for Comparing Hanford Deaths With Washington Deaths

<u>Source</u>	<u>Year of Data</u>	<u>Years of Hanford Deaths Used in Comparison</u>
Washington Vital Statistics Summary <sup>(13)</sup>	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, the age-year of death-specific proportions (for the U.S. or Washington) are multiplied by the number of Hanford deaths in that particular age-year category. These numbers are 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.

### RESULTS

Results of these calculations using U.S. statistics are presented in Table 4 for each ten-year age group along with observed Hanford deaths in

each category.\* The cancer categories are the standard categories used in Vital Statistics of the U.S. (12). Table 5 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 are pooled, and leukemia and lymphatic cancers are pooled. This is done to obtain high enough expected values for a valid use of chi-square tests.<sup>(2)</sup> The expressions  $(\text{Observed}-\text{Expected})^2/\text{Expected}$  are also presented to show which categories are contributing most to the total chi-square. The chi-square statistic is the sum of these expressions.

For each age group within Table 5, a total chi-square is calculated by summing over all cause-of-death categories. This total chi-square is then partitioned into three independent chi-squares to test 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 by type is the same for Hanford deaths as for the U.S. as a whole.
3. Within cardiovascular. The distribution of cardiovascular deaths into heart disease, cerebrovascular, and "others" is the same for Hanford deaths as for the U.S. as a whole.
4. Total. The distribution of deaths into the cause-of-death categories in Table 5 (those not in parentheses) is the same for Hanford deaths as for the U.S. as a whole.

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

Results of the chi-square tests are presented in Table 6. The observed cancer deaths for the under 65 group exceed somewhat those expected (115 vs. 100.4), but this difference has a probability of occurring by chance alone of 0.10. The largest individual contribution to the total chi-square for this age group is for cancers of the digestive system. Examination by specific types of cancer within this category leads to the following results for the under 65 group:

<u>Cancer Type</u>	<u>Observed Deaths</u>	<u>Expected Deaths</u>	<u><math>\chi^2</math></u>	<u>Level of Significance</u>
Stomach	6	6.02	.00	>.10
Colon	14	7.85	4.82	.05
Rectum	2	3.59	-*	-
Pancreas	13	5.62	9.69	.005

\*Not calculated since the expected frequency is too small.

Cancer of the colon and pancreas show significant excesses for this age group. These cancers are also examined for the total group and for those over 65. Only cancer of the pancreas in the total group shows a significant excess ( $p < 0.005$ ) with 18 observed deaths versus 8.1 expected.

The within cancer chi-square for the over 65 group also exhibits a probability of occurring by chance alone of only 0.10. We find that buccal cancer (with an individual chi-square of 7.78) yields by far the largest contribution to this statistic. Since the expected value for this cancer type is less than five, the validity of the chi-square statistic for testing this cancer type individually is questionable. (2) However, Poisson tables can be used to obtain a valid test. (5, p. 55) This test reveals that the buccal cancer excess is significant at the 0.02 level.

Table 7 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 are available for the particular age group. Although none of the results are significant, we note that the chi-square value (3.28) for cancer alone in the 45-64 age group is suggestive. To investigate this value we tested cancer alone with all other causes grouped together and obtained a chi-square of 4.32 ( $p < 0.05$ ). However, since this test was obviously suggested by the data, the p-value stated must be regarded as approximate. A similar comment applies to the significance levels for colon, pancreas, and buccal cancer.

#### COMPARISON WITH MILHAM'S FINDINGS

Our study includes 841 of the 842 deaths originally analyzed by Milham. Milham asserts that he has found a significant ( $p < 0.025$ ) excess of cancers in the under 65 group. If his test statistics had been correctly calculated he would have obtained significance at the 0.01 level.\* The primary reason for the discrepancy between his result and ours is the difference in expected frequencies. We use U.S. data and consider the year of death, while Milham uses Washington data pooled for the years 1950-1971. Consideration of the year of death, rather than use of U.S. data is primarily responsible for the different results. We calculated expected deaths for all cancer using Washington data (taking year of death into account) and obtained 155.5 as compared with 157.8 using U.S. data. By contrast, Milham obtained 148 expected cancer deaths.

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\* 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 very small relative to the first term 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 should be included.

Milham also claims a significant excess for a number of specific types of cancer. These are presented in Table 8 along with his and our expected and observed values. Many of our expected values are higher than Milham's, resulting in the disappearance of significant chi-squares for cancer of the tongue (buccal) and lung. In addition there are a few discrepancies in observed cancer deaths. After careful review of the death certificates with the Hanford Environmental Health Foundation,\* we determined that Milham had one too few cancers in each of the lung, bone, and prostate cancer categories, while he had two too many deaths from leukemia and one extra death from aplastic anemia (noncancer). In addition, there were a few discrepancies in age classification, including two tongue cancers and one cancer of the colon misclassified into the 20-64 age group. After the correction of these errors, the significance of aplastic anemia and cancer of the tongue disappears. These 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 generally felt to be appropriate for testing only when the expected frequencies are at least five.<sup>(2)</sup> In many instances this condition is not met. A more appropriate procedure for these data is to use a Poisson approximation to the binomial distribution.<sup>(5, p. 55)</sup> In Table 6 we have recalculated Milham's tests, using his observed and expected values to obtain the correct significance levels. In each case the level of significance is increased (making the result less significant). However, with the exception of aplastic anemia in the 20+ group, all results remain significant

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\* Hanford Environmental Health Foundation provides a variety of occupational medical, nursing, and mental health services, as well as pursuing medical research related to environmental health.

at least at the 0.05 level. Thus, the method of calculating expected frequencies rather than statistical technique primarily accounts for the discrepancies between the two sets of probabilities.

We did not calculate expected frequencies for cancer of the bone (these cancers are included in our "other" category), aplastic anemia (noncancer), or amyotrophic lateral sclerosis (noncancer). We did recalculate the probabilities using Milham's expected frequencies with our observed deaths and a correct statistical test. The excesses of bone cancers and of amyotrophic lateral sclerosis remain significant. Recalculation of expected frequencies to include year of death is unlikely to alter these findings substantially. We note that amyotrophic lateral sclerosis was singled out for testing precisely because it appeared excessive and therefore the application of standard statistical tests to that selected cause is not strictly valid.

Because Milham's data for the State of Washington are for the years 1950-1971, he later eliminated those Hanford deaths occurring in 1972 and 1973 (with obvious loss of information), and recalculated his expected frequencies considering the year of death. He also added a few deaths which occurred in other parts of Washington. Since we do not have data on these additional deaths and because we do not have access to the detailed data from which his expected frequencies were calculated, we cannot completely evaluate these later calculations. Again, he uses incorrect statistical tests and, since his errors include rounding off the expected frequencies to the nearest integer, we cannot correct them. However, it appears that no substantial changes in excess deaths will occur except that amyotrophic lateral sclerosis is no longer significant (three of the six deaths occurred in 1972 and 1973).

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(10% to be taken out of context)

SUMMARY

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How much more

Our data suggest that Hanford deaths occurring in Benton, Franklin, and Yakima counties exhibit a higher proportion of cancer deaths for those under 65 than ~~does~~ <sup>occurs in</sup> the U.S. or the State of Washington, but more data are necessary to substantiate this finding. There does appear to be an excessive proportion of cancer of the pancreas and very likely an excessive portion of cancers of the colon for those dying under age 65, as well as an excessive proportion of buccal cancers for those dying over age 65. As we have noted earlier, the Hanford population differs in many respects (other than exposure to radiation) from other populations so that there are a number of different possible interpretations of these findings. Specifically, we have not established that exposure to radiation or any other factor contributes to the cancer excesses noted above.

difficult?

In contrast, Milham found an excess in overall cancer deaths as well as excesses for several specific cancer types. The discrepancy between his findings and ours is primarily due to his failure to consider year of death in calculating expected frequencies and, to a lesser extent, to incorrectly calculating statistical significance levels.

correct work

More serious than these errors, however, is Milham's apparent attribution of the excess proportion of cancers to radiation exposure in view of other possible and plausible explanations which have not been investigated. In particular, the possibility of reduced deaths from other causes is not considered as a source of the observed elevation in the proportion of cancer deaths. As Dr. Milham correctly notes, a population-based study would be most helpful in unraveling the relationship of the variables involved.

APPENDIX A

BRIEF REVIEW OF DR. MILHAM'S METHODOLOGY

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APPENDIX ABRIEF 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.<sup>(1)</sup> 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 used 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 was 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 were counted by five-year age groups for the entire file, and the proportion of deaths due to the examined cause was calculated in each age class. The proportion was 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 were tabulated by age, and observed and expected deaths were summed over age and compared using a chi-squared test.

Dr. Milham discussed his work with Dr. Barkev 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 analysis was based on Hanford white males dying anywhere in the State of Washington during the years 1950 through 1971.

APPENDIX B

DETAILED LIST OF HANFORD STUDY POPULATION BY CAUSE OF DEATH

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APPENDIX BDETAILED 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

<u>Number of Deaths</u>	<u>Cause of Death</u>
	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
	Neoplasm of unspecified nature (230-239)
0	238 Neoplasm of unspecified nature of other genito-urinary organs
	• III. ENDOCRINE, NUTRITIONAL, AND METABOLIC DISEASES (240-279)
	Diseases of thyroid gland (240-246)
1	244 Myxedema
	Diseases of other endocrine glands (250-258)
9	250 Diabetes mellitus

<u>Number of Deaths</u>	<u>Cause of Death</u>
	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

<u>Number of Deaths</u>	<u>Cause of Death</u>
	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

<u>Number of Deaths</u>	<u>Cause of Death</u>
	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

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

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

<u>Number of Deaths</u>	<u>Cause of Death</u>
	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

TABLE 1. Description of Hanford Study Population  
Observed Deaths Due to All Causes

		<u>A. Observed Deaths, by Race</u>				
		<u>Caucasian</u>	<u>Negro</u>	<u>Indian</u>	<u>Mexican</u>	<u>Total</u>
Number		832	5	3	1	841
Percent		98.9	0.6	0.4	0.1	100

  

		<u>B. Observed Deaths, by Autopsy Information</u>		
		<u>Autopsied</u>		
		<u>No</u>	<u>Yes</u>	<u>Total</u>
Number		596	235	831*
Percent		71.7	28.3	100

\*10 Missing

  

		<u>C. Observed Deaths, by Age</u>								
		<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>	<u>85-94</u>	<u>Total</u>
Number		4	21	55	163	289	221	79	9	841
Percent		.4	2.5	6.5	19.4	34.4	26.3	9.4	1.1	100

  

		<u>D. Observed Deaths, by Year of Death</u>					
		<u>Year Of Death</u>					
		<u>50-54</u>	<u>55-59</u>	<u>60-64</u>	<u>65-69</u>	<u>70-74</u>	<u>Total</u>
Number		66	110	178	232	255	841
Percent		7.8	13.1	21.2	27.6	30.3	100

  

		<u>E. Observed Deaths, by Number of Years Worked at Hanford</u>						
		<u>Number Of Years Worked At Hanford</u>						
		<u>0-4</u>	<u>5-9</u>	<u>10-14</u>	<u>15-19</u>	<u>20-24</u>	<u>25-29</u>	<u>Total</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

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TABLE 1. (Cont'd)

F. Observed Deaths, by First Year Worked at Hanford

	<u>First Year Worked At Hanford</u>			
	<u>1943-45</u>	<u>1946-50</u>	<u>1951-</u>	<u>Total</u>
Number	424	226	153	803*
Percent	52.8	28.1	19.1	100

\*38 Missing

G. Observed Deaths, by Occupation

<u>Occupation</u>	<u>Number</u>	<u>Percent</u>
Professional and Technical	81	10.36
Managers and Administrators	50	6.39
Clerical	57	7.29
Craftsmen	190	24.30
Operatives	169	21.61
Transport Equipment Operatives	67	8.57
Laborers	8	1.02
Service Workers	46	5.88
Protective Service Workers	114	14.58
TOTAL	782*	100.00

\*59 Missing

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

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TABLE 4. Observed and Expected Deaths by Age and Cause with Expected Deaths Calculated Using Age-Year-Cause Specific Death Rates for U.S. White Males

Cause	Code	Age of Death									
		20-24	25-34	35-44	45-54	55-64	65-74	75-84	85 +		
Malignant Neoplasms	140-209	Observed	0	0	9	36	70	47	12	0	
		Expected	.24	2.1	7.3	29.3	61.4	44.7	11.9	.85	
Buccal Cavity and Pharynx	140-149	Observed	0	0	0	2	1	5	0	0	
		Expected	.00	.03	.22	1.3	2.4	1.2	.28	.02	
Of Digestive Organs and Peritoneum	150-159	Observed	0	0	3	14	21	11	3	0	
		Expected	.03	.32	1.8	8.3	17.9	13.8	4.0	.29	
Of Respiratory System	160-163	Observed	0	0	0	10	26	17	3	0	
		Expected	.01	.16	1.8	10.1	22.9	14.5	2.6	.10	
Of Genital Organs	180-187	Observed	0	0	0	1	3	2	4	0	
		Expected	.03	.24	.25	.56	2.6	4.3	2.2	.21	
Of Urinary Organs	188, 189	Observed	0	0	0	3	4	2	0	0	
		Expected	.00	.04	.28	1.5	3.3	2.8	.84	.06	
All Other and unspecified Sites	170-174 190-199	Observed	0	0	3	2	10	5	2	0	
		Expected	.07	.56	1.3	4.2	6.9	4.1	.98	.09	
Leukemia	204-207	Observed	0	0	2	0	0	2	0	0	
		Expected	.04	.30	.60	1.2	2.0	1.7	.54	.04	
Other Neoplasms of Lymphatic and Hematopoietic tissues	200-203 208, 209	Observed	0	0	1	4	5	3	0	0	
		Expected	.05	.45	.95	2.1	3.2	2.1	.53	.03	
Major Cardiovascular Disease	390-448	Observed	0	0	24	78	164	129	51	8	
		Expected	.25	2.7	19.5	80.5	157.2	130.3	50.5	6.4	
Diseases of Heart	390-398, 402, 404, 410-429	Observed	0	0	22	74	134	101	31	6	
		Expected	.17	2.0	13.9	71.0	133.4	101.2	35.9	4.3	
Cerebrovascular Diseases	430-438	Observed	0	0	.2	2	20	19	15	0	
		Expected	.04	.45	1.9	7.2	17.1	20.9	10.7	1.4	
All Other Causes		Observed	4	27	90	40	55	40	15	1	



TABLE 6. Results of Statistical Tests for the Comparison of Observed and Expected Deaths as Calculated in Table 4.

	<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	.14	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.

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TABLE 7. 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	$\chi^2$ *	Observed Deaths	Expected Deaths	$\chi^2$
Cancer	140-209	174	155.5	2.20	9	9.4	.02
Heart Disease	390-398,402, 404,410-429	366	355.7	.30	22	16.5	1.82
Cerebrovascular	430-438	58	62.9	.39			
Accidents	E800-E949				22	26.3	.69
All Other Causes		243	266.9	2.14	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	$\chi^2$	Observed Deaths	Expected Deaths	$\chi^2$
Cancer	140-209	106	88.9	3.28	59	57.2	.06
Heart Diseases	390-398,402, 404,410-429	207	200.2	.23	137	138.9	.03
Cerebrovascular	430-438	22	28.4	1.45	34	34.5	.008
Accidents	E800-E949	26	29.9	.50			
All Other Causes		91	104.6	1.76	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 0.10 level.

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TABLE 8. 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 $\chi^2$ )	Using Correct Procedure *	Milham's	Ours	Milham's	Ours	
All Cancers	20+	.05	.05	173	174	148.0	157.8	N.S.
	20-64	.025	.01	118	115	93.3	100.4	
Tongue	20+	.005	.02	4	4			N.S.
	20-64	.001	.007	4	2			
Mouth & Pharynx	65+	.001	.025	3	3			
Buccal	20+			8	8	2.78	5.46	N.S.
	20-64			5	3	2.24	3.92	N.S.
	65+			3	5	.74	1.54	.02
Colon	20-64	.005	.005	15	14	6.68	7.85	.05
Pancreas	20+	.01	.01	18	18	9.66	8.98	.005
	20-64	.005	.005	13	13	5.95	5.62	.005
Lung	20+	.05	.05	54	55	41.4	52.2	N.S.
Bone	20+	.02	.05	3	4	.81		.01
Aplastic Anemia	20+	.05	.10	2	1	.45		N.S.
	65+	.001	.02	2	1	.19		N.S.
Amyotrophic Lateral Sclerosis	20+	.001	.001	6	6	.83		.001
	20-64	.001	.025	3	3	.62		.025
	65+	.001	.001	3	3	.21		.001

\* 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.

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