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THE MINNESOTA HIGHWAY MAINTENANCE WORKER

MORTALITY STUDY: 1945 - 1984

PRELIMINARY REPORT
APRIL 1, 1987

MINNESOTA DEPARTMENT OF HEALTH
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16. Abstract (Limit: 200 words) The Minnesota Department of Health conducted a large scale study of all highway maintenance workers following the discovery of a possible increased risk of leukemia among these workers. The records were available to support a high quality epidemiologic study. The 5000 men identified worked in highway maintenance for at least 1 year between 1945 and 1984. The total number of deaths that occurred in this group was 1530, significantly less than the number expected. Despite this favorable overall mortality rate, there were increased risks of leukemia among long term workers and accidental deaths among short term workers. Also of potential concern are deaths from urinary cancers, colon cancer, and chronic renal failure. Several recommendations were offered including periodic updating of worker mortality and cancer morbidity, conducting specific studies to characterize any specific highway maintenance activities associated with increased mortality risks, conducting a pilot study of injury surveillance, monitoring for suspected exposures to hazardous agents, study the potential of cytogenetic assays to assess personal exposures to harmful substances, and minimize worker exposures.

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THE MINNESOTA HIGHWAY MAINTENANCE WORKERS MORTALITY STUDY
1945 - 1984

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PREFACE

The following report required over 18,000 hours of work and was the effort of many individuals who collaborated together for over two years. Although the overall mortality, as well as the total cancer mortality of the highway maintenance workers was substantially reduced, this study has raised several serious questions about certain aspects of highway maintenance safety and health. To fully respond to these questions, additional effort will be required. This effort will include a complete integration of the scientific literature with the results of this study and additional epidemiologic and environmental studies. It is in this context that this report is considered preliminary.

The report is divided into five sections -- introduction and background, methods, results, discussion, and recommendations. The introduction and background section outline the need for the study and events that led to its initiation. The methods section describes the record sources evaluated in establishing the cohort of highway maintenance workers and the techniques used in compiling and analyzing the data collected. The results section describes those findings that were believed by the investigators and reviewers to be important. The discussion section evaluates these results in the context of other epidemiologic and scientific data. The recommendations section outlines recommendations to further evaluate the questions that arose as a consequence of this study.

A glossary is provided at the end of this report that defines commonly used abbreviations and terms that are technical in nature.

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EXECUTIVE SUMMARY

ABSTRACT: A reported leukemia excess in Wheaton, Minnesota, was investigated by the Minnesota Department of Health (MDH) in 1979-1980. This investigation revealed that although four of the men with leukemia had been employed as highway maintenance workers by the State, the leukemia could not be associated with particular job histories, farming practices, or other personal data. In 1984 legal action against the state involving these cases again focused attention on the possible leukemia risks and exposures among highway workers. Following a review of all relevant information, the MDH concluded that a large-scale study of all highway maintenance workers was necessary. This conclusion was based on three factors: 1) The leukemia occurrence among highway workers in Wheaton was not, in and of itself, evidence of increased risk among these workers. Their work experience was not unique; more importantly, statistically unusual clusters of leukemia are frequently reported in the scientific literature; 2) Highway maintenance work may involve exposure to a variety of potentially harmful materials, and disease risks other than leukemia may be important; and 3) The number of past and current highway maintenance workers employed by governments (city, county, and state) in the U.S. probably exceeds 500,000.

A study of highway maintentance worker mortality was initiated in April 1985, after a feasibility study indicated that existing records would support a high quality epidemiologic study. Through various record sources, all men were identified who worked in highway maintenance for the Minnesota Department of Transportation (MNDOT) at least one year between 1945 and 1984. Almost 5000 workers were thus identified. The cause of death was ascertained for all workers who had died as of the end of 1984.

The number of men who had died from each of over 100 different causes of death was compared to the number that would be expected based on Minnesota mortality rates for men of the same age, who died during the same time period, and were from the same region of the state.

The total number of deaths that occurred in this group (1530) was significantly less than the number expected, a common finding in occupational studies. An unexpected finding was the lowered overall risk of cancer deaths, and especially of lung cancer. Despite the favorable overall mortality experience among highway maintenance workers, several findings raise serious questions about the health and safety of these workers. Most important among these findings are increased risks of leukemia among long-term workers and accidental deaths among short-term workers. Also of potential concern are deaths from urinary cancers, colon cancer, and chronic renal failure.

The extent to which these increased risks were directly related to workplace exposures or activities is not known. In view of these uncertainties and the large number of workers employed in this occupation in Minnesota and the U.S., the following actions are strongly recommended: 1) Worker mortality should be periodically updated and cancer morbidity should be assessed when possible from the statewide cancer surveillance system; 2) Specific studies should be conducted to characterize any specific highway maintenance activities that may be associated with increased mortality risks; 3) A pilot study of injury surveillance should be conducted; 4) Additional environmental monitoring for suspected exposures to hazardous agents should be performed; 5) A pilot study should be conducted using cytogenetic assays to assess personal exposures to harmful substances; and 6) Both management and labor should continue efforts to minimize worker exposure to hazardous materials and activities.

BACKGROUND

In 1978, an American Cancer Society representative reported that the number of leukemia cases seemed unusually high among residents in Wheaton, Minnesota. A preliminary investigation of this apparent excess of leukemia by the Minnesota Department of Health (MDH) revealed that six cases of leukemia in males had occurred over a ten-year period, while only one case would have been expected in a population of that size. Of greater concern than the actual number of cases was the finding that five of the six leukemias occurred in highway maintenance workers (HMWs), an occupation that was restricted to a small fraction of the Wheaton population.

A case-control interview study was conducted in 1979-1980 to explore whether personal, medical, or occupational factors might be associated with these cases. Similar work histories and other activities such as farming and smoking were found among workers with and without leukemia. This study did not reveal any obvious factors that would explain the occurrence of leukemia among the highway workers in Wheaton.

Interviews of 70 MNDOT employees stationed at District 4B (which includes the Wheaton area) were also conducted in 1979-1980 to obtain occupational, personal, and medical histories. This information, along with preliminary data from cytogenetic assays on several employees, was the basis of a proposal for a more detailed study that would evaluate evidence of HMW exposure to mutagenic agents. Federal funding for the proposed study was not approved. A recommendation for a large-scale epidemiologic study of highway workers was also put forward in 1980 by MDH staff, but this recommendation was not implemented due to budget and staff limitations.

In 1984, legal actions against the State of Minnesota stemming from the Wheaton observations again focused attention on leukemia occurrence in highway workers. It was concluded by many at that time that the

statistical improbability of the Wheaton cases occurring by chance alone and the nature of the workplace exposures experienced by these workers were substantial evidence of a causal relationship. Amidst these speculations, the present MDH staff moved to resolve the concerns over potential health effects of long-term occupational exposures among highway maintenance workers.

Following review of available information, the MDH concluded that a large-scale study of all causes of death among all HMWs was necessary to address the social and public health issues that had been raised. This conclusion was based on three considerations: 1) The Wheaton leukemia occurrence could not, in and of itself, establish that highway workers were at increased risk. No other reports of unusual leukemia occurrence in these workers had been received elsewhere in the state, although it was established that the work experience of the Wheaton highway workers was not unique and workers elsewhere would be expected to have similar experiences. More importantly, unusual clusters of leukemia (and other cancers) in particular groups have frequently been reported throughout the U.S., and these clusters can rarely be attributed to specific exposures; 2) Review of highway maintenance work indicated that it involved a variety of substances or exposures that are potentially harmful. These substances include asphalt and asphalt fumes, fuels and fuel exhausts, and herbicides. Considering the potential for diverse types of exposure, disease risks other than leukemia would need to be considered in any evaluation of these workers; and 3) The number of current and former HMWs employed at all levels of government in the U.S. (city, county, and state) probably exceeds 500,000. Thus, even modest risks could affect a large number of individuals.

In November 1984, after developing the required background information, the MDH, in collaboration with the University of Minnesota, began to investigate the feasibility of conducting a full-scale mortality study of HMWs employed by the state. The feasibility study addressed several key issues: 1) whether a cohort (group) of highway maintenance workers could be completely and accurately defined from existing records; 2) the types of exposures that might be expected among these workers as well as the number of workers that might have experienced such exposures; and 3) costs and time required to complete a study. The initial phase included a comprehensive review of employment and retirement records and historical documents within the MNDOT, its central and district offices, and other government agencies. A sample of approximately 1200 payroll and personnel records and several hundred historical documents were reviewed.

The feasibility study was completed in January 1985. The results indicated that existing records would support a high quality epidemiologic study of HMW mortality. It was estimated that at least 90% of the cohort of HMWs could be identified and their vital status determined. The large number of these workers (5000-7000 ever employed as HMWs) would provide an adequate study size to detect important increases in rare diseases such as leukemia. It was estimated initially that the study would cost $206,000 and would require approximately two years to complete. With approval of $150,000 from the MNDOT in early 1985 (the remainder of the cost to be provided by the MDH), the study was launched April 1, 1985.

STUDY METHODS

The study method selected is commonly employed in large scale epidemiologic studies of occupational groups, and is generally referred to as a retrospective cohort mortality study. Although extremely difficult and time consuming to actually implement, the study design is relatively simple in principle. All men who worked in highway maintenance for the MNDOT for at least one year anytime between 1945 and 1984 were first identified. This required development of a definition of a "highway maintenance worker," a task that was accomplished with assistance from both the AFSCME Union and the MNDOT.

An intensive search and review was then undertaken of approximately 80,000 MNDOT personnel and payroll records, both at the central (St. Paul) and district offices, to identify anyone who had worked in highway maintenance. Records were also reviewed from the Department of Employee Relations (DOER) and the Minnesota State Retirement System (MSRS). From this review, it was found that 4849 workers met the criteria for inclusion in the study. Once this group (or cohort) of workers was identified, an exhaustive effort was made to determine whether each individual was alive or dead as of December 31, 1984 (the end of the study). Workers were "traced" through a variety of means and sources, including Social Security Administration (SSA) records, MNDOT records, Minnesota State Retirement System, MDH death records, Department of Motor Vehicles, and phone tracing. If an individual had died, the cause of death as listed on the death certificate was determined. It was possible to determine the vital status of 99.6% of the 4849 eligible workers.

Because of the many possible errors that can arise when a large number of people (20 abstracters) review and tabulate such a large number of records, numerous error checking and quality control procedures were

implemented throughout the study. Records were reviewed and re-reviewed, both manually and by computer, until no errors in completeness or accuracy could be found. Consequently, despite the size of this study and the forty-year time period that it encompassed, an extremely high degree of completeness and accuracy was achieved.

Once the mortality experience of this cohort was determined, it was then compared to that of other Minnesotans. Because the time frame for this study encompassed five revisions of the system used to classify causes of death, it was necessary to develop a common coding system for all 1.3 million Minnesota death certificates dating back to 1945. Computer programs were developed to analyze the voluminous data generated in this study. For analysis, the number of deaths for each cause that occurred among HMWs was compared to the number of deaths that would be expected if these workers had the same mortality as men of similar age, during the same time period and from the same region of the state.

The comparison of observed and expected numbers of death was accomplished by dividing the number of observed deaths by the number of expected deaths (observed/expected deaths). The result of that division is referred to as a standardized mortality ratio or SMR, and indicates the relative magnitude of any excess (or deficit) of observed deaths. An SMR of 1.0 indicates that the number of observed deaths was exactly the same as the number that was expected. An SMR of 2.0 indicates twice as many deaths as expected (100% excess), while an SMR of 0.5 indicates half as many deaths as expected (50% deficit). To assist in interpretation and selection of data for further analyses, appropriate tests of statistical significance were applied to each SMR.

As part of this study, the MDH and the MNDOT undertook an evaluation of possible workplace exposures that may be experienced by HMWs at the present time. In August 1986, industrial hygiene field surveys were conducted during a resurfacing project in the Metropolitan area and during a painting project in the Detroit Lakes area. Personal air samples, general air samples, and bulk material samples were taken and analyzed for a variety of substances that might be present and may be hazardous to the workers. In addition, all available industrial hygiene data from the Minnesota Occupational Safety and Health Administration (MN-OSHA) and the MNDOT were reviewed.

MAJOR FINDINGS

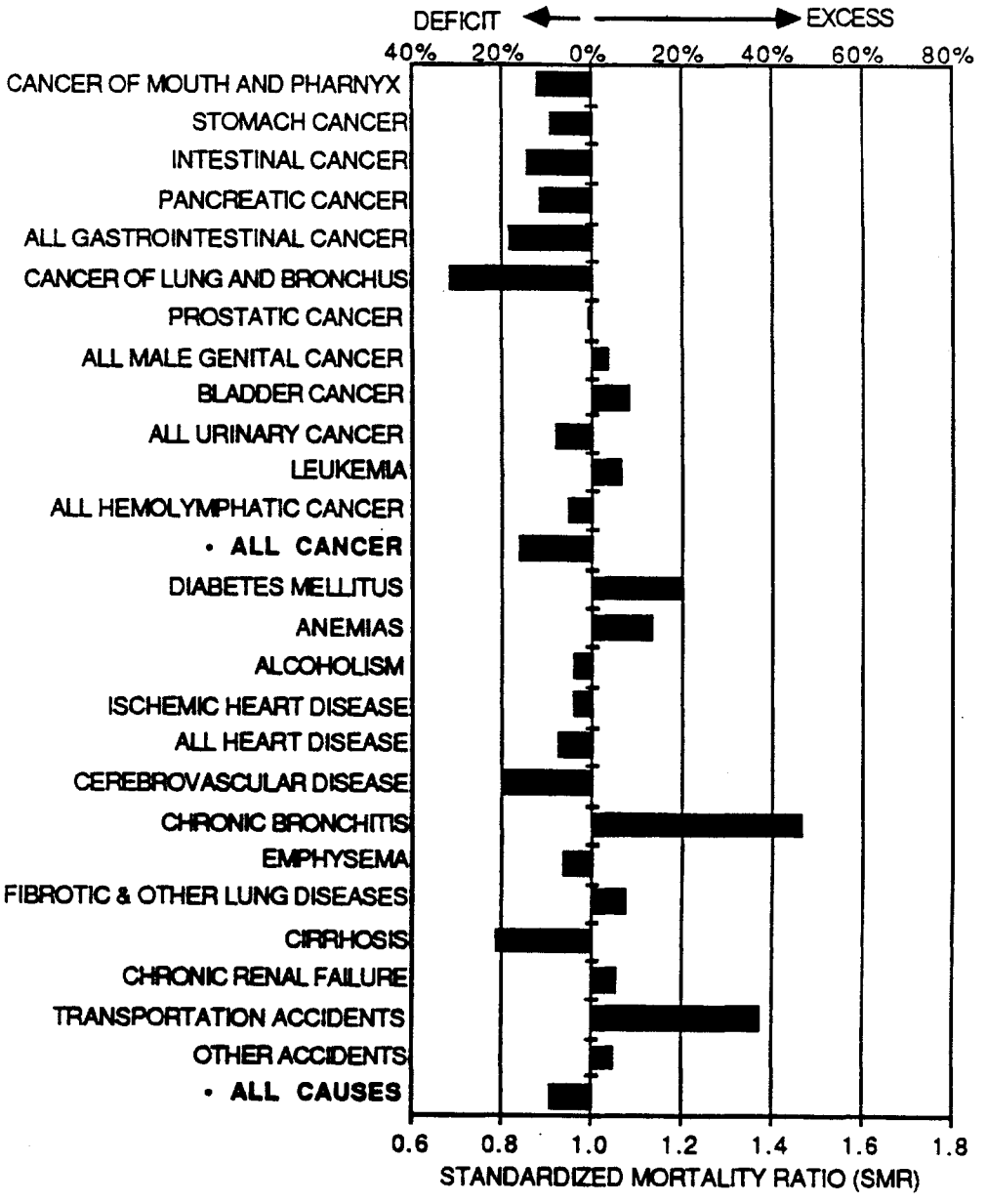
Description of Study Cohort: A total of 4849 workers were included in this study based on the three major eligibility criteria: 1) male; 2) worked at least one year as a HMWs; and 3) employed by the MNDOT anytime between 1945 and 1984. For purposes of analysis, several categories of workers were distinguished. Individuals who worked only in highway maintenance activities ("HMWs only") were considered separately in some analyses from the overall group ("All Workers"), many of whom had other duties in addition to highway maintenance. Of the total 4849 workers, 2094 were classified as HMWs only. A distinction was also made between urban and rural workers. Approximately one-third of the cohort was considered urban, (i.e., they had been stationed in the two Metropolitan area districts); "rural" workers were those stationed at any of the other 14 districts in the State. It was found that rural workers tended to work longer (15.1 years) than urban workers (11.3 years), and they also tended to start and end work with MNDOT at an older age. It was also observed that those who worked only as HMWs had a shorter duration of employment (8.5 years) than all workers combined (13.9 years).

An important aspect of cohort studies is the number of workers who are included and the number of years over which each worker is alive (and therefore, at risk of death) during the time frame of the study. This variable is expressed as "person-years of observation" and is dependent on both the number of workers and the number of years of follow-up. In this study, there were 96,567 person-years of observation for all workers. For HMWs only, there were 38,750 person-years of observation.

Causes of Death: There were 1530 deaths that occurred among the 4849 workers during the 40 year time frame included in this study. For analysis, the number of observed deaths was compared to the number that was expected based on Minnesota mortality rates for white males of the same age, time period, and region of the state (urban vs. rural).

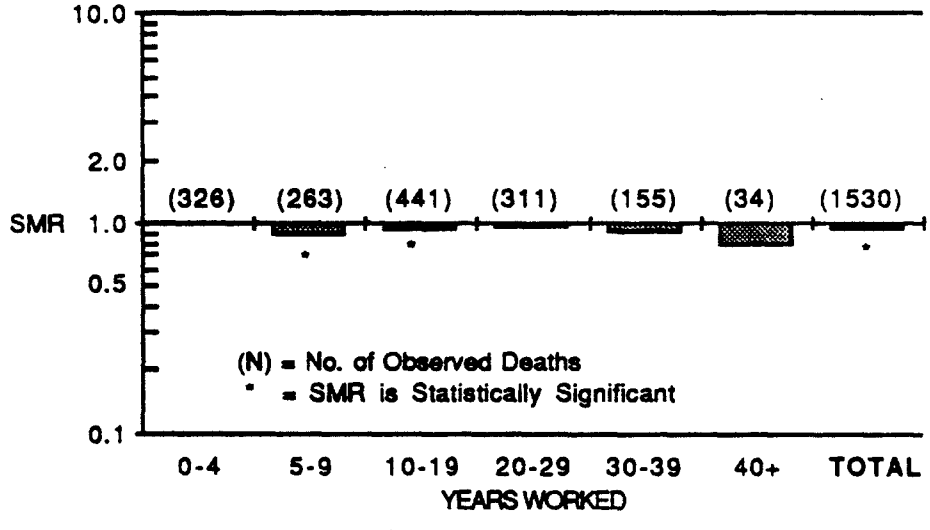
The proper interpretation of the results from a large study requires considerable professional judgement, involving many criteria. In this study, SMRs were calculated for approximately 100 causes of death for workers employed during specific time periods, for specific lengths of time, and age categories. When such a large number of SMRs are calculated, some can be expected to be "significantly" increased or decreased just due to chance. Therefore, statistical significance alone is not a sufficient guideline for interpreting a specific result. A variety of other criteria must also be employed, including such factors as whether a particular cause of death had been suspected before the study was conducted (an a priori hypothesis), the actual number of deaths involved, the magnitude of the SMR, trends over time or with work experience, the consistency with other known information about a disease or exposures, and other factors. Causes of death that were of specific interest at the outset of this study included leukemia, soft tissue sarcomas, other cancers, occupational lung diseases, and accidents (deaths due to injuries). A complete description and discussion of the HMW mortality experience is presented in the full report. A summary of the major categories of death is shown in Figure E-1. Following is a summary of the major findings of this study.

Figure E-1. Selected Causes of Death Among Highway Maintenance Workers (HMWs) Compared to Other Minnesota White Males



All Causes: The total number of deaths from all causes was 1530, while 1676 deaths were expected (SMR=0.91). There was no trend with increasing duration of employment (Figure E-2). The nine percent deficit was statistically significant and was accounted for by lowered mortality among all three major causes of death: heart disease, cancer, and cerebrovascular disease. A lower overall mortality among employed populations compared to the general population is a very common finding in occupational studies. This difference is attributed to the fact that reasonably good health is necessary for initial and continuing employment; thus, workers have slightly lower overall mortality rates at least over the time that they are employed. The lower mortality among working populations is called the "healthy worker effect." The all-causes deficit observed here was similar to that found in many other occupational studies.

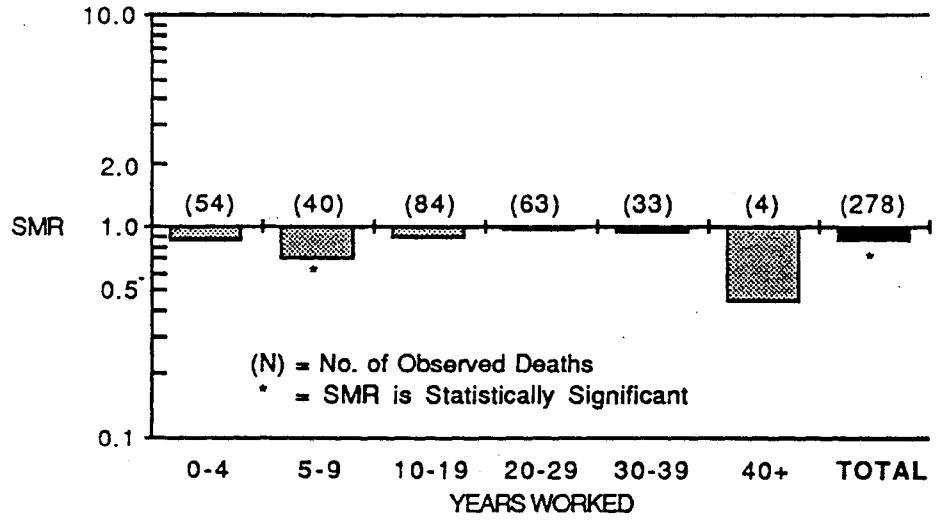
Figure E-2. Observed/Expected Deaths (SMR) Among HMWs By Years Worked: All Causes



All Cancers: There were 278 cancer deaths overall, which was 17% fewer than expected (SMR=0.83). This deficit was statistically significant. There was no evidence of increasing risk with increasing duration of employment (Figure E-3). In contrast to the overall mortality experience,

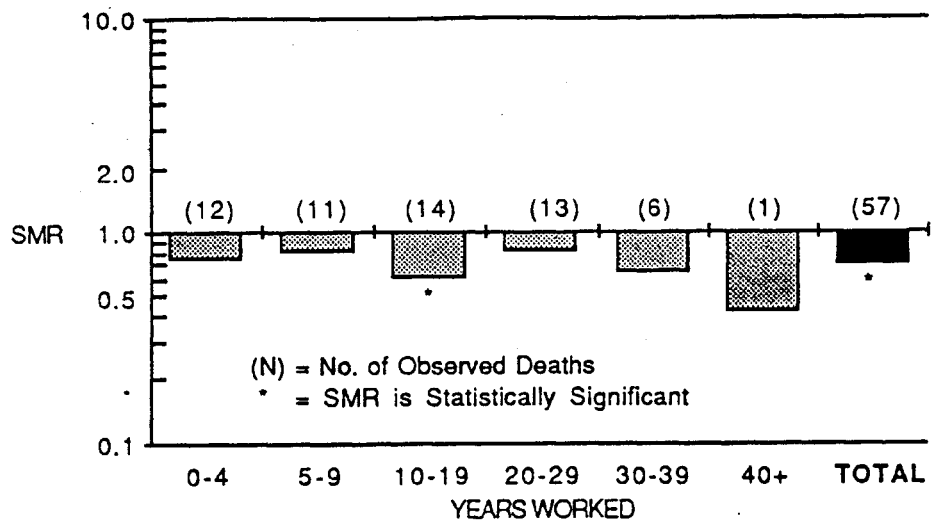
the deficit of cancer deaths cannot be explained in terms of the healthy worker effect, which appears to have little or no impact on cancer mortality. Overall cancer mortality in other large occupational cohort studies is generally much closer to the expected mortality based on the general population rates. The deficit in overall cancer deaths is affected by the observed deficits in several of the most common types of cancer, including lung cancers and gastrointestinal cancers (discussed below).

Figure E-3. Observed/Expected Deaths (SMR) Among HMWs By Years Worked: All Cancers



Respiratory Cancers: Most cancers in this category are of the lung and bronchus. The number of respiratory cancers was significantly less than expected. The 57 deaths represented a 30% deficit. Reduced respiratory cancer mortality was evident in both urban and rural workers, and risk was not associated with length of work or year started (Figure E-4). Since the major cause of respiratory cancers is smoking, this finding suggests that these workers tended to smoke less. This finding also suggests that widespread exposure to high levels of respiratory carcinogens (e.g., tar fumes) is unlikely; this is consistent with the very limited monitoring data.

Figure E-4. Observed/Expected Deaths (SMR) Among HMWs By Years Worked: Repsiratory System Cancers



Leukemias and Associated Cancers: No overall elevation was noted for the category that included leukemias, Hodgkin's disease, lymphomas, and multiple myelomas (SMR = 0.9). Within this category, however, a slightly greater than expected number of leukemia deaths was found (SMR = 1.1). All of the 17 observed leukemia deaths occurred during the period 1965-1984. None were observed during 1945-1964, although 5 were expected. As shown in Figure E-5, the significant elevation in leukemia (SMR = 4.2; 320% excess) occurred only among workers with 30-39 years of work experience, and who started work between 1900 and 1944. Excess risk was found for both urban and rural workers.

Since the conclusion of the study follow-up (December 1984), 2 additional leukemia deaths are known to have occurred, 1 of whom also had 30-39 years of work experience, but who started work between 1945-1954. Results from this incomplete follow-up are shown in Figure E-6, which indicates the minimum leukemia excess for HMWs who worked 30-39 years. Thus, it cannot be concluded that the excess leukemia mortality risk has subsided.

Figure E-5. Observed/Expected Deaths (SMR) Among HMWs By Years Worked: All Leukemias

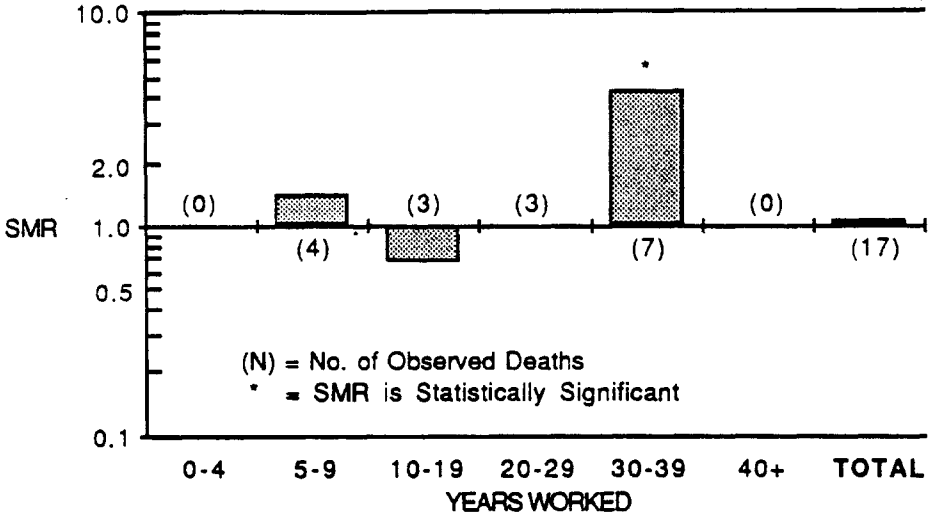
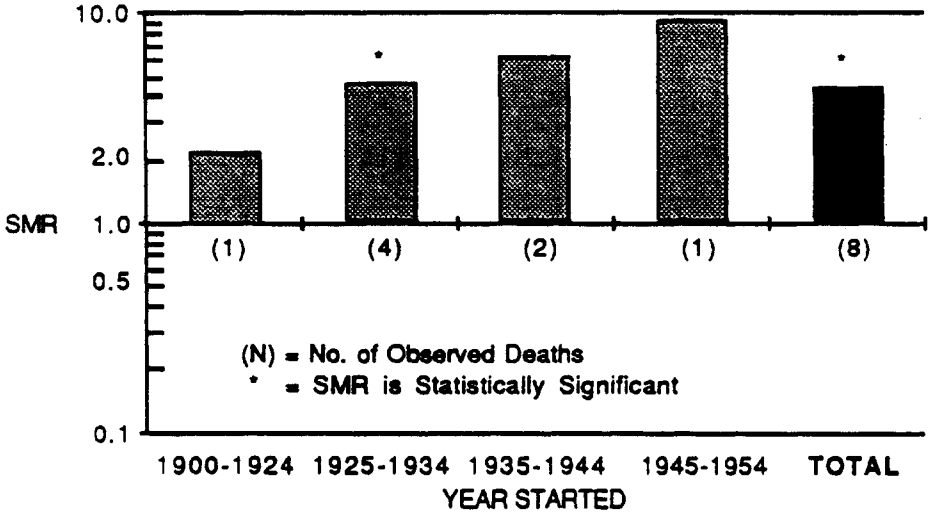


Figure E-6. Estimated Minimum Observed/Expected Deaths (SMR) Among HMWs With 30-39 Years Experience By Year Started With Follow-Up To December 1986: All Leukemias



It is important to recall that the possible connection between leukemia risk and HMWs was first suggested following the reported excess of leukemia in Wheaton, Minnesota in 1978. Preliminary investigation had indicated that several of the men with leukemia had been employed as HMWs. This observation, led, in part, to the eventual conduct of the present

study. It is interesting to note, therefore, that none of the Wheaton leukemia deaths involved workers with 30-39 years of experience and that these deaths were not part of the observed excess. In other words, although the Wheaton leukemia deaths were perceived as highly unusual and eventually led to the present study, they did not have an impact on the high risk profile for leukemia developed from this study.

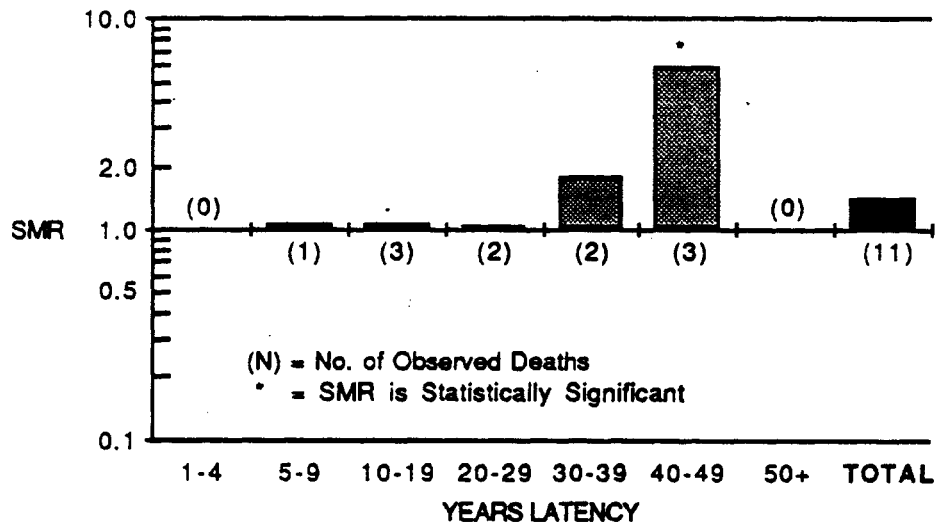
Studies in California and Washington have suggested an excess risk of hemolymphatic cancers or leukemias in transportation or highway maintenance workers . A vast body of research on the epidemiology of the leukemias has identified a number of risk factors for leukemia. Environmental or occupational exposures that have been associated with increased risk include ionizing radiation, benzene and possibly other solvent exposures, and some pesticides. Smokers also appear to have an increased risk.

It is not known which, if any, of these exposures may be related to the observed leukemias. For example, benzene is (or was) a constituent of some materials utilized by HMWs (e.g., gasoline and diesel fuel). Certain constituents of asphalt and tar fumes and auto exhausts are carcinogenic in animals, while coal tars are considered human carcinogens. While available recent monitoring data do not show excessive present exposures to these agents, no data are available on historical exposures. Thus, the observed leukemia excess cannot presently be attributed to any particular exposure, occupational or otherwise.

Intestinal Cancers: No overall excess was seen for intestinal cancers (SMR = 0.9). Among urban workers, a nonsignificant 40% excess was found, based on 11 deaths. There was a statistically significant excess (SMR = 5.8) for

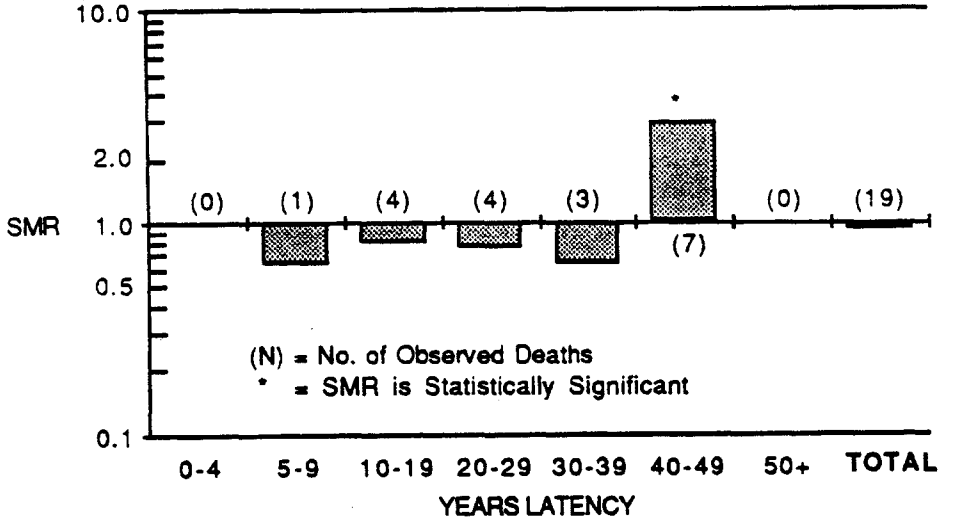
those deaths that occurred 40-49 years after the year in which a person had initially started their employment (referred to as latency in this study) (Figure E-7). This excess was due to three colon cancers. Although intestinal cancers are not generally viewed as occupationally-related (the main risk factors include diet, colitis, polyps, family history, and history of other cancers), several occupational groups, such as coke oven workers, appear to have an increased risk.

Figure E-7. Observed/Expected Deaths (SMR) Among Urban HMWs By Latency: Intestinal Cancers



Cancer of the Urinary System: This category consists of cancers of the kidney, bladder, and ureters. Overall, the 19 observed deaths were not different than expected (SMR = 0.9) and there was no trend with increasing duration of employment or year started. As shown in Figure E-8, however, there was a greater than expected number of deaths for those who died 40-49 years after the start of employment (SMR = 2.9).

Figure E-8. Observed/Expected Deaths (SMR) Among HMWs By Latency: Urinary System Cancers



Both kidney and bladder cancers contributed to this excess. Smoking, occupational exposures, and several other risk factors are associated with increased risk of these cancers. Increased bladder cancer risks have been associated with workers in the following industries: dyestuffs, rubber, leather, painting, and organic chemicals. Increased kidney cancer risks have been suggested for petroleum refinery workers and coke oven workers. The lower than expected respiratory cancer in this cohort suggests decreased smoking experience. Thus, some type of occupational exposure cannot be ruled out.

Prostatic Cancer: There were 38 deaths overall due to prostatic cancer, which was not greater than expected (SMR = 1.0). There was a significant excess for men who started work in 1955-1964 and were over 40 years of age when they started (SMR = 2.9). There was a significant deficit, however, for men who started in 1935-1944 and were over 40 when they started (SMR = 0.5). Risk did not increase for increasing duration of employment. Prostatic cancer has not generally been associated with occupational

exposures, and these findings are unlikely to be directly related to work experience.

Soft Tissue Cancers: These rare tumors were of interest in this study since there have been reports that herbicide exposures may be related to an elevated risk of soft tissue cancers. Although two deaths had been coded as soft tissue cancers, the death certificates actually indicated that these deaths were due to mesotheliomas - a rare cancer that is associated with exposure to asbestos.

Diabetes: There was a non-significant 20% excess of diabetes deaths, based on 30 deaths overall. The 18 deaths that occurred in the 1965-1974 time period was approximately two-fold the number expected. Most of these deaths occurred in men over 70 years of age. Risk did not increase with increasing duration of employment. Diabetes has not been commonly associated with occupation. Among the many risk factors are heredity, race, obesity, exercise, and infection.

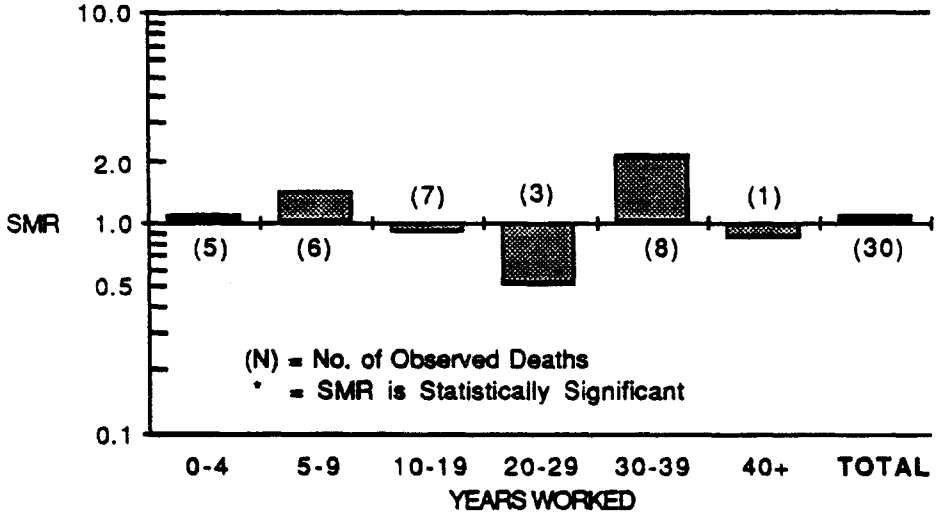
Diseases of the Blood Forming Organs: This category was of interest since it includes aplastic anemias, which may be caused by benzene exposure. Overall, there were five deaths in this category, approximately the number that was expected (SMR = 1.1). Of these five deaths, two could be classified as aplastic anemias.

Diseases of the Heart: Heart disease is the most common cause of mortality in the U.S. and in Minnesota. Heart disease was also the most common cause of death among HMWs, with 677 out of the total of 1530 deaths due to the various categories of heart disease. This was slightly less than expected (SMR = 0.93). Interpretation of findings in this category is difficult since these diseases are less accurately recorded and coded on death

certificates than cancers. A nonsignificant excess of deaths from chronic endocardial disease (SMR = 1.6) was due to heart valve diseases, which are not known to be work related.

Diseases of the Respiratory System (Non-Cancer): There was a nonsignificant excess of fibrotic and other chronic lung diseases (SMR = 1.1, based on 30 deaths, Figure E-9). Chronic bronchitis and emphysema deaths were nominal or nonsignificantly increased. The lack of a significant deficit in chronic obstructive pulmonary disease, chronic bronchitis, and emphysema is inconsistent with the deficit for lung cancer, since smoking is the major cause for all of these diseases. There were four deaths possibly attributable to pneumoconioses, lung diseases related to occupational dust exposure.

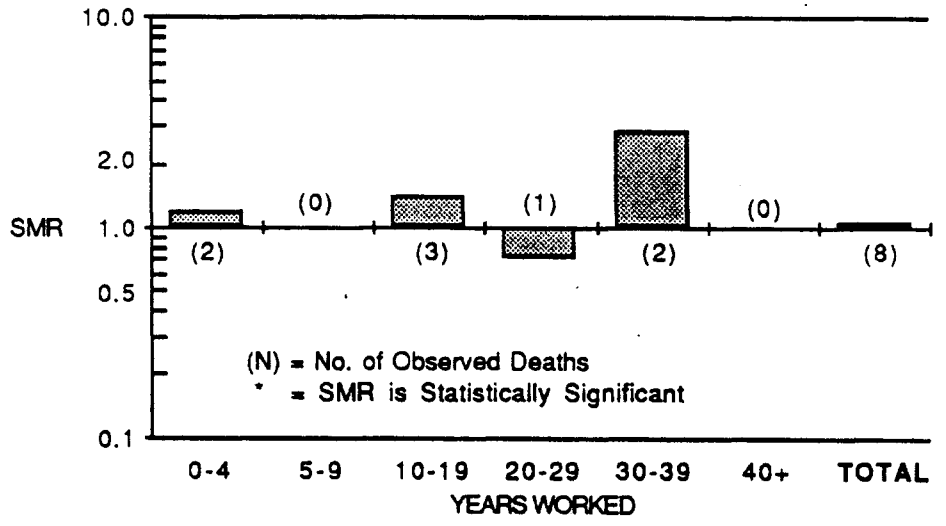
Figure E-9. Observed/Expected Deaths (SMR) Among HMWs By Years Worked: Fibrotic and Other Lung Diseases



Chronic Renal Failure: There was no overall increase in deaths from chronic renal failure (SMR = 1.1, based on eight deaths). Risk did not increase with increasing duration of employment (Figure E-10). There were three deaths, however, that occurred among men who had started work at

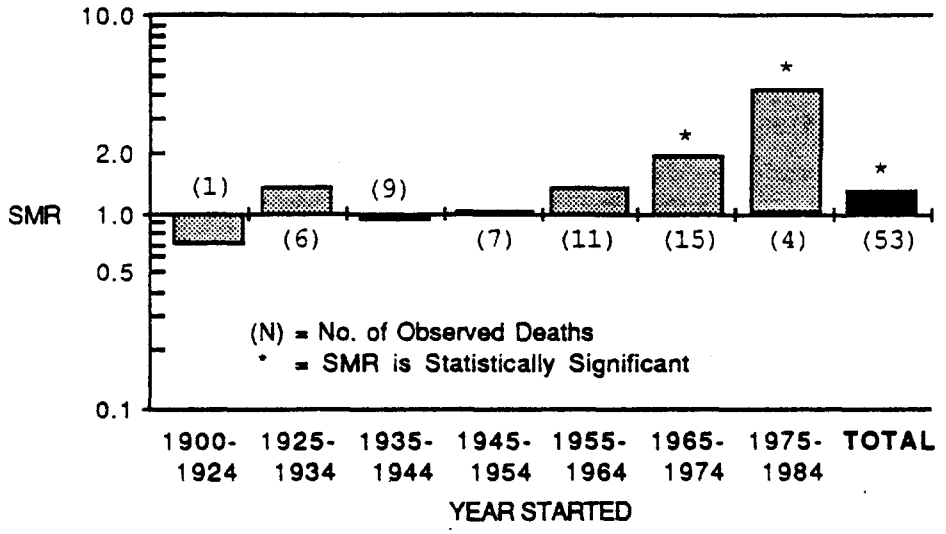
least 50 years before their deaths, a number significantly greater than expected (SMR = 6.6). There are many causes of chronic renal disease, including medical conditions, heavy metals, and pharmaceutical agents.

Figure E-10. **Observed/Expected Deaths (SMR) Among HMWs By Years Worked: Chronic Renal Failure**



Transportation Accidents: Ninety-seven deaths were due to accidental causes, a nonsignificant 20% excess. Since transportation accidents were considered to be a category of special interest prior to the study, these findings are presented in greater detail. Transportation accidents involved any accidental death involving a motorized method of conveyance (car, truck, motorcycle, boat, snowmobile, etc.). Overall, there were 53 such accidental deaths, a significant 40% excess. Among urban workers, however, there was a statistically significant two-fold excess compared to other Minnesotans. As shown in Figure E-11, the greatest degree of excess occurred in 1975-1984. It is important to note that transportation fatality rates during 1975-1984 for white male Minnesotans declined by 25% compared to previous decades.

Figure E-11. Observed/Expected Deaths (SMR) Among HMWs By Year Started: Transportation Accidents



At greatest risk were workers who had been employed less than five years. Many of these deaths occurred away from the job, while some clearly occurred on the job. Although present data do not permit a complete assessment, it was found that 14 of the 53 transportation deaths occurred at the workplace.

There were 44 deaths from all other types of accidents, which was not greater than expected. Ten of these are known to have occurred on the job.

SUMMARY OF MORTALITY FINDINGS

This study was able to provide a very detailed and complete examination of the mortality experience of a group of men who had in common work experience as a state Highway Maintenance Worker. Few other occupational groups in this state have been examined so closely. Because the overall mortality experience of working populations in Minnesota is not known, comparisons were made to the experience of the general population. This study did not find increased mortality risks among HMWs for the three major categories of death: heart diseases, cancers, and cerebrovascular disease. The lower all-cause mortality was an expected finding, based on other studies of employed populations elsewhere. However, the deficit in overall cancer mortality was not expected, and could be attributed to lower than expected overall cancer risks for respiratory and gastrointestinal cancers.

Despite the favorable overall risks, specific categories of workers were at elevated risk for specific causes of death. Most important among these are increased risks of leukemia among long-term workers and accidental deaths among short-term workers. Other findings that may be of significance include deaths from urinary cancers, colon cancer, and chronic renal failure.

The extent to which the elevated disease risks are related to workplace exposures and activities is unknown. In view of these uncertainties and the large number of workers employed in this occupation in Minnesota and the U.S., further investigations are required. Recommendations for further investigation are outlined in the following section.

RECOMMENDATIONS

Although this study did not find increased mortality risks among HMWs for the major causes of deaths, specific categories of workers were at elevated risk for specific causes of death. Inconsistencies in the findings, lack of detailed historical exposure data, lack of personal information on other important exposures, and other inadequacies in the available data prevent attributing increased disease risks to specific causes (occupational or otherwise). In light of the findings of this study and the limitations in available exposure data, the MDH proposes that the following actions be taken:

1. **The mortality experience of HMWs should be periodically updated. In addition, the cancer morbidity experience of these workers should be addressed if, and when, sufficient data are available from the statewide cancer surveillance system.**

Continued follow-up of past and current HMWs would assist in interpreting existing findings, corroborating trends or uncertain findings, and in targeting and evaluating any programmatic interventions. A very incomplete follow-up since the end of 1984 revealed, for example, that elevated leukemia mortality had continued into a later decade for those workers with over 30 years of experience. The benefits to be gained from such updates would greatly exceed the relatively modest costs. To reduce costs and facilitate future follow-up and tracing, the MDH should work with MNDOT and DOER to ensure that appropriate records are maintained. The first mortality update and complete follow-up should be scheduled for 1990 (five-years of additional follow-up). It should be possible by that time to assess cancer morbidity using data from the statewide cancer surveillance system. Although restricted to cancers, this would provide information on cancer occurrence and not just cancer mortality.

2. **Case-control studies should be conducted to further characterize any specific highway maintenance activities that may be associated with increased mortality risk.**

This study has indicated that HMWs are at increased risk for relatively few of the many causes of death. It is not presently known which, if any, of the many and diverse duties that comprise "highway maintenance work" are associated with these increased disease risks. Using existing record systems, case-control studies of diseases of greatest interest (leukemia, urinary cancers, and chronic renal disease) would attempt to distinguish any common elements of the job histories of those who died from these diseases. For those deaths due to injuries, personal interviews may be needed to provide more detailed information.

3. **A pilot study for injury surveillance should be conducted.**

This study found HMWs, particularly those with relatively short work experience in the urban areas, were at increased risk of death due to injury. A portion of these injuries were clearly job-related. Although not investigated in this study, it is probable that non-fatal injuries would greatly exceed the fatal injuries determined in this study. If non-fatal injuries are equivalently elevated, programs should be developed for the reduction of injury morbidity and mortality. The first phase of such a program is to determine the feasibility of a statewide injury surveillance within the MNDOT. The MDH would provide consultation and assistance to MNDOT for the conduct of a pilot or feasibility study.

4. **There should be additional environmental monitoring for suspected exposures to hazardous agents.**

Current monitoring data do not permit adequate characterization of all potential workplace exposures. Additional monitoring data are needed to

assess exposures that may be associated with particular job activities and conditions. These data, along with any historical information, would facilitate interpretation of observed disease risks and would further document that exposures to toxic substances were being minimized. Recent research studies may be useful in selecting appropriate substances and analytic techniques.

5. **A pilot study should be conducted using cytogenetic assays to assess personal exposures to mutagenic substances.**

Several cytogenetic tests can be performed on blood samples that can reveal current or past exposures to various types of chemical agents. Cytogenetic screening of a small group of selected employees who appear to be at highest and lowest risk would provide valuable information on the usefulness of this approach to identify potential exposures. A high risk group may be those, for example, with greater than 30 years of experience. If cytogenetic tests indicated that exposures have occurred, these data may be useful in assessing or directing environmental monitoring and in interpreting the findings of this study and follow-up studies.

6. **The potentially hazardous nature of the materials and some workplace practices utilized in highway maintenance requires continuing efforts on the part of both management and labor to reduce worker exposures to harmful agents and activities.**

This study was not able to link increased disease risks with specific occupational exposures, and limited monitoring data did not reveal exposures in excess of MN-OSHA standards. Nevertheless, it is apparent that a variety of the substances used by workers or to which workers could be exposed on the job are potentially harmful. These substances include

but are not limited to asphalts; gasoline; diesel fuels and their exhausts; other petroleum distillates; and herbicides. Continuing efforts to limit exposure to these materials to the extent practicable is clearly in the best interest of the employees, regardless of any study findings.

BUDGET

A budget has been developed for the implementation of the recommendations outlined above. Some funding has already been provided by the National Institute of Occupational Safety and Health (NIOSH). NIOSH has awarded the MDH $60,000 over the next two years to continue some study and follow-up of HMWs. Through existing staff support, the MDH can contribute another $40,000. An additional $170,000 (not including environmental monitoring or in-house MNDOT contributions) will be required over the next two years to begin implementation of these recommendations.

1. INTRODUCTION & BACKGROUND

The suspicion that there might be a health problem among highway maintenance workers (HMWs) arose in Wheaton, Minnesota in 1978. At that time, the American Cancer Society representative in Wheaton reported an apparent excess of leukemia in male residents of that town. A preliminary study by the Minnesota Department of Health (MDH) reviewed patient charts at the Wheaton Community Hospital and identified eight cases of leukemia among Wheaton residents. These patients were diagnosed between January 1, 1969 and December 7, 1978. One of the eight cases was a female, aged 78, and another had conflicting information with regard to diagnosis. Six patients were males, between the ages of 52 and 80.

The 1970 population of Wheaton was approximately 2000, including 240 males over age 65. The expected average annual incidence rate for all leukemias in males 65 and over based on the Third National Cancer Survey data for Minneapolis and St. Paul was 82.6/100,000. The observed average annual rate in Wheaton for the same age group over the ten year period of study was 208.3/100,000. These data indicated the existence of a "cluster" of leukemia cases in males aged 65 and older in Wheaton. More importantly, 5 of the 6 cases belonged to a single occupational group -- highway maintenance workers (HMWs). Four worked for the state and one worked for the Traverse County Highway Department.

This "cluster" of leukemia cases was further investigated to explore the possibility that the highway workers in Wheaton had been exposed to an agent (or agents) that might explain the high incidence of leukemia. Three steps were taken to accomplish this: 1) based on verbal accounts from workers and supervisors, a description was developed of the working environment for the highway workers in Wheaton; 2) a comparison was made of Wheaton HMWs with workers from the surrounding areas; and 3) a case-

control study was conducted involving highway maintenance workers. With the exception of farming, workers with leukemia exhibited no common occupational experiences or obvious exposure prior to the beginning of highway work. Although the workers in Wheaton were exposed to several potentially toxic substances, their work environment did not appear to differ from similar work sites throughout the state.

The results of this cluster study did not explain the occurrence of leukemia among the workers in Wheaton, and the results failed to establish a relationship between leukemia and specific occupational exposures in highway maintenance workers.

Following this initial investigation, a proposal was submitted to a federal agency to study the risk of mutagenic damage to highway workers who were exposed to petroleum products, tars, solvents, herbicides, asphalts, and other substances. This proposal was not funded. A recommendation was also made in 1980 that an epidemiologic study of morbidity and/or mortality be conducted of all highway maintenance workers in the state. This study was not initiated due to budget and staff limitations. In 1984, legal action against the state again focused attention on leukemia in HMWs.

In a workers compensation decision in May 1985, an award of approximately $250,000 was made to widows of two of the Wheaton workers. In that judgement, MNDOT was found to be at fault because workers had not been prevented from cleaning themselves with materials that contained benzene. Other claims have been settled out of court since that date.

In addition to the court, it was concluded by many at that time that the statistical improbability of the Wheaton cluster and the nature of their workplace exposures demonstrated a cause and effect relationship.

However, based on a review of existing information, the MDH concluded that such an inference was not warranted and that a large-scale study of all causes of death among all highway maintenance workers was necessary to address the public health issues that had been raised. This conclusion was based on three considerations: 1) the difficulty in interpreting the Wheaton cluster; 2) the broad range of potential workplace exposures experienced by highway maintenance workers; and 3) the large number of such workers both statewide and nationally. These considerations are described in further detail below. Following this description, the results of a feasibility study to evaluate the methodologic issues associated with a full-scale study are summarized.

PERSPECTIVE ON WHEATON AND OTHER CANCER CLUSTERS: To understand why the Wheaton leukemia cluster, or any cancer cluster, is difficult to interpret requires a detailed explanation. The most common form of cancer clustering is spatial and/or temporal clustering of cancer cases. The MDH averages five calls a month from concerned citizens, physicians, or other health professionals about what is perceived to be an excess of cancer in a neighborhood, school, or workplace. Technically, to be considered a cancer cluster, the perceived excess must, by statistical test(s), significantly exceed the amount of cancer expected in a comparable population of similar age, sex, and ethnic composition.

Because of this statistical requirement, there has been great emphasis on developing quantitative methods to evaluate the significance of cancer clusters. Often, however, the attention given to the statistical model totally obscures the known natural history of the disease in question. For example, in a recent report of occupational clustering of melanoma, a fourteen-fold excess was found (Aldrich, 1981). This high "risk" was

presented as evidence of an increased risk in the given occupational setting. This cluster, however, was based on three cases, all of whom had lived in Florida, had fair skin, spent substantial time outdoors, and had documented histories of overexposure to the sun (sunburning). Sunburning is a risk factor for melanoma.

Another misconception often encountered with cancer clusters is the public and clinical perception that the rarer the observation, the more likely that the cluster has an environmental etiology. For example, two of the most extensively studied types of cancer clusters are leukemia and lymphoma (Caldwell, 1976). Since these are relatively rare cancers, the probability of observing a number of cases in a small population is extremely small. Many studies of these clusters have reported probabilities of occurrence ("p values") of less than one in a million. This significance level is often incorrectly misconstrued as meaning that there are 999,999 chances out of a million that the cluster is not due to chance alone. This misconception arises for two reasons: 1) not understanding the basic limitations of statistics; and 2) not identifying the appropriate reference population.

In the context of statistical evaluation of a cancer cluster, a significance level is meaningful and interpretable only if the observations are drawn at random from a defined population. This seldom occurs with cancer cluster reports. A cancer cluster report involves recognition of an unusual event (i.e., perceived excess of cancer). This recognition does not represent a random sample, but rather a sample already suspected of being rare and therefore probably at the extreme of a "normal" distribution.

The appropriate reference population is usually not the group in which the cancer cluster occurred. By the logic described above, one can expect

extreme observations in a "normal" distribution to be perceived as unnatural and therefore reported to public health authorities. It is also possible to circumscribe any group of cancer cases in a manner that gives the appearance of more cancer than is expected for the overall population.

A good example of how easy it is to observe clusters is given by a study of leukemia clusters in Los Angeles (Glass, 1968). The distribution of cases was examined in advance and subpopulations within Los Angeles were defined in a way that generated pockets of high leukemia rates. Nine of thirty-two areas were found with leukemia rates as high or higher than Niles, Illinois (Heath, 1963) or Orange, Texas (Heath, 1964), where two of the most publicized leukemia clusters have occurred. When the data were analyzed for the entire city, no evidence of clustering was found.

Cancer clusters may, therefore, represent "expectedly unexpected" events. Another example of the population-wide commonality of cancer clusters comes from a study of leukemias and lymphomas in Great Britain (Cartwright, 1984). In this study, 1520 cases were distributed among 2645 geographically defined sectors. There were many more occasions than expected with three or more cases within a sector. The implications of these and other findings is that, if a large area is examined in detail for a long period of time, a statistically significant excess of cancers will be observed. Therefore, clusters occur continually within any large population and their population-wide occurrence is often no greater than that expected by chance alone (Pike, 1980). Thus, the appropriate reference population in which to judge the statistical significance of the cluster is all subgroups in the large population similar to the one in which the cancer cluster was identified. The appropriate larger population, however, is often difficult to define.

In view of the above discussion, it is easy to understand why merely calculating the statistical significance of an observed cluster is falling into disfavor. The number of observed cancers is usually statistically elevated; yet it is impossible to draw any conclusions from the finding. In an attempt to incorporate biologic principles into the evaluation of the significance of a cancer cluster, more sophisticated methods are being developed. Case-control studies which contrast the case group's interaction with putative environmental factors (or other agents) to a control group's interaction with the same factors are being recommended as a method to evaluate the significance of observed cancer clusters (Pike, 1975).

These methods are expensive and time consuming and have been successfully completed in only a handful of studies. In many instances, such as Wheaton, case-control studies cannot further resolve the problem.

Another method used to explore the significance of a reported cancer cluster is to study a much larger group that is representative of the group in which the cluster was observed. The rationale is that if the cluster were an artifact of time and space statistics, it will not be generalizable to a much larger group (e.g., all highway maintenance workers). In addition, the larger numbers of the cohort (group) provide for more powerful inferences about the plausibility of an association between the work group and the cancer. If the association is verified, then a relatively larger number of subjects may become available for case-control studies to analytically define the most specific risk factors. This was the method used in the current study.

HMW EXPOSURE OVERVIEW: Highway maintenance has been defined as the preservation and upkeep of a highway in as nearly as practical, its original condition or its subsequently improved condition. The upkeep of highways includes repairing road surface failures, sealing joints, maintaining shoulders, and repairing and improving drainage structures. Maintenance operations include many traffic services such as sanding and the removal of snow and ice. Other operations included in highway maintenance are the maintenance and construction of road signs and traffic markers, weed control, and general maintenance of the right of way (Tessman, 1970).

Highway maintenance workers have or had many potential exposures to hazardous materials. These exposures include: 1) diesel fuel; 2) diesel exhaust; 3) asphalt and tars; 4) herbicides; 5) gasoline; 6) polynuclear aromatic hydrocarbons; and 7) benzene. This list is not exhaustive, rather it comprises those substances believed to be of primary concern at the outset of this study. These substances are discussed below. Other substances of potential importance that are not discussed here include lead, dusts, and solvents (nonbenzene). Also not discussed below are job-related activities or practices that pose potential risks of traumatic deaths or injuries. The following discussions are not intended to be critical and comprehensive reviews of the literature.

Diesel Fuel: Diesel fuel, like all petroleum-derived liquid fuels, is a complex blend of many hydrocarbons. It is called a "middle distillate" fuel as it is separated by distillation from lighter hydrocarbons, which make up gasoline, and heavier hydrocarbons. Three types of diesel fuel are currently sold in the United States; two of these are used for highway vehicles.

Diesel #1 contains hydrocarbons with boiling points between 180 degrees and 250 degrees celsius. Diesel #2, a heavier fuel, contains hydrocarbons boiling between 200 degrees and 350 degrees celsius. Diesel #1 is used primarily as a fuel for automobiles and city buses. Heavier vehicles, such as those used for farming, construction, and highway transportation, use diesel #2. Both kinds of fuel are composed mainly of three primary types of hydrocarbons: paraffins, napthenes, and aromatics.

The substance of greatest potential concern in diesel fuel is benzene. Benzene is quite volatile because of its low boiling point. Gasoline has a higher concentration of benzene than diesel fuel; gasoline may contain up to 4% benzene. Little data exist on the concentrations of benzene in diesel fuel; however, it is substantially lower than gasoline. The aromatic (e.g., benzene) content of both gasoline and diesel fuel has been steadily increasing since 1976. With decreasing lead content, the concentration of aromatics has increased in order to maintain the octane rating. Thus, benzene levels in gasoline and diesel fuel are higher at present than in the past (John Walls, personal communication). Diesel fuel also contains low levels of polynuclear aromatic hydrocarbons (discussed below) (Guerin, 1978).

Diesel Exhaust: Diesel exhaust is a complex mixture of thousands of chemical components which have not been completely characterized. A small number of these components, including organic compounds such as polynuclear aromatic hydrocarbons (PAHs), nitro-PAH, and aromatic amines, are of potential toxicologic and biologic significance (NAS, 1983). When these organic compounds are adsorbed onto soot particles in diesel exhaust, their retention in the lung is substantially greater than when they are inhaled in their pure form. Since the great majority of organic compounds are

relatively lipid soluble, they may be directly absorbed through the pulmonary circulation into the blood. For this reason, the lung may not be the only organ affected by diesel exhaust.

Most epidemiologic studies of the health effects of diesel exhaust have examined respiratory cancers. Though early studies were predominantly negative, some of the more recent studies have suggested increased lung cancer risk in groups exposed to diesel exhaust (Higgins, 1987). A major limitation of these studies, however, is the lack of measurements of diesel exhaust and the inability to control for other factors (e.g., smoking) that also influence cancer risk.

Two recent studies of railroad workers exposed to diesel exhaust lend support to the hypothesis that exposure to diesel exhaust increases lung cancer risk. Garshick (1987) conducted a case-control study of deceased railroad workers. The cases were railroad workers who had died of lung cancer and the controls were railroad workers who had died of other causes. Determination of which workers had been exposed to diesel exhaust was based on a comprehensive industrial hygiene survey of current exposures and assessment of job histories. Controlling for both previous asbestos exposure and smoking, the investigators reported that workers 64 years of age or less at the time of death, who had been exposed to diesel exhaust had a 40% higher risk (SMR = 1.4) of developing lung cancer than unexposed workers. These investigators also studied a cohort of railroad workers. They reported that workers with the longest duration of exposure to diesel exhaust had an SMR of 1.45 (i.e., 45% increase) for lung cancer.

The relationship between bladder cancer and diesel exhaust has also been investigated, primarily with case-control studies. These studies have suggested an increase in bladder cancer among truck, bus, and taxi drivers (Higgins, 1987). Data from the National Bladder Cancer Study, the largest

epidemiologic study of bladder cancer done to date, indicated that males usually employed as truck drivers or delivery men had a 50% increase (SMR = 1.5) in risk of bladder cancer (Silverman, 1987). The risk increased with increasing duration of exposure. The investigators recontacted truck drivers in Detroit who had the highest risk of all truck drivers in the study. Drivers who had driven vehicles with diesel engines experienced a ten-fold increase in risk. However, as there were no actual measurements of exposure to diesel exhaust, the investigators could not rule out the possibility that the risk was attributable to other factors.

In summary, data suggest that diesel exhaust exposure may be causally related to lung cancer. Evidence for an association between diesel exhaust and bladder cancer is much weaker. Because organic compounds adsorbed onto diesel particles can be absorbed through the lung into the bloodstream, other organ systems besides the lung and bladder may also be affected. This possibility has not yet been systematically investigated in epidemiologic studies.

Asphalts and Tars: Asphalts and tars have had similar applications in road paving and maintenance, roofing, as protective coatings, and in many other industrial applications. Because of their similar appearance and uses, they are often confused with each other. There are, however, important distinctions between the two in terms of their origins, chemical and physical properties, current usage, and evidence of carcinogenic potential (IARC, 1985; Puzinauskas and Corbett, 1978). Asphalts are derived from crude petroleum oil while coal tars are produced through the high temperature carbonization of bituminous coal.

The manufacturing, handling, and application of many asphalt and tar products requires maintaining the product at an elevated temperature, which allows fumes and vapors to be emitted into the workplace air or atmosphere. A primary concern regarding these exposures relates to the presence of polynuclear aromatic hydrocarbons (PAHs), a large family of compounds that includes some potent animal carcinogens.

Although, at present, tars are infrequently used in road construction and maintenance in the U.S. (McNeil, 1983), they may have had greater use historically. As with roofers, some highway workers may have worked with both materials over time. Thus, both asphalts and tars are reviewed below. A separate overview of PAHs is also presented in this section.

1. Asphalts: The National Institute of Occupational Safety and Health (NIOSH, 1977) defines asphalt as a "dark brown to black cementitious material in which the predominating constituents are bitumen which occur in nature or occur in petroleum processing." Crude petroleum oils contain varying amounts of asphalts - from less than 5% to over 70%, but typically 10-50% (Puzinauskas and Corbett, 1978; IARC,1985). Several procedures can be used to separate the asphalts from other materials in the crude petroleum. A fractional distillation process, at atmospheric and under reduced pressures, in the presence or absence of steam, is the basic process used to manufacture asphalt. These processess involve relatively low temperatures, generally less than 385^{0} Celsius (C), avoiding thermal degradation of the hydrocarbon compounds.

Different asphalt products or grades are made through refining and/or the addition of petroleum distillates or emulsification with water (Asphalt Institute, 1977). In general, these materials fall into one of three categories: asphalt cements, cutback asphalts (or road oils), and

emulsified asphalts. These substances are used to produce dozens of different asphalt products used over a wide range of temperatures and conditions. Asphalt cements are asphalts refined to meet specifications for paving grade materials (Puzinauskas and Corbett, 1978). Of the asphalt used in 1975, 77.9% was for paving, 17.4% for roofing, and the rest for miscellaneous purposes (NIOSH, 1977).

Chemically, asphalts are extremely complex materials. The composition depends on the petroleum and the refining process used in their manufacturing. Consequently, asphalts vary in their exact chemical composition, and they are not characterized according to their precise chemical constituents. Asphalts consist of a very large number of chemical compounds of relatively high molecular weight including alkanes, cycloalkanes, aromatics, and heteromolecules containing sulfur, oxygen, nitrogen, and heavy metals (IARC, 1985). Based on chemical separation procedures, these constituents can be grouped into four broad classes of compounds: asphaltenes, polar-aromatics (resins), naphthene-aromatics (cyclics), and saturated aromatics. Asphalts contain mostly high molecular weight paraffinic and naphthenic hydrocarbons and their derivatives, as opposed to road tars, which contain mostly highly condensed-ring aromatic and heterocyclic hydrocarbons.

Asphalts contain polynuclear aromatic hydrocarbons (PAHs), a large family of compounds that includes some potent animal carcinogens (Santodonato et al., 1981; NAS, 1983; IARC,1983,1985). The PAH content is less than that of the petroleum crude, since lower molecular weight compounds (including PAHs) are removed during the distillation process and the temperatures involved are too low for significant PAH formation (IARC, 1985). The PAH content of eight different asphalt cement samples and two coal tar samples is shown in Table 1-1.

The most frequent exposures to asphalt and asphalt fumes occur in highway and street construction, roofing and sheet metal work, and blast furnaces and steel mills. A summary of studies providing exposure data for road paving operations, roofing operations, and other operations is provided in a report by the International Agency for Research on Cancer (IARC, 1985). Detailed analyses of asphalt fumes under both laboratory and field conditions (involving road maintenance and construction activities, roofing, indoor mastic laying, and tank loading) have been provided by Brandt (1985). Data are presented in these surveys for total particulates, benzene-soluble material, and specific PAHs.

In general, for road surface dressing and paving activities, eight-hour time weighted average (TWA) total particulate measurements from personal samplers averaged around 1 mg/m^3 or less, and ranged from about 0.1 to 15 mg/m^3. Exposure to benzene-soluble material (which includes a PAH fraction) ranged from 0.1 to 0.6 mg/m^3. The concentration of the sum of eleven 4-,5-, and 6-ring PAHs in the benzene-soluble material from personal monitors ranged from 69 to 229 ppm (road maintenance exposures were not included). In laboratory generated asphalt fumes, these PAHs comprised between about 200-300 ppm of the benzene-soluble fraction. Brandt concluded that the amount of PAHs in the breathing zone was directly associated with the amount of benzene-soluble fume material. Benzene-soluble exposures were, in turn, related to the temperature of the asphalt material and the proximity of the worker to the material.

IARC (1985) has recently reviewed the data pertaining to the potential carcinogenicity of asphalts. NIOSH (1977) has also reviewed data on the potential health effects of asphalt fumes. These reviews, along with several other studies not included in the reviews, provide the basis for the following summary.

IARC (1985) reviewed eight studies in which various asphalt products were applied to the skin of mice and four studies in which asphalt preparations were injected into mice or rats. Interpretation of many of these studies was hampered by inadequate study design or reporting. In general, however, it was found that steam-refined asphalts were able to produce skin tumors. When various asphalt preparations were administered to mice or rats by injection, sarcomas could be produced at the injection sites.

Other toxic effects were also noted by IARC. Chronic inhalation of apshalt fumes, aerosol or smoke produced respiratory pathology in guinea pigs, rats, and mice. Pathologic changes included patchy regions of emphysema, bronchiolar dilatation, pneumonitis, and severe localized bronchitis (IARC, 1985). Skin effects in mice included epidermal hyperplasia.

IARC (1985) cites data showing that a "road-coating tar" containing dimethyl sulphoxide was mutagenic in a bacterial assay. Vapors and aerosols emitted at various temperatures were also weakly mutagenic.

In a study by Robinson (1984) coal tar and asphalt paints were tested in a bacterial assay for mutagenic activity and in mouse skin carcinogenesis bioassays. All coal tar paints showed mutagenic activity, while none of the petroleum asphalt paints had mutagenic responses. Both types of coatings resulted in positive responses in an initiation/promotion study. The coal tar paints gave rise to 1000-1800 times the tumor response observed with petroleum asphalt products. The biological responses to the products were greater than expected from their PAH content. These findings suggest that the hazard posed by these coatings may not be fully explained by their PAH contents.

Overall, available evidence indicates that asphalt materials are less carcinogenic than the coal tars with which they are frequently confused (see below). However, no good indicator for the possible carcinogenicity of asphalts has been identified to date. In all likelihood, PAH compounds cannot be used for this purpose. Belinky (personnel communication) notes that one cannot account for the carcinogenicity of asphalt in terms of its specific benzo(a)pyrene concentration or content of polynuclear aromatics in general. IARC (1985) concluded that "there is sufficient evidence for the carcinogenicity of steam-refined bitumens, air-refined bitumins, and pooled mixtures of steam- and air-refined bitumens in experimental animals."

There have been several reports of acute adverse effects from asphalts. Tarvis (1984) investigated an indoor air complaint of 19 individuals in an office complex. The people complained of headache, eye irritation, sore throat, and nasal congestion. These symptoms were traced to malfunctioning light ballasts which melted and volatilized the asphalt contained inside. There have also been reports of severe burns resulting from coal tar or asphalt These burns comprised 2.8% of burn patients admitted to a Utah burn center (Stratta, 1983).

The only study done to date of asphalt workers was that of Baylor (1968). A survey was done of 462 asphalt workers and 379 controls in 25 oil refineries. The average length of work was 15.1 years. The authors stated that there was no evidence to implicate asphalt as an etiologic agent for cancer or illness other than dermatologic problems. However, serious flaws in this study and lack of exposure data preclude any conclusions.

Hammond and colleagues (1976) conducted a mortality study of 5939 members of the United Slate, Tile, and Composition Roofers, Dump and

Waterproof Workers Association. Local unions that were confined to slate and tile work were excluded. In former years, pitch was used more commonly than asphalt, but at the time of this study, use of asphalts was more common. There were a total of 1798 deaths. It appears that there was an increase in the incidence of lung cancer deaths in those with longer duration of exposure. Smoking habits were not accounted for in this study. Among workers with 20 or more years membership in the union, the following SMRs were noted: cancer of the oral cavity, larynx and esophagus, SMR = 1.95; stomach cancer, SMR = 1.67; leukemia, SMR = 1.68; and bladder cancer, SMR = 1.68. No exposure data were presented in this study.

Using pooled mortality data (1968-70) and incidence data (1972-73), Menck and Henderson (1976) examined occupational differences in lung cancer rates in white males in Los Angeles County. A significant excess was found among roofers (SMR = 4.96) based on six deaths and five incident cases. In Milham's (1982) proportionate mortality data for 1950-79 for Washington males, a PMR of 1.61 was found for roofers and slaters for cancer of the lung and bronchus, based on 53 observed deaths. Neither of the above studies had data on smoking histories; and as noted by Hammond et al. (1976), most workers had probably been exposed to both asphalts and coal tar pitches.

NIOSH (1977) states that "irritation of the serous membranes of the conjunctivae and mucous membranes of the respiratory tract are the principal adverse effects on health from exposure to asphalt fumes," and that "reliable reports associating malignant tumors of parenchymatous organs with exposure to asphalt fumes have not been reported in the literature." However, since some asphalts have small quantities of carcinogenic hydrocarbons, NIOSH believes asphalt fumes should be considered somewhat more hazardous than a nuisance dust.

A report by the Asphalt Institute (Puzinauskas and Corbett, 1978), concluded that asphalt fumes have not produced harmful effects in workers or test animals, and could be classified as nontoxic materials.

IARC (1985) found no epidemiologic studies of workers exposed only to asphalts. Studies of roofers suggest excess risks for several cancer sites. However, as these workers were also exposed to other materials, the excess risk could not be attributed specifically to asphalts. IARC concluded that there was inadequate evidence that bitumens alone are carcinogenic to humans. It should be noted, however, that IARC takes the following position with respect to animal data: "In the absence of adequate data on humans, it is reasonable, for practical purposes, to regard chemicals for which there is sufficient evidence of carcinogenicity in animals as if they presented a carcinogenic risk to humans."

2. Coal Tars: Although road tars are presently rarely used in the U.S. for road construction and maintenance, they have been used in the past (McNeil, 1983). Thus long-term workers may have had exposures to both types of materials. Since these materials are sometimes confused, and workers may have had exposures to both, it is important to distinguish the properties and evidence of carcinogenicity for these materials.

In contrast to asphalts which are derived from crude petroleum oils, coal tars are derived from coals. More specifically, coal tars are by-products in the production of coke through the destructive distillation of coal, called carbonization or coking (IARC, 1985). The gas that is produced during the carbonization process is collected and cooled, producing the coal tar condensate. Although there is both a low temperature and a high temperature carbonization process, most coal tars in the U.S. are produced through the high temperature (880-1200^{o}C) process

(Puzinauskas and Corbett, 1978). Coal tars are black, viscous liquids or semisolids with a characteristic naphthalene-like odor and sharp burning taste (EPA, 1984). As with asphalts, coal tars are very complex mixtures of compounds, including hydrocarbons, phenols and heterocyclic compounds with oxygen, sulfur, and nitrogen. Several hundred compounds have been identified in coal tars, and probably as many as 10,000 compounds are actually present (although many in trace amounts)(EPA, 1984; IARC, 1985). Because of the complexity and variability in their composition, coal tar products are usually assayed and specified by physical characteristics, rather than by chemical composition.

In contrast to asphalts, PAH compounds comprise a large portion of many coal tar products. The PAH profile of coal tars depends mainly on the temperature used in production. PAHs comprise at least 75% of some creosotes; coal tar pitches (e.g. roofing pitch) contain 40-50% PAH compounds with 4 to 7 rings (most of the carcinogenic PAHs are in this size range). The sum of 5 specific PAH compounds (3 known animal carcinogens) in 3 road tars ranged from 5-9% (IARC, 1985).

From the crude coal tar, additional distillation and/or blending processes are employed to produce various coal tar products. In 1980 and 1982, approximately two-thirds of coke-oven coal tars in the U.S. were utilized by tar distillers for refining and blending into various products (IARC, 1985). Commercial products produced from coal tars through the high temperature process include carbolic oils, naphthalene, creosote, benzene, wash oils, fluxing oils, anthracene pastes, pitches for roofing and water-proofing, carbon-black oil, refined tars, road tars, electrode pitches, and protective paints and other coatings (IARC, 1985). Roughly two million tons of coal tar pitches are believed to be used in the U.S. annually (IARC, 1985).

Road tars may be produced in a process similar to that used to produce pitches, or they may be produced by blending pitches with various coal tar oils to obtain a product of the desired viscosity. Road tars may also be blended with asphalts for particular applications (IARC, 1985). Road tar production in the U.S. in 1971 totalled 152 million liters (IARC, 1985). In 1981, only about 1% of coal tar production was used in road materials (McNeil, 1983). Coal tar production is closely linked with steel production, since coke is used in steel making. Coal tar production has been declining in recent years in the U.S. and in western Europe.

Exposure to coal tar products and emissions occurs in a wide variety of occupational settings. Occupations or processes involving exposure include coke-oven workers in the steel industry, aluminum production, wood preserving facilities, coating of pipes with hot coal tar enamels, roofing operations (including tarring of flat roofs and tear-off of old roofs), road paving, silicon carbide production, refractory brick production, and in optics. OSHA has estimated that 121,000 workers are exposed to tars (NTP, 1985). OSHA has set an exposure limit to coal tar pitch volatiles of 0.2 mg/m^3 (TWA), while NIOSH has established a guideline of 0.1 mg/m^3. The most important aspect of occupational exposure to coal tar products and fumes is considered to be the PAHs (IARC, 1985). Unfortunately, only limited occupational exposure data are available for coal tar products (volatiles or specific PAH compounds), and most of these data are for operations other than road paving or maintenance (Santodonato et al., 1981; NAS, 1983; IARC, 1985). However, the considerable exposure to PAHs that occurs during roofing operations (e.g., PAH concentrations ranging from <1 to >1000 ug/m^3) would suggest that road tarring operations would also

involve significant exposure potential. PAHs have been reported in the skin oil of roofers and in the clothing of workers in a pitch-manufacturing plant (IARC, 1985).

Studies dating back to the early part of the century demonstrated that coal tars produce tumors when applied to the skins of animals. In the late 1700s it was recognized by Pott that chimney sweeps, who had exposure to soots and tars from coal combustion, had an unusual risk of scrotal cancer. Since these early human and animal observations, it has been well established that coal tars and other coal-derived products are both animal and human carcinogens. Occupational studies of (coal) gas workers and coke-oven workers (steel industry) have shown large increased risks (2-fold to over 10-fold) of lung cancer (Santodonato et al., 1981; IARC, 1985). The greatest risks were among those with the greatest exposures to coke-oven volatiles (e.g., top-side coke workers). Elevated risks among these workers have also been reported for cancers of the kidney, pancreas, large intestine, buccal cavity and pharynx and for respiratory diseases other than cancers (Santodonato et al., 1981; NAS, 1983). Among roofers who are likely to have had exposures to both asphalts and tars, elevated risks have been reported for cancers of the lung and bronchus, oral cavity, larynx, esophagus, stomach, and bladder, and for leukemia and nonmelanoma skin cancer (IARC, 1985). Non-malignant respiratory diseases were also elevated. A case-control study of kidney cancer conducted in Minnesota found an elevated, although not significant, risk for occupational exposures to petroleum or tars (McLaughlin et al., 1983).

Other reported toxic effects from occupational exposures or therapeutic use of coal tars include: cutaneous photosensitivity, dermatitis, chronic tar dermatosis, chronic melanosis, folliculitis, acne,

conjunctivitis, burning sensations in the eye, and photophobia (IARC, 1985).

Studies dating back to 1918 have demonstrated that coal tars and pitches can produce skin tumors when applied to the skins of various rodents (IARC, 1985). Other toxic effects in animals from coal tar exposures were also noted by IARC (1985): a coal-tar aerosol produced a necrotizing tracheobronchitis in mice; skin application induced epidermal hyperplasia in mice; and ingestion by pigs and ducklings resulted in liver lesions.

IARC (1985) concludes that there is "sufficient evidence" that coal tars and coal tar pitches are causally associated with cancers in both animals and humans.

Herbicides: Chemical preparations derived from chlorophenols (particularly the phenoxy acid herbicides), are widely used as fungicides, pesticides, wood preservatives, and herbicides. Two of the most widely used phenoxy acid herbicides are 2,4,5-trichlorophenoxyacetic acid (2,4,5,-T) and 2,4-dichlorophenoxyacetic acid (2,4-D). Most commercial grades of chlorophenol preparations contain some degree of toxic contamination. These contaminants include dioxins such as 2,3,7,8,- tetrachlorodibenzo-para-dioxin (TCDD), a potent animal carcinogen.

The herbicide 2,4-D does not appear to contain TCDD, although it may contain other toxic contaminants. Of concern is 2,4,5-T: TCDD is formed during both the manufacture of 2,4,5-T and its combustion. Results of animal studies suggest that both 2,4-D and 2,4,5-T should be considered health hazards (Sterling, 1986).

Epidemiologic data regarding the human carcinogenic potential of these compounds have been derived from studies of occupationally exposed workers, using both case-control and cohort approaches. These data, while inconclusive and inconsistent, provide information on the types of cancers of potential concern.

Attention was first drawn to a possible association of phenoxy acid herbicide exposure and soft tissue sarcoma when a Swedish physician reported that five of seven men with soft tissue sarcoma had been exposed to phenoxy acid herbicides (Hardell, 1977). To follow up this observation, Hardell conducted a case-control study (Hardell, 1979). The subjects consisted of 52 cases of soft tissue sarcoma and over 200 controls matched for age, sex, place of residence, and vital status. The relative risk for those exposed to chlorophenols or phenoxyacetic acids, compared with those who were not exposed to these substances was 5.7.

Eriksson (1981) studied 110 men with soft tissue sarcoma. He reported that exposure to phenoxyacetic acids or chlorophenols was associated with a relative risk of 5.1. Exposure to phenoxyacetic acids alone gave a relative risk of 6.8, and exposure to chlorophenol alone resulted in a relative risk of 3.3. While the relative risk associated with TCDD-contaminated herbicides was 17, the risk associated with noncontaminated herbicides was also significantly elevated at 4.2. The authors concluded that phenoxy acids were associated with soft tissue sarcomas even in the absence of TCDD contamination.

Hardell (1981), in another case-control study, demonstrated an association between malignant lymphoma (both Hodgkin's and non-Hodgkin's) and herbicide exposure. Exposure to both phenoxy acids and chlorophenols was associated with a relative risk of 6.0. This association between herbicide exposure and non-Hodgkin's lymphoma was also found by Hoar (1986)

and colleagues. They conducted a case-control study of soft tissue sarcoma, non-Hodgkin's lymphoma, and Hodgkin's disease in Kansas. They reported that farmers who were exposed to herbicides 20 or more days per year had a six-fold excess risk of developing non-Hodgkin's lymphoma. The primary herbicide used was 2,4-D. No risk was found for soft tissue sarcoma or Hodgkin's disease.

Several studies of cohorts with occupational exposure to phenoxyacetic acids have been performed. These studies have uniformly been too small to provide more than suggestive evidence of an association between phenoxy acid exposure and cancer.

Axelson (1980), in a case-control study of 348 railroad workers exposed to phenoxy acid herbicides during spraying to clean rights of way, reported that the workers' cancer mortality was 2.2 times higher than the cancer mortality of a control group, and 3.4 times higher among workers exposed to both amitrol (another herbicide) and phenoxy acids. Hogstedt and colleagues (1980) compared the cancer mortality experience of 142 forestry workers exposed to phenoxy acids and 244 unexposed forestry workers. They reported that work supervisors, who had a more intense exposure to herbicides, had significantly elevated cancer mortality (5 observed, 1.4 expected) when compared to national rates. No particular type of cancer predominated.

Studies of armed forces personnel exposed to Agent Orange (a dioxin-contaminated phenoxy herbicide) have failed to demonstrate increases in cancer mortality. The Ranch Hand Study, the most comprehensive study done to date, reported an increase in skin cancer but no other malignancies (Lathrop, 1984). However, the cohort was small and the period between exposure and occurrence of cancer may have been too short for any increase to be demonstrated.

Workers exposed to high concentrations of TCDD following industrial accidents have also been studied. Theiss (1982) followed the mortality experience of 74 workers exposed to TCDD in an accident at a trichlorophenol plant. While overall cancer mortality was not significantly elevated, a small increase in stomach cancer was noted in workers approximately 10 years after the exposure. Zack (1980) examined the mortality experience of 121 workers who had developed chloracne (a marker of dioxin exposure) after an industrial accident. No increase in mortality was found. Ott (1980) also failed to find an increase in the mortality experience of 204 employees of a 2,4,5,-T manufacturing plant.

In summary, limited data suggest that exposure to phenoxy acid herbicides may be associated with an increase in soft tissue sarcoma and non-Hodgkin's lymphoma. Evidence for an association between this exposure and other cancers is more speculative, although such an association cannot be ruled out. An association between leukemia and phenoxy acid herbicide exposure has not been reported in the literature.

Gasoline: Gasoline is a petroleum-derived liquid fuel consisting primarily of volatile hydrocarbons: alkanes, alkenes, cycloalkanes, and aromatics (including PAHs). In addition, gasoline may contain up to 4 percent benzene. Benzene volatilizes from gasoline into the atmosphere at normal room temperatures.

Recent concerns about the health effects of gasoline vapors have been stimulated by the report of increased kidney tumors in male rats and increased liver tumors in female mice exposed to unleaded gasoline vapors over a two year period (MacFarland, 1984). Many questions have been raised concerning the implications of this report for human health effects.

Specific concerns have focused on the nature of the exposure and the validity of extrapolating results from these species to humans (HEI, 1985).

Epidemiologic studies support the hypothesis that gasoline vapors may increase the incidence of kidney cancer. Some, but not all, cohort studies of petroleum refinery workers with potential exposure to gasoline have shown elevated risks of kidney cancer. This risk was highest among long-term workers (Enterline and Viren, 1985). The studies that have not shown any excess risk have generally had a short follow-up period. Kidney cancer may not develop until 20-30 years after first exposure, thus an increase would not have been evident without longer periods of follow-up. Unfortunately, available studies have not had adequate exposure data, and investigators have had to rely on job histories to determine exposure status.

In summary, limited data suggest that exposure to gasoline vapors may cause kidney cancer. This association, however, is far from established. If such an association exists, it is likely to be weak or moderate, with a relative risk of less than two.

Polynuclear Aromatic Hydrocarbons (PAHs): The discussions above have considered the effects from exposures to crude mixtures of asphalts, coal tar products, gasoline, and diesel fuel. As previously noted, PAHs are constituents of major concern in these mixtures, although the presence or concentration of specific PAHs (e.g., benzo(a)pyrene or BaP) does not fully account for the carcinogenic potential of these materials. Since PAHs are also present in exhausts from gas and diesel engines (and from most other combustion processes including smoking), it is useful to briefly summarize some of the findings from the enormous body of research on PAH carcinogenicity and toxicity.

Most of the research on health effects of PAH exposure has focused on their carcinogenic potential. Carcinogenic effects occur at exposure levels much lower than those needed to produce other types of toxic effects. However, other toxic effects have been recognized with several PAHs. Damage to the hematopoietic and lymphoid systems in experimental animals is a particularly common observation following acute exposures (Santodonato, 1981). In general, normally proliferating tissues (intestinal epithelium, bone marrow, lymphoid organs, testes) are the major targets of PAHs toxicity (Santodonato, 1981). In the skin, sebaceous glands are the most sensitive structure. Chronic intratracheal exposure in hamsters to certain PAH resulted in acute pneumonia and chronic pneumonitis as well as significant mortality (before the appearance of lung cancer). Epithelial proliferation and cell hyperplasia is a common observation in the tracheobronchial mucosa of animals directly exposed to carcinogenic PAHs. Carcinogenic PAHs can also produce an immunosupressive effect, although the importance of this effect to carcinogenesis is unclear (Santodonato, 1981).

PAHs were the first class of compounds shown to be carcinogenic in animal experiments. Benzo(a)pyrene and dibenz(a,h) anthracene were shown to produce skin cancer in mice approximately fifty years ago. Since that time, a large body of research has shown that many other individual PAH compounds and PAH-containing mixtures (such as coal tars, asphalts, coke-oven emissions, cigarette smoke, and auto exhausts) are carcinogenic in a variety of animal species and by different routes of administration (Santodonato, 1981; NAS, 1983; IARC, 1983; 1985). As described by Santodonato, (1981), carcinogenic PAHs are distinctive in that "(1) several [PAHs] are among the most potent carcinogens known to exist, producing tumors by single exposures to microgram quantities, (2) they act both at

the site of application and at organs distant to the site of absorption, and (3) their effects have been demonstrated in nearly every tissue and species tested, regardless of the route of administration."

Oral administration of certain PAHs to rodents can produce tumors of the forestomach, mammary gland, ovary, lung, liver, and lymphoid and hematopoietic tissues (Santodonato, 1981). Intratracheal or direct pulmonary exposure to very small doses can produce tumors of the respiratory tract. In addition, as previously mentioned, application of a variety of PAHs to the skin can produce skin tumors.

In short-term in vitro cell tests (bacterial mutation, mammalian cell transformation, etc.), many PAHs have shown mutagenic activity. In addition, some PAHs are positive in in vivo tests for genetic or chromosomal effects such as sister chromatid exchange (NAS, 1983). No correlation has been found, however, between the quantitative aspects of sister chromatid exchange and carcinogenicity of PAH. Reviews of the findings from a large battery of short-term tests for various PAHs can be found in Santodonato (1981), NAS (1983), IARC (1983), and IARC (1985).

It has been demonstrated in many tissues and species (including humans) that certain PAH metabolites can bind at specific locations on DNA, RNA, and proteins. The PAH metabolite-DNA adducts are of particular interest in that it is currently believed by most researchers that this interaction is the essential first step in PAH-induced carcinogenesis (NAS, 1983). Numerous studies have examined various qualitative and quantitative aspects of the formation and the elimination of these adducts and their relation to carcinogenesis. It has been shown that administration of inducers of PAH-metabolizing enzymes to animals prior to BaP exposure reduces BaP metabolite-DNA adduct formation in vivo, although the opposite

effect occurs in vitro. These same inducers also sharply inhibit BaP carcinogenesis in animals. A consistent correlation does not exist, however, between the ability of a tissue to form adducts and its sensitivity to carcinogenesis (NAS, 1983). It has been shown in several studies that a dose-response relationship appears to exist between formation of PAH metabolite-DNA adducts and PAH exposure dose, and that there is no observed threshold. Based on these and other aspects of adduct formation, a committee of the NAS concluded that specific PAH metabolite-DNA adduct amounts are clearly a good measure of effective biologic dose that could be used for "low-dose extrapolation of carcinogenic data, for the ranking of a series of similiar carcinogens, and for determining the effect on neoplasia of pretreatments that alter the metabolism of a carcinogen" (NAS, 1983).

Numerous studies have shown that in addition to these enzyme inducers, antioxidants and certain other compounds are effective inhibitors of PAH-induced carcinogenesis. Among other compounds, this action has been demonstrated with selenium, alpha-tocopherol (Vitamin E), ascorbic acid (Vitamin C), butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA), flavones, Vitamin A, benzyl isothiocyanate, and phenethyl isothiocyanate (both the latter are found in cruciferous plants) (Santodonato, 1981).

Environmental exposures to PAHs almost always involve a complex mixture of PAHs (along with other compounds), and a few studies have examined the carcinogenic effects of mixtures of PAHs. Such mixtures offer the potential for various types of interactions such as synergism or antagonism. Studies reviewed by Santodonato (1981), and NAS (1983), indicate that such mixtures are frequently either inhibitory or have no effect on the activity of the carcinogenic PAHs present in the mixture.

For example, NAS (1983) cites data from Misfield that demonstrated that a mixture of 13 PAHs in proportions that simulate auto exhaust condensate, most of which were carcinogenic, was essentially similar to the BaP fraction alone in inducing skin tumors in mice. Data of Falk cited by Santodonato (1981), showed that when BaP was administered to mice together with various noncarcinogenic PAHs commonly found in polluted atmospheres, a marked inhibition of carcinogenesis was observed in all cases. Early studies of the effects of simple pairs of PAHs, however, show all possible interactions -- no effect, additive, antagonistic, and synergistic. In addition, it has been shown that the timing and sequence of application of the pair affects the outcome, further complicating the situation.

There is convincing evidence that heavy exposures to PAH-containing materials is etiologically associated with an excess of lung cancer. The best known and most common source of exposure is, of course, smoking. Although there remains little doubt that smoking is the overwhelming cause of lung cancer, it is less clear to what degree the PAHs in cigarette smoke contribute to the risk. As described previously, there have been a number of occupational epidemiologic studies that clearly demonstrate that very high workplace exposures to such PAH-containing mixtures as coal gas, tars, soot, and coke-oven emissions confers elevated risks of lung and other cancers (Santodonato, 1981; NAS, 1983; IARC, 1985). Individual PAH levels in such workplace environments show enormous variability but are frequently in the microgram/m^3 range or higher, and human exposure can thus be several orders of magnitude higher than from smoking (IARC, 1985). As in the case with smoking, it is difficult to determine to what degree the PAH component of the workplace air contributes to the risk.

Benzene: Benzene, a volatile aromatic hydrocarbon, is a colorless, clear liquid with a distinctive odor. It is produced principally from coal tar distillation, from petroleum by catalytic reforming of light naphtha, and in coal processing and coal coking operations. Benzene is readily absorbed through inhalation and, to a lesser degree, through the skin. As a lipid soluble compound it accumulates in fatty tissues (Brief, 1980).

Because of its utility, benzene is used in a wide variety of industries. Benzene exposure is likely to be highest in individuals employed in the petroleum, chemical, and rubber industries. It is also used as an adhesive in the shoe making industry; for rotogravure, lithographic and photographic printing; the manufacture of explosives, pesticides, plastics, detergents, conditioners, antioxidants, chemicals, and pharmaceuticals; and as a solvent in numerous processes (Fishbein, 1984). As recognition of benzene's toxicity has spread, toluene and other less toxic solvents have been substituted where possible.

The bone marrow toxicity of benzene has been recognized since early this century. While the mechanism of this toxicity has not been fully elucidated, benzene depresses bone marrow function with effects ranging from decreases in certain blood elements (white and red blood cells, platelets) to bone marrow suppression (aplastic anemia). On the basis of case reports and epidemiological studies of occupationally exposed workers, benzene has more recently been recognized as a leukemogen (i.e., leukemia causing agent) (Snyder, 1984).

A lack of scientific consensus exists concerning two major areas of benzene's leukemogenicity: 1) whether benzene causes all forms of leukemia, or only acute myelogenous leukemia; and 2) whether a threshold exists for its effects. Regarding the first controversy, acute myelogenous leukemia has been repeatedly associated with benzene exposure. Other

leukemias, including chronic myeloid leukemia, acute and chronic lymphocytic leukemia, and erythroleukemia, have been less frequently associated with benzene. One widely quoted study reported an association between chronic lymphocytic leukemia and exposure to solvents including benzene (McMichael, 1975). Probably the least evidence exists for a causal association between benzene and chronic myeloid leukemia (Goldstein, 1977). However, most epidemiologic studies to date have lacked sufficient statistical power to detect significant increases in these less common forms of leukemia.

The concentration of benzene necessary to cause leukemia is disputed. While no cases of leukemia have been documented in persons with exposures under 10 parts per million (ppm), risk estimates using assumptions of a linear dose-response relationship with no minimum threshold have predicted that even exposure to 1 ppm of benzene may result in leukemia (Infante, 1983). Other scientists have argued that leukemia develops only after exposures that are high enough to produce serious bone marrow damage, generally 40-50 ppm (VanRaalte, 1982). In either case, epidemiologic studies of benzene are unlikely to demonstrate an excess of leukemia unless benzene exposures are high or the cohort (group) is large.

SUMMARY OF THE HEALTH EFFECTS REVIEWED ABOVE:

Diesel Fuel and Exhaust	Diesel fuel contains benzene; whereas, upon combustion diesel exhaust contains polynuclear aromatic hydrocarbons (PAHs), nitro-PAH, and aromatic amines. These are the substances of potential concern. Recent studies have suggested that diesel exhaust exposure may be related to lung cancer. Other data have associated diesel fuel exhaust and bladder cancer, but the evidence is not conclusive. It is important to note that the organic compounds adsorbed onto diesel particles can be absorbed through the lungs into the bloodstream and, thus, other organ systems may be affected. Potential harmful effects to other organ systems have not been systematically investigated.

Asphalts and Tars	Both asphalts and tars contain PAH compounds although there is a much larger PAH content in coal tars. Asphalt materials are less carcinogenic than the coal tars with which they are frequently confused. Tumors and respiratory effects have been associated with asphalt exposure in laboratory animals. Human data suggest acute adverse effects in relation to asphalt exposure. The evidence that asphalt exposure alone is carcinogenic is inadequate at present. In contrast, human and animal observations have established that coal tars and other coal-derived products are both animal and human carcinogens.
Herbicides	Most commercial grades of herbicides contain some degree of toxic contamination, such as dioxins. Based on limited data, herbicide exposure has been associated with soft tissue sarcoma and malignant lymphoma (non-Hodgkin's). Increases in other cancers have been suggested; however, the evidence is more speculative.
Gasoline	Gasoline consists primarily of volatile hydrocarbons and may contain a small percent of benzene. Existing data indicate that exposure to gasoline vapors may cause kidney cancer. However, this association has not been firmly established.
Polynuclear Aromatic Hydrocarbons (PAHs)	Most research on the health effects of PAH exposure has focused on their carcinogenic potential. Normally proliferating tissues such as bone marrow are considered the major targets of PAH toxicity. A large body of research has shown that PAH compounds and PAH-containing mixtures are carcinogenic in a variety of animal species and by different routes of administration.
Benzene	Benzene has toxic effects on the bone marrow (e.g., decreases in certain blood elements or bone marrow suppression). In addition, benzene has been recognized as causing leukemia. It is not clear, however, whether benzene causes all forms of leukemia or what concentration of benzene is necessary to cause leukemia. Acute myelogenous leukemia has been repeatedly associated with benzene. No evidence currently exists for leukemias resulting from benzene exposures of less than 10 ppm; however, certain risk models support a conclusion that there is no safe dose of benzene.

NUMBER OF HIGHWAY WORKERS: Nationally, the number of past and current city, county, and state highway maintenance workers probably exceeds 500,000. Despite the large number of workers in this occupation, these workers had never been systematically studied. Based on the large number of workers in this occupation, the wide range of workplace exposures posing diverse health risks, and the unresolvable Wheaton findings, the MDH concluded that a large-scale mortality study of all state highway maintenance workers was necessary. Once the need for a study was established, the feasibility of conducting the study was addressed.

FEASIBILITY STUDY: The feasibility portion of this study was started in November 1984 and was completed in January 1985. During the feasibility study there was a comprehensive review of employment and retirement records and historical documents within the Minnesota Department of Transportation (MNDOT) and other state agencies. This effort was designed to determine if a cohort (group) of HMWs could be completely and accurately defined from existing records. In addition, an effort was made to clearly define potential job related exposures and the number of workers exposed. A sample of approximately 1,200 payroll and personnel records and several hundred historical documents were reviewed.

In order to study HMW mortality, it was first necessary to define a group of workers that could be located and identified as HMWs. This process included: 1) evaluation of accuracy and completeness of records; 2) estimation of cohort size and years of follow-up; 3) development of preliminary abstract forms to identify data gathering problems; 4) estimation of length of time to complete a study; and 5) estimation of study cost.

Based on a review of available data, it was estimated that there were between 5,000 and 7,000 HMWs who had worked at least one day since 1950 and that there were over 120,000 person years of follow-up. It was determined that the records were between 90-98 percent complete with no evidence of systematic losses that might bias a study. It was also determined that such a study would have sufficient statistical power to detect meaningful increases in the diseases of interest (e.g., leukemia).

In February 1985, the MDH recommended to the MNDOT and Council 6 of the American Federation of State County and Municipal Employees (AFSCME) that a study of HMW mortality was necessary and feasible. The study would require two years and cost $206,000, of which $58,000 could be contributed by the MDH. In April 1985, through an interagency agreement, the MNDOT provided the remaining $148,000 and finalization of the study protocol began.

Table 1-1. Polynuclear Aromatics in Different Bitumens and Coal-Tar Pitches

PAH, ppm	Formula	Bitumen Sample								Coal-Tar Pitch	
		A	B	C	D	E	F	G	H	A	B
Anthracene	$C_{14}H_{10}$	---	---	---	---	---	---	---	---	8,600#	10,000#
Phenanthrene	$C_{14}H_{10}$	2.3	0.4	3.5	1.3	0.6	35#	1.1	2.3#	31,000#	29,000#
Pyrene	$C_{16}H_{10}$	0.6	1.8	4.0	8.3	0.9	38	0.3	0.08	20,000	29,000
Fluoranthene	$C_{16}H_{10}$	+	+	2.0	+	+	5	---	---	40,000	43,000
Benzofluorenes	$C_{17}H_{12}$	+	+	+	+	+	+	+	---	7,300#	5,100#
Benz(a)anthracene	$C_{18}H_{12}$	0.15	2.1	1.1	0.7	0.9	35	0.2	---	8,900	12,500
Triphenylene	$C_{18}H_{12}$	0.25	6.1	3.1	3.4	3.8	7.6	1.0	0.3	1,500	1,100
Chrysene	$C_{18}H_{12}$	0.2	8.9	2.3	3.9	3.2	34	0.7	0.04	7,400	10,000
Benzo(a)pyrene	$C_{20}H_{12}$	0.5	1.7	1.3	2.5	1.6	27	0.1	---	8,400	12,500
Benzo(e)pyrene	$C_{20}H_{12}$	3.8	13	2.9	3.2	6.5	52	1.6	0.03	5,400	7,000
Benzo(k)fluoranthene	$C_{20}H_{12}$	+	---	+	+	+	---	---	---	7,100	9,000
Perylene	$C_{20}H_{12}$	---	39	2.2	6.1	2.9	3.0	0.1	---	2,000	3,300
Anthanthrene	---	---	---	Tr	Tr	Tr	+	1.8	---	---	1,300	2,100
Benzo(ghi)perylene	$C_{22}H_{12}$	2.1	4.6	1.0	1.7	2.7	15	0.6	Tr	3,200	3,300
Indeno(1,2,3-cd)pyrene	$C_{22}H_{12}$	Tr	---	Tr	Tr	Tr	1.0	---	---	7,300	9,300
Picene	$C_{22}H_{14}$	+	+	+	+	+	1.0	+	---	NE	2,000
Coronene	$C_{24}H_{12}$	1.9	0.8	0.5	0.2	0.9	2.8	0.9	---	700	700

Estimate includes alkyl derivatives
Tr Trace
NE Not estimated but present in substantial amount
\+ Not estimated but present in small amount
--- Not detected

Source: Wallcave, et al., 1971

2. METHODS

PROTOCOL DEVELOPMENT: An occupational cohort mortality study was the method used to investigate the mortality experience of Minnesota Highway Maintenance Workers (HMWs). A cohort is a group of individuals who share a common experience within a specified time period (Mausner, 1985). This study involved an occupational cohort comprised of all individuals employed by the Minnesota Department of Transportation (MNDOT) who were male, worked one or more years in highway maintenance type work, and worked at least one day after January 1, 1945. Ultimately, a comparison was made between the study cohort and all male Minnesotans of the same age and region of the state. The first phase of the HMW cohort study involved finalization of the study protocol.

Finalization of the study protocol began in April 1985 following funding of the study. The timeline for this study is shown in Figure 2-1. The months of April through June 1985 were spent comprehensively reviewing record sources, developing a complete list of HMW job titles, refining abstract forms, developing abstract protocols, and defining the structure of the data base to be used during the study. An outline of the entire cohort development and follow-up process is shown in Figure 2-2.

RECORD SOURCES: Seven record sources were used during this study: 1) microfiche of records for workers who terminated employment before 1978; 2) microfiche and inactive records of workers who terminated employment between 1978-1984; 3) active records; 4) district records; 5) the Minnesota State Retirement System (MSRS); 6) the Department of Employee Relations (DOÉR); and 7) state health departments. Each of these record sources is described below.

1. Microfiche Records Pre-1978: In 1978, in order to preserve payroll files, the MNDOT microfiched all payroll cards of retired workers and workers no longer with the MNDOT. The records that were microfiched included all past MNDOT/Department of Highways records available at the time of copying. These records included maintenance and construction workers, secretarial and other support staff. They also included old Highway Patrol records for the period before July 1970 when the Highway Patrol was part of the Department of Highways. Following microfiching, the paper records were destroyed. This set of microfiched records consisted of 57 acetate fiche. Each fiche consisted of payroll records organized alphabetically by name and chronologically for each worker. Each record normally contained name, address, sex, date of birth, work district, job titles, time period jobs were held, and salary history.

2. Microfiche and Inactive Records: MNDOT workers who left employment after 1978, but prior to the end of 1984, had payroll records that for the purposes of this study were also microfiched onto acetate fiche. Each payroll record consisted of one or more entries. Records were organized alphabetically by name and chronologically for each person. In addition, paper copies of each record were retained by MNDOT as a set of "inactive" records.

3. Active Records: Active records consisted of all payroll cards and personnel files maintained for current employees. Payroll cards consisted of index cards alphabetically organized by district. Maintenance and construction districts were filed separately. Active payroll cards contained data that were similar to those found in microfiche records.

4. District Records: District records consisted of all payroll and personnel files maintained by each of the 16 MNDOT districts on its workers. District records varied considerably in the amount of detail they contained. These records ranged from complete personnel files to small index cards that contained a name, address, date of birth, and a single job entry.

5. Minnesota State Retirement System (MSRS): The Minnesota State Retirement System maintained retirement and pension records on current and previous state employees. Workers were coded at MSRS according to the department in which they were working at the time they left state employment. MNDOT employees were always given a department code of 79. Highway maintenance workers were not distinguishable from other MNDOT employees.

MSRS has seven data sources. Each source contained approximately the same data on different employee groups (e.g., retired pre-1961, retired, and beneficiaries 1962-1975, etc.). Data available from these sources included all or part of the following: name, date of birth, social security number, dates of employment, and payments from the state retirement system.

6. Department of Employee Relations (DOER): The Department of Employee Relations had payroll records on all present and past state employees. These records existed primarily on microfilm.

7. State Health Departments: The MDH and other state health departments maintain vital records on residents of their respective states. These records were used to obtain death certificates on deceased members of the cohort.

JOB CLASSIFICATIONS: Job titles from old records were reviewed with Union and MNDOT officials to categorize work experience. Three job classifications were created as proxies for on the job experiences: 1) Highway Maintenance Worker (HMW) -- the individuals who in the course of their daily activities were involved in jobs ranging from fixing roads, maintaining rights of way, painting, cleaning, operating equipment, or any of the other jobs required to maintain roadways; 2) Light Equipment Operator (LEO) - the jobs involved in the operating of small equipment for the purposes of maintenance work. Included in this category were grader operator, light grader operator, etc. Most of the men in these jobs when not operating machines, were usually maintaining roads along with other HMWs; and 3) Other - this included jobs such as heavy truck or heavy tractor operators, as well as other jobs that did not directly involve maintaining highways (e.g., mechanic helper and highway technician).

Thus, for each job title and its corresponding time period an individual could be classified as either "HMW," "LEO," or "Other." To be eligible for the study a worker had to have worked for at least one year in highway maintenance type work (e.g., HMW and/or LEO).

Between the mid 1920s and late 1940s, many workers were given job titles that corresponded to the type of task that was done. Because highway maintenance tasks changed frequently, job titles also changed. This led to long lists of jobs that approximated the task done and changed as often as every 2-3 weeks.

Jobs such as man and team, dump man, mixer operator, truck operator, etc., are examples of the types of job titles that were thought to correspond to the type of work done. It was not initially clear from the title whether a job should have been classified as an HMW, LEO, or Other.

For example, a laborer II was a skilled trades helper, yet a maintenance laborer II was a HMW. The jobs driver 1, driver 2, first operator, power patrol operator, patrolman, and first driver are other examples of where the nature of the job was not known from the title.

Individuals working as either a driver 1 or driver 2 were thought to drive a team of horses. This type of work was done in the early 1930s and even later in some areas of the State. These workers were given a section of road or entire road which was theirs to maintain (i.e., duties similar to what was later called a section man). The man and team job title and patrolman were also considered to be comparable to a section man. Thus, the jobs driver 1, driver 2, first operator, power patrol operator, patrolman, and first driver were thought to be the same as a section man.

Concern has been expressed by some workers about their exposure to materials in MNDOT's bituminous plants. Numerous retired workers wanted bituminous workers placed in a separate exposure category. These were the workers who worked in bituminous plants for MNDOT. After a review of MNDOT records, only 21 out of 69 bituminous workers' records mentioned their bituminous work. It was concluded that bituminous workers could not be adequately identified from existing records. These workers were classified as HMWs.

Bridge workers were not included as HMWs for several reasons: (1) their primary work on bridge surfaces did not involve the use of asphalt materials; (2) there was minimal need for using herbicides; and (3) there was probably a greater use of leaded paints, welding materials, and blasting equipment. Bridge workers therefore had considerably different exposures than HMWs.

The type of work done by HMWs has remained relatively constant for the period between 1945 and the present. In Table 2-1, there are several descriptions of jobs for this time period. About 30-40% of the work during a given year was spent in snow related activities. Spring and summer activities included clearing debris, repairing road surfaces, and cleaning brush, and fall activities included finishing road repair and preparing for winter.

Using the above criteria a list of HMW and LEO jobs was defined (Table 2-2). Any individual who ever worked as a HMW and/or LEO as defined in Table 2-2 was abstracted during the study.

ABSTRACT & PROTOCOL DEVELOPMENT: Several forms and protocols were developed as part of the HMW study: 1) data abstract form and protocol; 2) quality control; and 3) tracing protocol The first two are summarized here.

Data Abstracting:

Minnesota HMW Abstract Form: Abstract development was an interactive process. At each iteration, a form was developed, multiple abstracts completed, and revisions made. The abstract form included basic demographic data, work dates, work history, and vital status (if known). The complete form is described in Appendix A-1.

Race was not included on the abstract form for several reasons: 1) It was only sporadically available in work records; 2) A review of 200 sequentially selected HMW death certificates revealed that all were "white", and 3) Minnesota was racially 99% white in 1950, 1960, and 1970, and 96% white in 1980.

Microfiche and Inactive Records: Prior to the start of abstracting, abstracters attended a comprehensive training session for one week. By the end of the week, each abstracter was required to complete several dozen error free abstracts representing the type of records included in the study. After passing the review, each abstracter was assigned one microfiche to work on until completed. Each abstracter worked approximately 4 hours per day. All abstracts were checked by the shift supervisor for errors. The complete set of abstracts for each fiche was then sent for data processing. This process continued until all fiche were completed.

Active Records: All payroll records at MNDOT-St. Paul were examined. Any person who ever worked as an LEO and/or HMW was abstracted. Each card was marked after it was reviewed to avoid missing workers.

District Records: All abstracts from active, inactive, and microfiche records were compared with district records in order to: 1) locate and abstract records that had not been abstracted; and 2) evaluate record completeness. Abstracts were updated when new work history and/or demographic data were found. New records were abstracted.

For each of the original abstracts compared to district records, a status of Found, Updated, or Not Found, was recorded. "Found" meant that a previously abstracted record was also found in district records but no new data were added. "Updated" meant that a previously abstracted record was located and the district record contained additional data such as social security number, date of birth, missing work history, or date of death. "Not found" meant a previously abstracted work record was not found in the district records.

Quality Control:

Data Accuracy: To eliminate or minimize errors, quality control procedures were used during data collection, entry, and analysis. During data abstracting, quality control took several forms: 1) error checking; 2) re-abstracting; 3) review for missed records; and 4) review of records for duplicate entries. A second quality control process was used to evaluate the completeness of the cohort. Steps included in the latter process included: 1) review of MSRS records; 2) review of DOER records; 3) review of district records (as described above); and 4) review of independent lists of workers (e.g., credit union records). After exhaustive review, it was determined that no complete and independent record source could be found. Each record source had data that were not available in the other three sources.

Error Checking: After each abstract was completed, it was reviewed by the data abstracter and the staff supervisor for consistency and completeness. For example, all dates had to be sequential and the date a worker left MNDOT had to be later than the date he started at MNDOT.

Following review by staff supervisors, abstracts were sent for data entry, where they were keyed and verified. Completed abstracts were then reviewed by computer for errors. Any abstract with an error was flagged by the computer and the location of the error in the abstract identified. A total of 93 possible errors were evaluated in this manner. Errors were corrected and the process was repeated until all abstracts were free of detectable errors. Examples of items that were checked for errors included: missing abstracter number; dates of birth that had a person working at age eighteen or less; a missing entry for sex; and chronological relationship of the job history.

Re-Abstracting: In order to evaluate the quality of data abstracts, a random sample of the original abstracts was evaluated for abstracting errors. During this process the abstract was compared with the original record. An item was considered in error if, in the opinion of the reviewer, a name, number, or date was entered incorrectly and the correct entry was obvious on the original record.

Missed Records: In order to be certain that no worker records were missed during abstracting, the first three lines of the odd and the last three lines of even numbered fiche were reviewed for missing workers. Because of the number of missing records (approximately 1.5% to 2.0%) found during the first review, all fiche, active and inactive records, were re-reviewed in their entirety for missing HMW/LEO workers. This was followed by a third review for missing records in which the fourth line of fiche, and inactive and active records were examined.

Record Cohort Completeness: Two sources were identified to determine cohort completeness: The Minnesota State Retirement System (MSRS), and the Department of Employee Relations (DOER). There were several issues associated with using the MSRS as an independent source with which to determine cohort completeness:

1) The exact type of work done by MNDOT employees found at MSRS was unknown. The MNDOT and the old Department of Highways were identified by department code number 79. However, type of work was not further identified. For this reason, a record listed as a "79" may have been that of a HMW, secretary, engineer, or any of the other jobs at the MNDOT;

2) Those who changed from one state department to another were listed as having worked in the last department in which they were employed;

3) The Department of Highways, now MNDOT, used to contain the State Patrol, now part of Public Safety;

4) Completeness of MSRS records could only be approximated. A sample of 158 records was abstracted from MSRS and compared with MNDOT records. The completeness of MSRS records with respect to the HMW cohort was also evaluated by searching for study members within the MSRS record system. Out of 782 HMWs/LEOs searched for at MSRS, 737 (94%) were found and 45 (6%) were not found.

Attempts were also made to find other independent listings of MNDOT personnel and/or HMWs. The sources that were evaluated included the State Credit Union, AFSCME Union offices, state tax offices, Minnesota Historical Society, and the Department of Employee Relations. Thus, multiple sources were used to create the HMW cohort.

Tracing: After completion of data abstracting all workers were traced to determine their vital status and, if deceased, to obtain their death certificates. The tracing process is outlined in Figure 2-3. During data abstracting, social security numbers were recorded when present. Workers were divided into two groups: those <u>with</u> and those <u>without</u> social security numbers. Those without social security numbers were sent to the Minnesota State Retirement System (MSRS) to search for social security numbers and vital status (e.g., alive or dead).

Workers for whom a social security number was available were sent to the Social Security Administration (SSA) to ascertain vital status. Those who were returned from the SSA with an unknown vital status and those

without a social security number were traced by other means, including the use of motor vehicle registration, the National Death Index (NDI), reverse directories, regional telephone directories, contacting coworkers, etc.

After a cohort member was found to be deceased, it was necessary to obtain his death certificate and abstract a numeric (nosologic) code for the underlying cause of death. For those dying in Minnesota, workers were matched by computer to death certificate information maintained by the Minnesota Center for Health Statistics and the original nosologic classification was obtained. Individuals who died in other states had the underlying cause of death abstracted off the death certificate if the nosologic code was clearly written. Workers who had no underlying cause of death recorded on their death certificate, had their cause of death coded according to the coding scheme in use during the year in which they died. All coding was done by a certified nosologist at the MDH.

DATA ANALYSIS:

Definition of SMR and PMR: Standardized mortality ratios (SMRs) were used to analyze mortality data for this cohort. The SMR is defined as the observed number of deaths among the cohort population divided by an estimate of the expected number of deaths from a standard population (Miettinen, 1981). In this instance, the mortality experience of HMWs was compared to the mortality experience of all Minnesotans of the same age, sex, calendar period, and region of the State. The equation for the SMR is:

SMR = Observed number of deaths/ Expected number of deaths

The estimate of the expected number of deaths for the HMW cohort was calculated by applying the age, sex, race, and time specific rates for the general population to the number of years of follow-up contributed by the

HMWs. Years of follow-up (person-years), take into consideration the number of individuals and the length of follow-up for each person. Follow-up in this study began January 1, 1945. Study participants contributed person-years of follow-up until death, until they were lost to follow-up (18 individuals) or until termination of the study (December 31, 1984).

Another statistic that was used to assess relative mortality was the proportionate mortality ratio (PMR). The PMR was computed by taking the ratio of the observed deaths for the cohort to the expected number of deaths determined from the Minnesota population. For a given cause, the number of observed deaths in the cohort was the same as the number of observed deaths used in computing the SMR. In contrast to the SMR however, the expected deaths were computed by applying the proportion of deaths due to the cause of interest in the Minnesota population to the total number of deaths in the cohort (Mausner, 1985). Age, sex, and date of death were also controlled in calculating the PMR. The PMR is not as useful as the SMR because by definition the all cause of death PMR is always equal to 1.0. The PMR is best used when it is not possible to compute the SMR (Miettinen, 1981). (See Appendix A-2 for an example of how to calculate a PMR and an SMR.)

ICD Classifications: The HMW Study spans four decades and five revisions of the International Classification of Diseases (ICD). The ICD is a set of standard codes used to classify causes of death according to rigidly defined rules. This coding has been used to standardize mortality data throughout the United States for many decades. The ICD manual has been in use in the United States since 1900, and it has been revised decennially in order to be consistent with changing medical knowledge, diagnostics, and

terminology. The dates when pertinent revisions were adopted and put into use in Minnesota are given in Table 2-3.

Each revision of the ICD manual presents difficulties in comparing cause specific mortality over time. Classification changes and differences in the rules used in selecting the underlying cause of death must be considered when comparing mortality data coded according to different versions of the ICD manual. For example, the fifth revision had a single classification for leukemia which included lymphatic leukemia, myeloid leukemia, and other leukemias (HEW ICD, 1939, 1948) . The sixth revision had separate classifications for lymphatic leukemia, myeloid leukemia, monocytic leukemia, and other leukemias. Therefore, an analysis of leukemia that includes deaths coded during the fifth revision must examine all leukemia deaths in aggregate, whereas, an analysis of leukemia deaths coded in the sixth or later version of the ICD can examine more specific cell types. Another illustration of the impact of changes in the rules for classifying the underlying cause of death is an apparent abrupt decline in mortality from diabetes observed in 1949. The majority of this deficit was attributed to the assignment of the underlying cause of death to arteriosclerotic heart disease when both diabetes and arteriosclerotic heart disease were listed on the death certificate (Mausner, 1985).

The method used in this study to code mortality data from different ICD revisions was to construct equivalent cause of death categories across the years spanned by ICD revisions. Causes of death coded by different ICD revisions were "translated" into a unique set of codes. As noted for leukemia, the level of specificity of these codes corresponds to that of the least specific revision. In the leukemia example, a single cause in an earlier revision was compared with several aggregated leukemia causes of death in later revisions.

The translation codes used in this study were a modified set of codes derived from the National Institute of Occupational Safety and Health (NIOSH) classification scheme dated 3/13/86 (NIOSH, personal communication). The NIOSH codes were changed primarily because of the availability of data in Minnesota in the 1940s for specific causes that were not available nationally. All codes and causes of death assigned to them were reviewed and compared to those used by Dr. Richard Monson of Harvard University (Monson, 1978). These categories of aggregated causes of death were used in assessing the relative mortality of the cohort population to that of the comparison population. A total of 142 categories were utilized. (See Appendix A-3 for a table of the codes and causes of death assigned to them.)

Comparison and Cohort Populations: It was essential to select the appropriate comparison population in assessing the relative mortality of the cohort. The best available comparison population for the HMW cohort was the male population of Minnesota. For most diseases, Minnesotans have lower mortality rates than the general population of the United States. For some diseases such as leukemia, the Minnesota mortality is higher than the United States. If the higher mortality rates of the United States were used to determine the expected number of deaths, the resultant number of expected deaths would have been greater (for most causes) which consequently would have produced a lower and misleading SMR. Therefore, a comparison of the mortality of the HMWs to the mortality of the entire United States would have masked real excesses of mortality in the HMWs.

Using Minnesota as a comparison population required that the state's existing mortality data be reformatted. Information derived from Minnesota death certificates was stored on magnetic tapes within the Minnesota Center

for Health Statistics. There were separate tapes for each year from 1945 through 1984. All deceased Minnesota residents and non-residents who died in the state of Minnesota were included on these tapes. Different coding schemes and record formats were used for different time periods. The coding schemes and record formats were redefined, necessary information extracted, and data reformatted using a common record format for all years. Next, a matrix containing the number of deaths categorized by 142 causes of death, age, sex, race, and geographic regions was created for each year. This matrix represented the aggregated causes of death for 1.3 million Minnesotans dating from 1945-1984. For analysis of the HMW study, the number of deaths by age and calendar period for white males was used.

Census data were compiled by age, race, sex, and geographic region as "denominators" for the calculation of mortality rates. The midpoints of the four calendar periods used in the study were census years, (i.e., 1950, 1960, 1970, and 1980). Therefore, the figures from the Minnesota census reports for the above years were used in estimating the numbers of Minnesota residents for these calendar periods in order to calculate the baseline mortality rates for Minnesota.

The cause of death for each HMW was translated into an equivalent cause of death category as described above. Additional information such as date of birth, last date of follow-up, work history, and vital status was maintained for each member of the cohort.

Subcohorts: Subsets of the cohort population were defined on the basis of job classifications. One subset comprised all workers regardless of job classifications. The other subset consisted of those workers who had only worked in the HMW job classifications throughout their employment. During the preliminary analysis, it was found that the mortality experience

of those classified in a subgroup including HMWs and/or LEOs did not differ from the mortality experience of HMWs only. Therefore, the LEO subgroup was not used during the analysis. Due to varying rates of mortality by region, both the cohort and comparison populations were divided into two regions: urban and rural. Individuals in the comparison population were classified as urban if they were residents of Hennepin County, Ramsey County, the city of Duluth, or the city of Rochester. All other individuals were classified as rural.

MNDOT records provided information on the district in which an individual worked. The HMWs were classified as urban if they worked in the Golden Valley or Oakdale district and rural if they worked in any other district. This classification was based on the first district in which a person worked. These classifications allowed comparisons of urban workers to an urban population and rural workers to a rural population.

After assembly of the cohort and comparison populations, data analyses were done using a computer program called M.O.R.T.AL. (Minnesota Occupational Risk Tabulating Algorithm). M.O.R.T.AL. was developed to provide interactive analysis of the occupational cohort mortality using a personal computer (IBM AT). The M.O.R.T.AL. program did both SMR and PMR analyses. The patterns of mortality were given by combinations of the following variables: age at death, calendar year of death, age started work, year started work, years worked, and latency. Latency represented the amount of time from when an individual first started work (i.e., first date as HMW or LEO) until death, loss to follow-up, or termination of the study).

M.O.R.T.AL. provided a number of statistical tests. In the tables described in the results section, 95% confidence limits for the SMR were given for statistics along the margins (column or row sums) of the tables.

Confidence limits specify a "probable" interval for the particular SMR, (e.g., the chance that the interval contained the "true" SMR). A common probabilty used is 0.95. Thus, there was a 95% chance that the interval contained the true SMR. In other words, if many independent studies were conducted and for each of these studies 95% confidence intervals were calculated, in the long run 95% of these intervals would contain the unknown true value (Brown, 1977). (Details of statistical methods and additional statistics and information provided by the program are in Appendix A-4).

After extensive evaluation and successful benchmarking against the established mainframe program of Dr. Richard Monson, M.O.R.T.AL. was used for all analyses presented in this report (Monson, 1974).

ENVIRONMENTAL MONITORING: Because industrial hygiene monitoring is a relatively new practice for most occupations, early environmental exposures to HMWs were estimated from present data and old purchasing records when available. The first industrial hygiene monitoring on HMWs in Minnesota was conducted by the Minnesota Occupational Safety and Health Administration (MN-OSHA) in 1981. Several investigations have been conducted by MNDOT and/or MN-OSHA since that date. In addition, MNDOT and the MDH undertook a cooperative evaluation of HMWs in August 1986. Each of these evaluations will be described briefly. Every attempt was made to eliminate jargon from this section; however, it was impossible to avoid the use of some chemical and product names.

July 8, 1981: The first MN-OSHA study was conducted in July 1981 as part of an evaluation of silk screening processes in Detroit Lakes. Silk screening of highway signs was done in the sign shop by two or three employees for approximately three hours each day. Breathing zone samples for xylene were collected.

Most of the signs were printed using a black ink containing petroleum distillates. Approximately one gallon of ink was used each week. This was the only ink in use at the time of the investigation. Employees stated that they occasionally used other, more offensive smelling inks, (MN-OSHA, September 1981).

August 1984: The next exposure report was dated August 27, 1984. This survey monitored bituminous paving activities in Virginia, Minnesota. The location of the workers in relation to the source of vapors was not indicated in the report. Breathing zone samples for total hydrocarbons were collected (MNDOT, October 1984).

November & December 1984: The general areas covered by this OSHA inspection were solvents, herbicides, and asphalts. The report noted that for the facility inspected (Wheaton), pesticides were applied by licensed applicators. Herbicide exposure data were not collected.

On the second day of this inspection, crack filling operations were evaluated. The process involved the heating of asphalt (AC-3) with a propane burner until the asphalt was liquified. The heated asphalt was maintained at approximately 300^{0} Fahrenheit (F). The asphalt was then dispensed onto the roadway from "sprinkle cans" with a 1/4 inch diameter spout. Two employees applied the AC-3 coat while one acted as a flagman. The workers rotated positions every half hour.

During the repair process, breathing zone samples were collected for benzene. Weather conditions on the day of sampling were inclement (winds of 10-25 miles per hour and a temperature of 10^{o} F) (MN-OSHA, January 1985).

March 1985: On March 3, 1985, a survey was done in Willmar, Minnesota during a crack filling operation. The survey was done to evaluate exposures to asphalt fumes, polynuclear aromatic hydrocarbons (PAHs), toluene, xylene, benzene, hexane, and petroleum distillates. In addition, procedures and equipment as well as explosion hazards were reviewed. The processes surveyed involved the heating of a naphtha containing cutback asphalt (RC-250) in a 600 gallon distributor and a 250 gallon kettle. The temperature of the asphalt was brought up to and maintained at 250^{o} F by use of a propane burner.

The first sample was taken six inches downwind from the kettle hatch while the asphalt was being heated. The hatch was left open slightly to vent. The wind was 3 mph, and the temperature was 30^{o} F. Two employees were present during this process. During the 1 1/2 hours needed to heat the asphalt, the workers periodically monitored the asphalt temperatures to assure proper equipment function. Their task did not involve opening the kettle hatch.

Once the asphalt reached the operating temperature, the kettle and distributor were towed to the work site. Eight employees worked in two crews of four. The kettle and distributor were used simultaneously about four miles apart. The operation required one person to drive the truck pulling the kettle/distributor. Another drove an "Early Warner" behind the operation and two people applied the asphalt. The RC-250 asphalt was dispensed onto the roadway from "sprinkle cans" with a single oriface

spout. The workers rotated positions approximately every 30 minutes. Breathing zone samples were collected on the employees applying the RC-250 asphalt during 5 1/2 hours of crack filling.

As the employees rotated, the air sampling equipment was transferred to the employee doing the crack filling. It was thought that this represented the maximum possible exposure. One additional sample was gathered downwind of the distributor about 12 inches from the hatch (MNDOT, May 1985).

March 18 and 27, 1986: A road patching operation in Virginia, Minnesota was evaluated for exposure to benzene solvents and total dust. MNDOT road patching on March 18 was performed as follows: First, there was broom cleaning of the cracks or holes in the road surface. After cleaning, an oil applicator applied a heated mixture of Murphy MC-250 liquid asphalt, (petroleum asphalt and #1 fuel oil) and Trumbull petroleum asphalt (petroleum asphalt and mineral spirits). Application was performed with a single orifice dispenser can which was usually filled by the oil applicator from a spout on the "tar kettle" trailer. The second step involved the application of the above mixture to which taconite tailings had been added. This "mix" was kept heated in the "patching" trailer and was shoveled from the trailer through a rear hatch by two employees who then applied it to the road surface. The asphalt "mix" piles were then raked into the cracks and holes to complete the process. Workers indicated that fumes arose when the heated asphalt made contact with the cool road surface as well as from the patching trailer hatch, especially when the mixing bin became empty near the end of the day.

On March 18, 1986, breathing zone samples were taken of the oil applicator and a patching trailer shoveler to determine their exposures to

benzene, hexane, petroleum distillates, toluene, xylene, and total particulates. It was thought these substances were good indicators for exposure to asphalt fumes. The above contaminants were also sampled for at the hatch opening of the patching trailer (one foot above the vertical opening). On this day, the patching operation was stopped at midday due to bad weather. Workers indicated that conditions were not "average" in that the asphalt in the patching trailer never reached the desired application temperature. Less than 70 minutes of personal sampling was obtained.

On March 27, 1986, sampling for the above contaminants was performed for an entire day's road activity. The ambient temperature ranged from 40^{0}-43^{0} F during the work shift with winds of 10-20 mph. The actual road applications began about 10:15 a.m. and ended about 3:15 p.m. with the remainder of the shift spent traveling to and from the work site. Workers indicated that conditions were representative of a typical day of road patching. Three workers: the oil applicator, a patching trailer shoveler, and the "mix" raker, were sampled for exposure to benzene, hexane, petroleum distillates, toluene, and xylene using personal sampling pumps and charcoal tubes. Samples were also taken at the patching trailer hatch opening (MN-OSHA, March 1986).

August 1986: On August 27, 1986, air sampling was conducted in the breathing zones of the paving operator and the screen operator during a resurfacing project. General air sampling and collection of bulk samples were also conducted.

Samples taken in the breathing zone of the screen operator and the paving operator were analyzed for pyrene, benz(a)pyrene, benz(a)anthracene, chrysene, dodecane, n-hexane, benzene, toluene, chlorobenzene, and other solvents. Bulk samples of MC70 Tack Coat, 23/41 modified bitumin, and AC

85/200 penetrating oil were analyzed for pyrene, benz(a)anthracene, chrysene, benz(a)pyrene, and dodecane.

On August 28, 1986, breathing zone samples were collected for two silk screen painters at the Detroit Lakes MNDOT facility. The Scotchlite 708 Green that was being used contained 10-15% aliphatic petroleum distillates, 5-10% aromatic petroleum distillates, less than 5% xylene, and less than 3% aliphatic alcohol. The Scotchlite Thinner that was used contained petroleum distillates and xylene.

At the time of sampling, employees were relying on local exhaust and general ventilation to control airborne contamination. The employees indicated that vapor odors were much stronger and some eye and respiratory irritation occured when they used other Scotchlite products, some of which contain isophorone and cyclohexanone (MDH, September 1986).

Bulk Samples: Two sets of bulk samples were analyzed for either benzene or polynuclear aromatic hydrocarbons. The first set of samples was submitted in December 1984 (MNDOT, June 1985) and the second set in August 1986 (MN-OSHA, 1985).

Figure 2-1 Highway Maintenance Worker Study Timeline

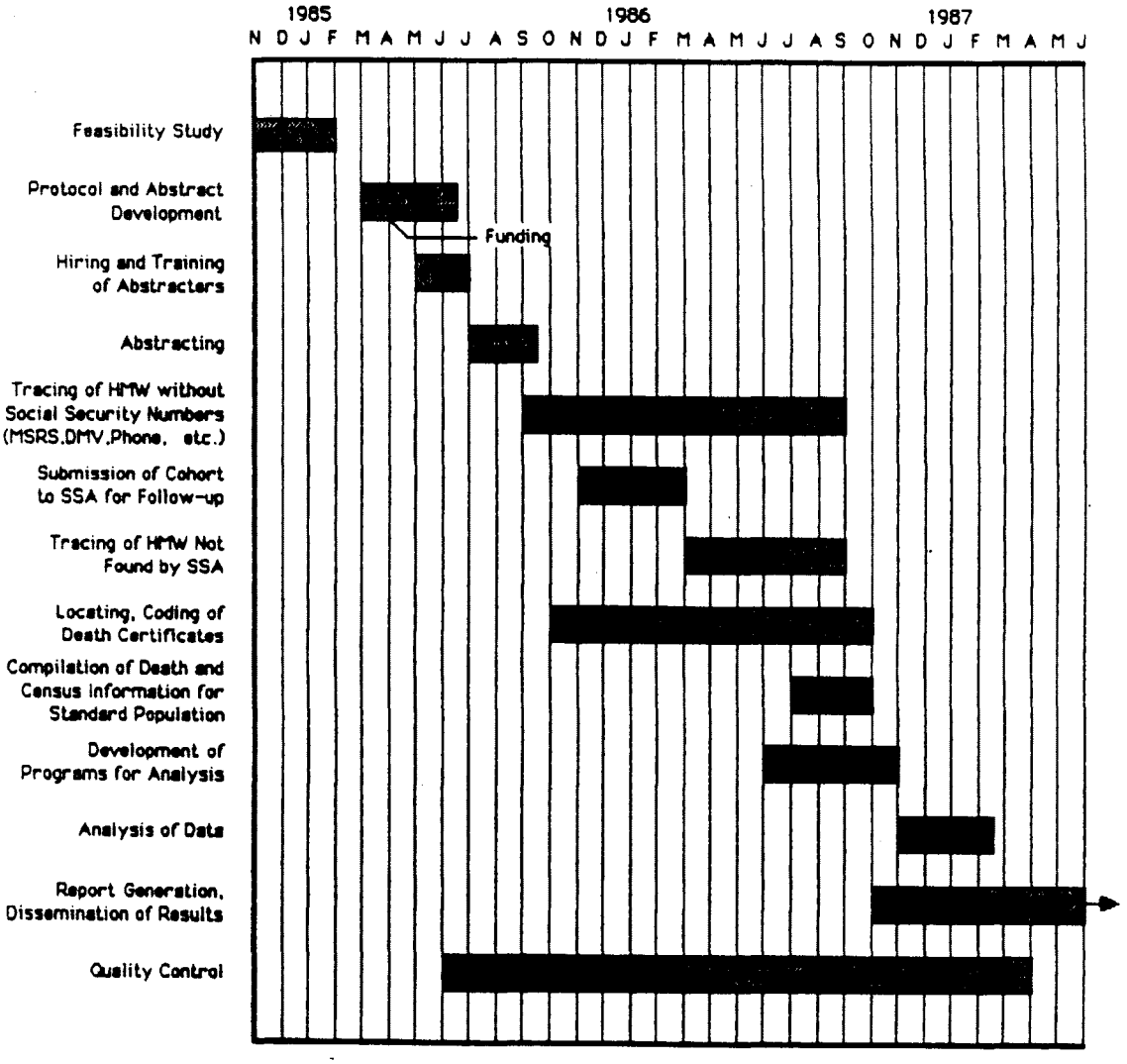


Figure 2-2 HMW COHORT DEVELOPMENT AND FOLLOW-UP SCHEMA

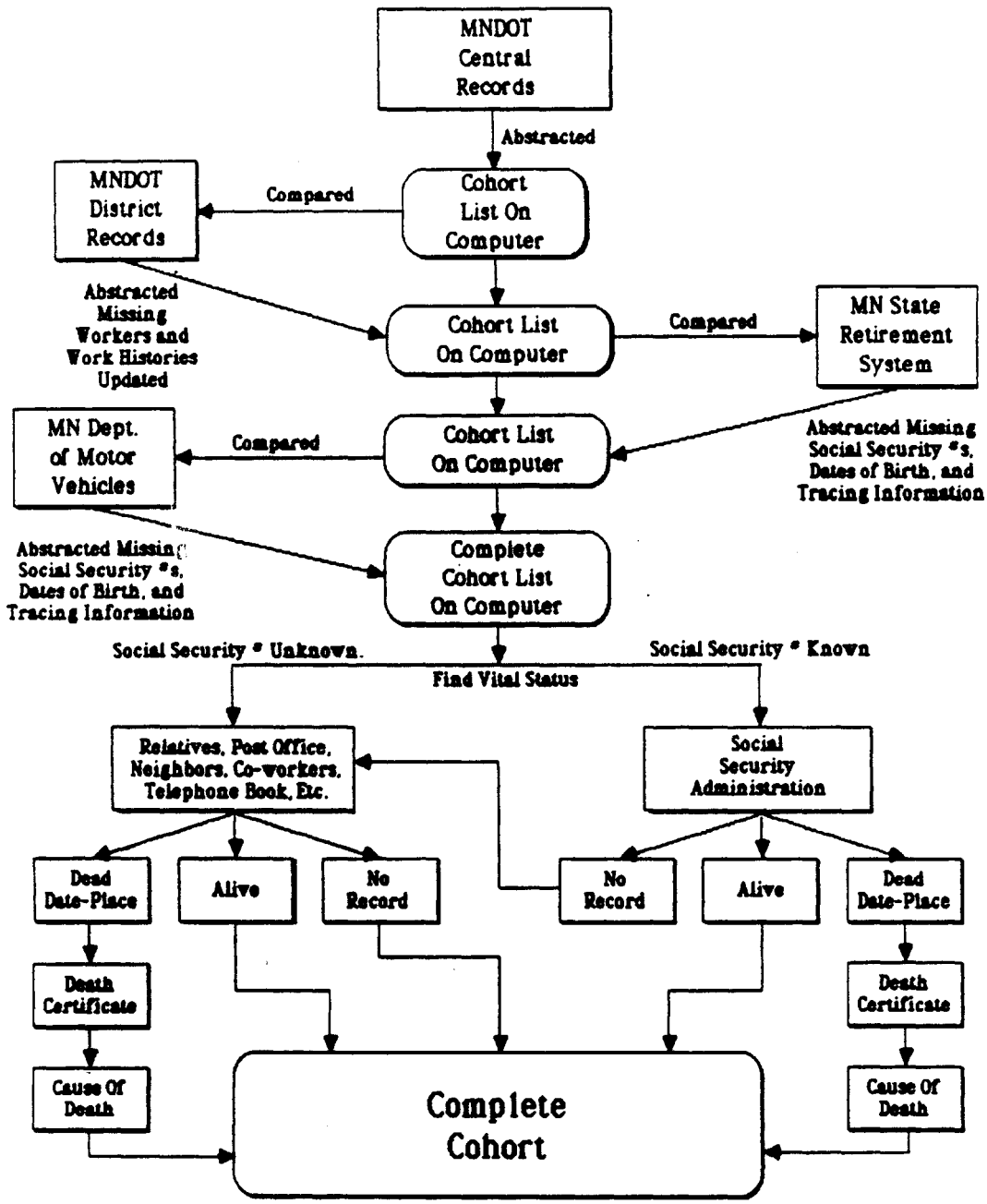


Figure 2-3. Schematic for Tracing Vital Status of Highway Maintenance Workers

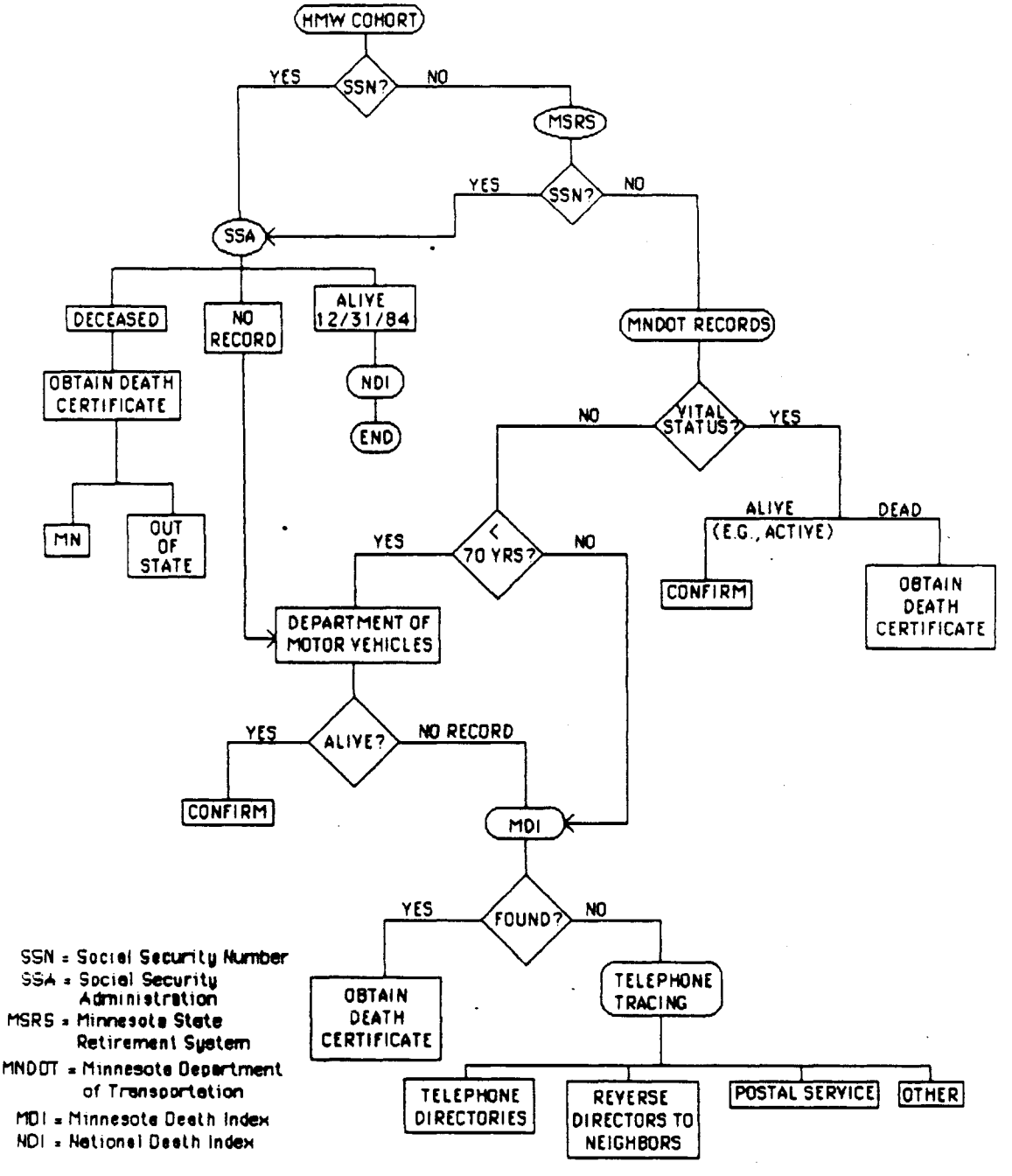


Table 2-1. Seasonal Variation of Highway Maintenance Work Between 1946 and 1980

Year	Job Title	Percent Time	Description
1946	HMM I	50	maintaining oil & gravel roads
		30	plowing snow
		10	cutting weeds & brush
		10	repairing road signs & equipment
1951	HMM I	22	patching
		20	snow removal
		11	putting up & taking down snow fences
		9	cutting weeds & moving guard rails
		5	repairing guard rails
		5	cutting brush
		3	ditching & draining water
		10	filling washouts
		9	repairing shoulders
		6	sanding
1960	HMM II	Not Stated	spring: drain water, fill cracks, repair shoulders, remove snow fences, and patch highways
			summer: patch highways, clean culverts, spray weeds, grass, and brush
			fall: prepare sand for winter, haul gravel, cut & clear brush
			winter: plow & shovel snow, sand where needed, cut brush
1972	HMW (Sr)	40	snow & ice control
		40	surface repair
		20	clearing debris, filling washouts, mowing grass, and miscellaneous
1980	HMW (Sr)	5	equipment maintenance
		40	keep roadway clear of ice & snow
		30	maintain safe driving conditions during summer months
		10	prepare for winter season, including clearing drainage systems, erecting snow fences and mixing sand & salt
		10	maintenance activities for damage done during the winter, including shoulder repair, washing signs, repairing guard rails, & placing flags
		5	ensure that MNDOT safety & administration requirements are met

Table 2-2. Complete Listing of HMW or LEO Job Titles

Highway Maintenance Worker (HMW)

Bituminous worker
CS Laborer
Driver 1
Driver 2
First Operator/First Driver
Freeway Maintenance Man
Freeway Maintenance Man 2
Helper
Highway Maintenance Man
Highway Maintenance Man I
Highway Maintenance Man II
Highway Maintenance Worker
Highway Maintenance Worker Sr.
Highway Section Helper
Highway Section Man
Inter. PHMF
Laborer
Laborer I (Does Not Include Laborer I In a Construction District)
Laborer I - Tenured
Maintenance Helper
Maintenance Laborer
Maintenance Laborer II (Not LaborerII)
Man and Team
Man and Truck
Misc. Laborer
Operator I
Patrolman
Power Patrol Operator
Second Operator
Section Helper
Section Man
Section Man II
Teamster

Light Equipment Operators (LEO)

Dump Man
Grader Operator
Heavy Equipment Operator-Intermittent
Landscape Maintenance Man
Light Grade Operator
Light Truck Operator
Machine Operator
Maintenance Equipment Operator
Mixer Operator
Power Grade Operator
Tractor Operator
Truck Driver
Truck Operator
Power Equipment Operator
Light Power Equipment Operator

Table 2-3. **International Classification of Disease (ICD) Used in Minnesota**

Revision Number	Years in Use
ICD5	1944 - 1949
ICD6	1950 - 1957
ICD7	1958 - 1967
ICD8	1968 - 1978
ICD9	1979 - present

3. RESULTS

COHORT DESCRIPTION: A total of 9406 workers were abstracted from MNDOT records. Of these, 4451 worked less than one year as a HMW and/or LEO or left MNDOT prior to January 1, 1945 (Figure 3-1). Another 35 workers were ineligible because they were female and 71 were either duplicate entries or were never HMWs/LEOs. A total of 4849 workers met all criteria for eligibility in the study (i.e., they worked at least one year as a HMW and/or LEO, were male, and worked at least one day after January 1, 1945).

Of the 4849 workers eligible for the study, 211 were initially found in district records and 4638 from records in St. Paul. The distribution of workers by the record source in which they were initially found is given in Table 3-1. It should be recalled, however, that district records were reviewed last and only newly identified HMWs or new information on previously identified HMWs were abstracted from them. The largest number of workers were located in microfiche records, followed by active records, inactive records, and finally district records.

The distribution of workers by the first district in which they worked is given in Table 3-2. The largest number of workers started in Golden Valley, and the fewest number of workers started in the districts of Crookston and Marshall.

During analysis, two groups served as proxies for potentially different work experiences: 1) All workers; and 2) HMW only. The group of "All workers" included all workers regardless of job classifications. "HMW only" included those workers who worked strictly in the HMW classifications throughout their employment. Each of these groups was subdivided into three subgroups -- state, urban, and rural (Table 3-3). The state group was the composite of the urban and rural groups. **Unless otherwise specified, all tables and figures refer to "all workers" for the**

entire state. As defined previously, urban workers were those who worked in Oakdale or Golden Valley and rural workers were defined as those who worked in all other districts.

Table 3-3 also contains the number of workers, average years worked, average age started work and the average year workers started employment with MNDOT. Approximately 1/3 of the cohort was urban and 2/3 of the cohort was rural. Rural workers in both categories worked longer than urban workers. They also tended to start work with MNDOT at an older age.

The total persons by age and year of entry into follow-up are given in Table 3-4. The first date of follow-up was January 1, 1945 or one year after a worker started at MNDOT. The largest number of workers entered the cohort during the 1960s and between their 20th and 30th birthdays.

QUALITY CONTROL AND TRACING:

Re-Abstracting: After all routine clerical and computerized data checks were completed, a stratified random sample of 371 records was evaluated for data accuracy. The following data items were evaluated: last name, social security number, date of birth, first date at MNDOT, and last date at MNDOT. As seen in Table 3-5, there was no field with more than 1.1% of the abstracts in error and for the last name there were no errors. The overall error rate was 0.2%.

Records Missed: During the initial review of the first 3 lines of odd numbered and the last 3 lines of even numbered fiche, 11 workers eligible for the study were missed (e.g., not abstracted). From the same fiche lines, a total of 500 HMWs/LEOs were identified. At this stage, it was estimated that between 1.5% and 2.0% of workers eligible for inclusion in the cohort were missed and this prompted another complete review. During

the second review of all active, inactive, and microfiche records, it was determined that 177 HMWs/LEOs were missed, and of these, 39 were eligible for the study.

During a final review, the fourth line of all microfiche and a sample of inactive and active records were reviewed and no eligible workers were missed. During this final random sample, 293 workers were evaluated, 185 were determined to be eligible for the study, and none were missed. Based on existing records the cohort was judged to be more than 99% complete, (i.e., over 99% of records of HMWs were included in this study).

District Record Comparisons: A cross-comparison was made between MNDOT (St. Paul) and district records (Table 3-6). All records from St. Paul were evaluated as having been found, not found, or updated. Found meant a record was located, but no new data were added; not found meant a record from St. Paul was not found among the district records; and updated meant new data were added. As seen in this table, 39.6% of records were found and needed no change, 50% were not found and 10.4% were updated.

Record (Cohort) Completeness: In a review of 158 randomly selected records from MSRS, 134 (85%) out of 158 MNDOT workers were employed sometime after January 1, 1945 A total of 70 (52%) of these 134 worked one or more years after January 1, 1945. Of these 70 workers, 61 (87%) were located in MNDOT records (Table 3-7). This 87% is, for two reasons, a low (worst case) estimate of cohort completeness: 1) It was unknown if a worker with department code 79 was a HMW or held another position within the MNDOT; and 2) When district records were sent by the MNDOT to the MDH, it was primarily records for maintenance districts that were sent. Thus, when a comparison was made between MSRS and MNDOT as many as two-thirds of district records may not have been evaluated.

Tracing: Figure 3-2 shows the results of cohort tracing. A total of 4326 (89.2%) of 4849 workers were sent to the Social Security Administration (SSA), and of those sent, 1078 (24.9%) were identified as deceased, 133 (3.1%) were not located, and 3115 (72.0%) were determined to be alive. A total of 523 (10.8%) of the 4849 workers were not sent to the SSA. For those not sent to the SSA, 418 (79.9%) were deceased, 16 (3.1%) had an unknown vital status, and 89 (17.0%) were alive. Thus, vital status was determined for 4831 (99.6%) out of 4849 workers. The methods used to determine the vital status of workers not sent to or not found by the SSA are also shown in Figure 3-2. In general, a comprehensive search of Minnesota death certificates was the most useful means of locating deceased cohort members. Either telephone tracing or motor vehicle records was the most useful means for locating living cohort members who were not identified by the SSA or had no social security number.

COHORT MORTALITY: As described in the methods section, the standardized mortality ratio or SMR is the ratio of observed deaths for a given cause to the expected number of deaths for that cause. The expected number of deaths was based on the mortality experience of other white Minnesota males of the same age and time period.

An SMR may be interpreted as follows: An SMR of 1.0 means that the observed number and expected number of deaths were equal. An SMR greater than 1.0 means that more deaths occurred than were expected, and an SMR less than 1.0 means that fewer deaths occurred than were expected. For example, an SMR of 1.2 means that 20% more deaths occurred than were expected, while an SMR of 0.7 indicates that there was a 30% deficit in the observed number of deaths compared to other Minnesotans.

The overall SMR in this cohort for all causes of death was 0.91 (Table 3-8). There were 1530 deaths among the 4849 HMWs during the forty-year period of study while 1676 deaths were expected. In other words, 146 fewer deaths occurred than were predicted. All three major categories of death contributed to this deficit. The SMR for all cancer deaths was 0.84 with a deficit of 54 deaths; the SMR for all heart disease was 0.93 with a deficit of 50 deaths and the SMR for cerebrovascular disease (e.g., stroke) was 0.80 with a deficit of 32 deaths.

It is common to find a lowered overall mortality when comparing an employed population to the general population. The factors which operate to exclude the less robust, less healthy members of a population from a work force is referred to as the "healthy worker effect." More will be said about this effect and its implications for the HMW study in the following discussion section.

As described in section 2, several subcohorts and corresponding comparison populations of HMWs were used in this study. Table 3-9 contains a summary of the overall SMRs for selected causes of death for all workers and "HMWs only" for the entire state, urban and rural regions. Each of the listed causes of death is explored in more detail below. The SMRs for all causes of death are listed in Appendix A-5.

The number of deaths (in parentheses in Table 3-9) become fairly small when distributed into these categories. Almost all of the summary SMRs in Table 3-9 range between 0.7 and 1.5. As a summary, the overall SMR may conceal substantial variation and information that is required for the interpretation of the HMW mortality experience. In addition, finding an SMR greater than 1.0 (or less than 1.0) does not imply that a true excess (deficit) exists, since some variation was expected on the basis of chance alone. For these reasons, overall SMRs may not be very informative. The

interpretation of the SMR is examined in more detail in the discussion section.

The tables presented in this report were selected from nearly 6,000 tables. A summary table was presented for all major categories of death. Several criteria were used to determine which other tables to present. If a particular cause of death was of interest before the study was conducted, it was automatically included. These causes included leukemia, pneumoconioses, accidents, and soft tissue cancers. If a cause of death had a summary (marginal) SMR that was significantly elevated or an SMR that increased with an increasing number of years worked, it was included. If a single result within a table was significantly elevated and that result contained 3 or more deaths, the table containing that result was included.

In presenting the analytic results, all SMRs were recorded to one decimal place for clarity, 95% confidence intervals for the marginal totals are given, and specific SMRs that were statistically significant at the 0.05 and 0.01 levels are noted. Due to rounding, the 95% confidence intervals may appear to include 1.0 when the significance of the SMR was at the 0.05 level.

All Causes of Death (Table 3-10): As indicated above, the overall SMR for all causes of death was 0.9. This SMR was significant at the 0.01 level and the reduced mortality experience was independent of the number of years worked. The HMWs that started work in 1955-1964 were the only group that experienced a small (nonsignificant) excess mortality (SMR = 1.1).

All Cancer (Table 3-11): There were 278 cancer deaths. The overall SMR for all cancer deaths was 0.8 ($p < 0.01$). There was no evidence of the SMR increasing with an increasing number of years worked or increasing latency.

The only time period for starting work for which the all cancer SMR was elevated was 1955-1964 with an SMR of 1.1.

Cancer of the Mouth and Pharynx (Table 3-12): There were 7 deaths from this cause. Those who worked 40 or more years had an SMR of 11.1($p < 0.05$). There were 2 deaths in this subgroup, and all of the risk was incurred by men starting work in the years 1900-1924. No elevations of the SMRs were found in men working 40 or more years who started work after 1925.

Cancer of the Digestive System (Table 3-13): This category included cancer of the esophagus, stomach, intestines, rectum, liver, and pancreas. The overall SMR was 0.8 with a total of 90 deaths. None of the SMRs for this general category were significantly elevated and no trend with increasing number of years work was observed.

For mortality due to intestinal cancer, the picture was very similar (Table 3-14). The SMR for all workers was 0.9 based on 30 deaths and there was no pattern of an increasing SMR with number of years worked or year started work.

Urban workers had a somewhat different profile (Table 3-15). Their overall SMR was 1.4 based on 11 deaths. For urban workers with 40-49 years of latency, there was an SMR of 5.8 ($p<0.05$) based on 3 deaths. All 3 of these deaths were due to colon cancer. Workers who started in 1935-1944 were the sole contributors to this SMR. There was some evidence of an increasing SMR with increasing latency.

Cancer of the Respiratory System (Table 3-16): The HMWs had an SMR of 0.7 ($p<0.05$) for lung cancer mortality and other cancers of the respiratory system. There was no trend of an increasing SMR with length of work or

with year started. Decreased respiratory cancer mortality was seen for both urban and rural highway maintenance workers as well.

Cancer of the Male Genital Organs (Table 3-17): Overall mortality due to cancer of the testis and prostate was not elevated (SMR = 1.0). However, based on 13 deaths, workers starting in 1955-1964 had a significantly elevated SMR of 3.3 ($p < 0.01$). As seen in Table 3-18, this increase was due to deaths from prostatic cancer. Table 3-19 demonstrates that the increase in prostatic cancer mortality was due to workers who started in 1955-1964 at the age of 40 or older. Curiously, men who started between 1935-1944 at the age of 40 or older had a significantly reduced SMR of 0.5 ($p < 0.05$).

Cancer of the Urinary Organs (Table 3-20): Cancers of the kidney, bladder, and other urinary organs had an SMR of 0.9 based on 19 deaths. No trends in the SMRs were apparent. However, based on 7 deaths, workers with 40-49 years of latency had an SMR of 2.9 ($p<0.05$) (Table 3-21). This was due to workers who started in 1935-1944 who had an SMR of 6.6 ($p < 0.01$). A nonsignificantly elevated SMR of 1.7 was found for workers who started 1925-1934. The increased SMR for workers with 40-49 years latency was contributed to by both kidney (Table 3-22) and bladder cancers (Table 3-23). The 6.4 SMR for bladder cancer for workers starting in 1935-1944 who also had 40-49 years latency was significant ($p<0.05$). SMRs did not increase with the number of years worked for either kidney or bladder cancer. A description of the urinary cancers is given in Table 3-24.

Cancer of Connective and Soft Tissue (Table 3-25): There were 2 deaths incorrectly coded as soft tissue cancers. Both were mesotheliomas and should have been coded to cancer of the respiratory system (Table 3-26).

Cancer of Hematopoietic System (Table 3-27): This category included the leukemias, lymphomas, Hodgkin's disease, and multiple myeloma. There were 34 deaths in this category with an overall SMR of 1.0. Based on 9 deaths, there was a significantly elevated SMR of 2.4 ($p < 0.05$) for individuals with 30-39 years of work experience. There was also a trend of increasing SMR with an increasing number of years worked.

There were 17 deaths from all leukemias during the 40 year follow-up (Table 3-28). The overall SMR was 1.1 and all of the deaths occurred in the last two decades (e.g., 1965-1974 and 1975-1984) with identical SMRs of 1.5. For the first 20 years, 4.7 deaths were expected and none occurred. There was no age predilection for leukemia mortality.

The increased SMR for hematopoietic malignancies seen in Table 3-27 is almost completely due to workers with 30-39 years of work experience that died of leukemias (Table 3-29). Based on 7 deaths, these workers had an SMR of 4.2 ($p < 0.01$) with contributions to this SMR from the workers that started in 1900-1924, 1925-1934, and 1935-1944. No deaths were observed for workers who started in 1945-1954; however, only 0.1 death was expected. No deaths were observed for workers with less than 5 years of experience while 3.3 deaths were expected. There was little evidence of an increasing SMR trend for leukemia with increasing years of work.

A similar picture of elevated leukemia mortality existed for both urban and rural workers. For workers with 30-39 years of work experience, the urban SMR was 16.0 ($p < 0.01$) (Table 3-30), based on 3 deaths and the rural SMR was 2.8 based on 4 deaths (Table 3-31). For workers that had

only HMW experience, 1 death occurred in individuals with 30-39 years of work. For all workers, there was little indication of an increasing SMR trend with latency (Table 3-32).

Table 3-33 contains a detailed description of the 17 workers that died of leukemia. When the 4 leukemia deaths included in this study that were part of the reported Wheaton cluster were excluded, the SMR for the workers with 30-39 years work experience was still 4.2. None of the 4 Wheaton workers worked more than 29 years. Epidemiologically, the Wheaton cluster did not contribute to the high risk profile for leukemia mortality. The distribution of leukemia deaths by type of leukemia for both the entire cohort and for workers with 30-39 years of experience, was similar to the expected distribution based on national statistics ($p > 0.1$).

The end of follow-up for this study was December 31, 1984. Deaths that occurred before this date were actively traced. During this tracing, deaths that occurred after December 31, 1984 were occasionally found and their documentation filed for later updates. Therefore, knowledge of the mortality experience of all workers after 1984 is incomplete. However, two additional leukemia deaths were identified among those who were known to have died after 1984. One person worked 32 years and started in the period 1945-1954. Another worked 19 years and started in the same time period. Using these data, it was possible, in a conservative manner, to update the leukemia mortality.

Assuming no other leukemia deaths occurred (which is not known) and that all workers alive on December 31, 1984 were also alive as of December 31, 1986 (which is certainly not true) estimates of the smallest SMRs for leukemia deaths for workers with 30-39 years of work experience were calculated (Table 3-34). The true SMRs must be larger since the number of leukemia deaths was at least 1 and the expected number of deaths was

inflated by assuming all workers lived another 2 years. The estimates of Table 3-34 indicate that the leukemia risk has not subsided for HMWs with 30-39 years of work.

Diabetes (Table 3-35): There were 30 deaths due to diabetes mellitus with an overall SMR of 1.2. For the years 1965-1974, 18 deaths occurred resulting in an SMR of 2.1 ($p < 0.01$) for these years. There were no indications of a relationship between deaths due to diabetes and the number of years worked or the year started work (Table 3-36). The overall SMR for urban workers was 1.9, and for rural workers the overall SMR was 1.0 (Table 3-9). For all workers for the years 1965-1974, the SMR for urban workers was 3.3 ($p < 0.05$) and the SMR for rural workers was 1.8.

Diseases of the Blood Forming Organs (Table 3-37): This category contains causes of death due to anemias and coagulation disorders. Five deaths occurred with a resultant SMR of 1.1. Two of these five deaths were aplastic anemias. One worker had 39 years of HMW experience and the other had 24 years of experience.

Diseases of the Nervous System and Sense Organs (Table 3-38): This category contains multiple sclerosis and other degenerative nervous system conditions. Fourteen deaths were observed and the overall SMR was 0.8. There were no trends in the SMRs with length of work or year started work.

Diseases of the Heart (Table 3-39): Diseases of the heart is a large category containing the most common causes of death for Minnesota males. For the HMW cohort, 677 out of 1530 deaths (44%) were attributed to heart disease. The overall SMR was 0.9 and several statistically significant ($p <$ 0.05) excesses and deficits were noted (Table 3-39). The 2.0 SMR for

workers that started in 1925-1934 and worked more than 40 years was due to ischemic heart disease (Table 3-40). Both urban and rural workers had similar patterns of ischemic heart disease (heart attack) mortality.

Chronic endocardial disease (disease of the heart valves) was listed as the cause of death for 10 workers (Table 3-41). These cases are listed in Table 3-42. The overall SMR was 1.6 with the major contribution coming from HMWs who had worked 10-19 years. For these workers, based on 6 deaths, the SMR was 3.4 ($p < 0.05$). All of the increased risk was accounted for by workers starting in 1925-1954. Since that time, no deaths have occurred in workers with 10-19 years experience. Table 3-43 demonstrates that this increased SMR was accounted for by workers starting after they were 40 years old. For this group, the SMR was 5.1 ($p < 0.01$). Identical patterns of mortality for chronic endocardial disease were observed for urban and rural workers (Table 3-9).

Diseases of the Circulatory System (Table 3-44): Diseases of the circulatory system included cerebrovascular disease (stroke) and arteriosclerosis. The overall SMR was 0.8 based on 189 deaths ($p < .05$). The SMRs for the men that worked 30-39 years was 0.6, and the SMR for the men that started work in 1945-1954 was 0.7. Both of the latter SMRs were significantly reduced ($p < 0.05$). For diseases of the arteries and veins (e.g., pulmonary emboli and aneurism), the overall SMR was 1.1 with an urban SMR of 0.6 and rural SMR of 1.4 (Table 3-9). Workers that started in the years 1900-1924 with 50 or more years latency had an SMR of 4.2 ($p < 0.05$) based on 4 deaths (Table 3-45).

Diseases of the Respiratory System (Table 3-46): This category includes influenza, pneumonia, bronchitis, emphysema, and pneumoconioses (dust related lung diseases). There were 107 deaths in this category and the

overall SMR was 1.0. There were no trends of the SMRs with number of years worked or the year started work. The overall SMR for emphysema was 0.94, for chronic bronchitis the SMR was 1.5, (Table 3-9) and for fibrotic and other lung diseases the SMR was 1.1 (Table 3-47). Of the 30 deaths in this latter category, 24 could be classified as chronic obstructive lung disease and 3 as pulmonary fibrosis (Table 3-48). Based on 8 deaths, the SMR for workers with 30-39 years of experience was 2.1 and this increase was restricted to the years of starting work from 1900-1944.

Diseases of the Digestive System (Table 3-49): Diseases of the digestive system included deaths due to ulcers, intestinal obstruction, and cirrhosis of the liver. The overall SMR was 0.8 based on 53 deaths. For workers starting in 1935-1944 with 20-29 years of experience, the SMR was 2.4 ($p < 0.05$) while for all workers starting in 1925-1934, the SMR was only 0.1 ($p < 0.01$). The overall SMR for cirrhosis was 0.8 (Table 3-9).

Diseases of the Genito-Urinary System (Table 3-50): Diseases of the genito-urinary system consisted primarily of deaths due to renal failure and infections of the urinary tract. The overall SMR was 0.8 based on 17 deaths. Nearly half of these deaths were due to chronic renal failure (Table 3-51). The largest increase was seen in rural workers (Table 3-52). Based on 3 deaths, workers with 50 or more years of latency had an SMR of 6.6 ($p < 0.05$). In addition, the SMRs were 0.0, 0.6, 1.3, and 1.8 for the decades 1945-1954, 1955-1964, 1965-1974, and 1975-1984, respectively. A description of the 8 deaths coded to chronic renal failure is given in Table 3-53.

Diseases of the Musculoskeletal System and Connective Tissue (Table 3-54): This category of diseases included arthritis and osteomyelitis (bone infections). Five deaths occurred in this category. The overall SMR was 1.5.

Accidents (Table 3-55): Accidents included deaths due to falls, poisoning, transportation mishaps, and other injuries. There were 97 deaths listed as accidents and the overall SMR was 1.2. There was an indication of an increasing SMR with the later years of starting work.

The overall SMR for deaths due to transportation accidents (e.g., boat, automobile, truck) was 1.4 ($p<.05$) (Table 3-56). Of the 53 deaths, 14 were determined from the death certificate to have occurred at work (Table 3-57). There was a trend of increasing SMR with the later years of starting work. However, Table 3-56 conceals several different trends; 1) The overall SMR for urban workers was higher than for rural workers. For urban workers, the SMR was 2.2 ($p< 0.01$) and for rural workers, the SMR was 1.1 (Table 3-9); 2) For urban workers 10 out of 17 deaths occurred among workers with less than 5 years experience (Table 3-58), (SMR = 2.8, $p< 0.05$); 3) In contrast, based on 6 deaths, rural workers with 30-39 years experience had an SMR of 3.2 ($p< 0.05$) This latter excess was accounted for by the experience of highway maintenance workers that started work in the period 1900-1944; and 4) There was an increasing trend of the SMRs for urban workers the later the decade of death. The SMRs for urban workers were 0.0, 0.7, 2.3, 3.8, ($p< 0.01$) for the years 1945-1954, 1955-1964, 1965-1974, and 1975-1984, respectively. This trend was not seen for rural workers.

For urban workers that were "HMWs only," there was a similar but more pronounced mortality trend with the year started work (Table 3-59). The

overall SMR for these workers was 3.3 ($p < 0.01$). The SMRs for these workers for the decades 1945-1954, 1955-1964, 1965-1974, and 1975-1984 were 1.4, 2.6, 5.0, and 21.4, respectively. For these same time periods, workers with less than 5 years of experience had SMRs of 0.0, 2.6, 4.7, and 24.1. Neither of these trends was seen for rural "HMWs only."

The overall SMR for "other" accidents (e.g., falls, drowning, electrocution) was 1.0 for the entire cohort, based on 44 deaths. There was no difference between all urban and all rural workers. The SMR increased to 1.2 when restricted to urban HMWs and to 1.1 for rural HWMs (Table 3-9). No trend was seen for age or decade in which a person started work or the total number of years worked (Tables 3-60, 3-61). Table 3-62 lists these individual deaths by cause. Ten of these deaths were reported on the death certificate to have occurred at work with the MNDOT.

Violence (Table 3-63): Violent deaths consisted of suicide and homicide. The overall SMR was 0.6 ($p < 0.05$) based on 16 deaths. The SMRs for year started work and length of work were all low.

Tuberculosis (Table 3-64): The SMR for tuberculosis was 0.8 based on 5 deaths.

ENVIRONMENTAL MONITORING: The results of environmental monitoring conducted for numerous substances between July 1981 and March 1985 are presented in Table 3-65. This monitoring evaluated a variety of processes in a variety of settings. None of the levels seen in the table exceeded OSHA guidelines. The petroluem distillate level of 1107 mg/m^3 (March 1985) was a sample obtained during the heating of asphalt. The area sampled was six inches downwind from the kettle hatch opening. The level obtained was slightly over one half of the threshold limit value (TLV).

Tables 3-66 through 3-69 show the results of environmental monitoring for March 27, 1986. These data are expressed in parts per million (ppm) in Tables 3-67 and 3-70. The TWA represents the average exposure over a period of time. None of the levels detected exceeded OSHA guidelines.

Table 3-70 gives the results of monitoring for xylene and petroleum distillates obtained from a sign shop during a silk screening process. The levels detected were well below OSHA guidelines. Table 3-71 shows the results of monitoring during a paving operation. Benzene, n-hexane, and chlorobenzene were not detected during this sampling. Breathing zone samples collected on a paving operator and a screen operator also failed to detect pyrene, benz(a)pyrene, chrysene, dodecane, terphenyl and hydrogen sulfide.

The results of analysis of bulk samples of asphalt are presented in Table 3-72. These samples were analyzed in late 1984. Bulk samples of MC-70 Tack Coat and 23/41 modified bitumen with AC 85/200 penetrating oil collected in 1986 had no detectable levels of benz(a)pyrene, benz(a)anthracene, pyrene, and chrysene. The MC-70 Tack Coat, however, contained 13,100 ppm of dodecane. No standard for dodecane has been established.

Figure 3-1 Determination of Cohort Eligibility

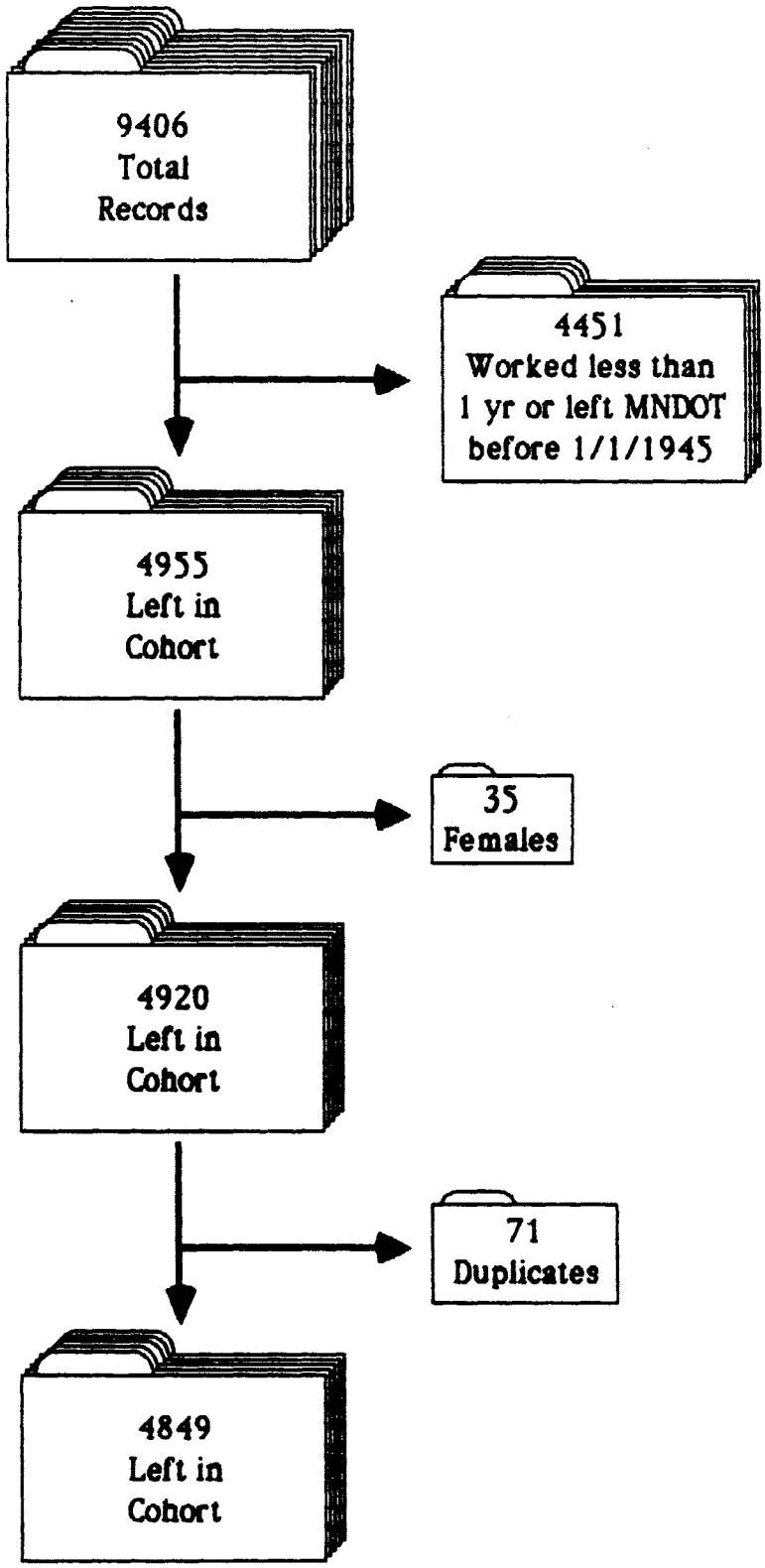


Figure 3-2. Vital Status and Record Source

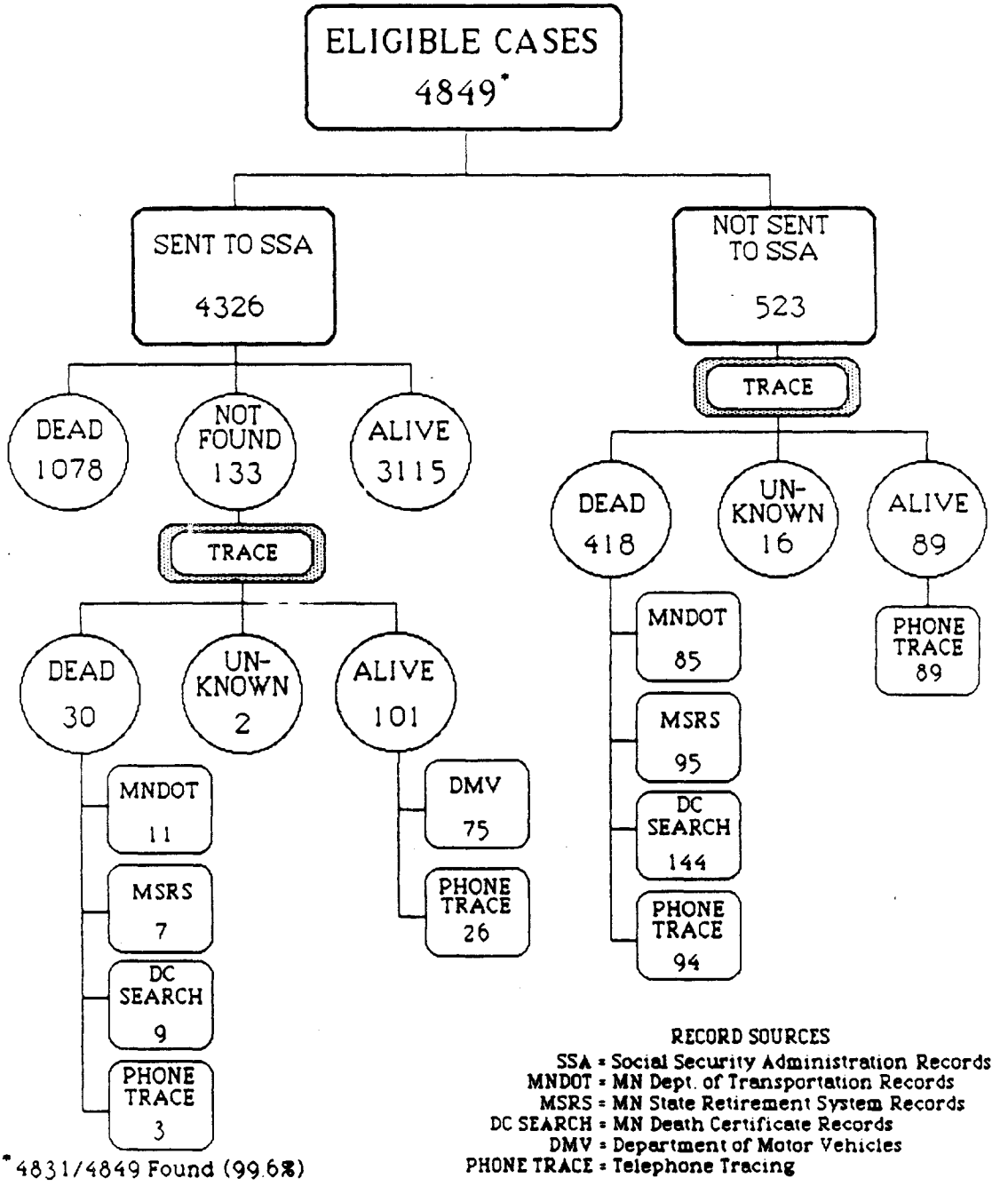


Table 3-1. Distribution of Eligible Workers by Record Source

RECORD SOURCE	NUMBER	PERCENT
MICROFICHE	2417	49.8
INACTIVE	705	14.5
ACTIVE PAYROLL	1516	31.3
DISTRICT ARCHIVES	211	4.4
TOTAL	4849	100.0

Table 3-2. **Distribution of Workers by the First Maintenance District in Which They Worked**

NAME	FIRST WORK DISTRICT	NUMBER	PERCENT
Duluth	1A	419	8.6
Virginia	1B	286	5.9
Bemidji	2A	183	3.8
Crookston	2B	173	3.6
Brainerd	3A	216	4.5
St. Cloud	3B	251	5.2
Detroit Lakes	4A	222	4.6
Morris	4B	181	3.7
Golden Valley	5A	799	16.5
Rochester	6A	296	6.1
Owatonna	6B	293	6.0
Mankato	7A	234	4.8
Windom	7B	213	4.4
Wilmar	8A	177	3.6
Marshall	8B	173	3.6
Oakdale	9A	709	14.6
Unknown	99	24	0.5
TOTAL		4849	100.0

Table 3-3. Description of Highway Maintenance Worker Cohort

Subgroup	Number of Workers	Years Worked Mean (SE)#	Beginning Age Mean (SE)	Ending Age Mean (SE)	Year Started Mean	Year Ended Mean	Person Years of Follow-Up
All (State)	4849	13.9 (.15)	35.3 (.17)	49.9 (.21)	1957	1972	96,567
All (Urban)	1508	11.3 (.22)	34.7 (.32)	46.5 (.38)	1963	1974	25,817
All (Rural)	3341	15.1 (.19)	35.5 (.20)	51.5 (.24)	1955	1971	70,750
HMW Only (State)	2094	8.5 (.16)	37.9 (.28)	47.0 (.34)	1959	1968	38,750
HMW Only (Urban)	818	7.6 (.21)	36.5 (.48)	44.5 (.56)	1964	1972	13,001
HMW Only (Rural)	1276	9.1 (.22)	38.7 (.35)	48.6 (.43)	1956	1966	25,749

SE = Standard Error

Table 3-4. Total Persons by Age and Year of Entry into Follow-Up

	YEAR								
Age	1945	1950	1955	1960	1965	1970	1975	1980	TOTAL
20	21	25	18	62	99	39	28	9	301
20 - 29	168	70	93	175	326	236	192	78	1338
30 - 39	344	77	101	177	238	104	69	58	1168
40 - 49	493	79	93	161	240	62	39	16	1183
50 - 59	389	54	47	65	90	29	11	8	693
60 +	117	8	17	11	10	0	2	1	166
TOTAL	1532	313	369	651	1003	470	341	170	4849

Table 3-5. Abstract Error Rate for Selected Data Items

Data Item	Number of Errors	% Error (N = 371)
Last Name	0	0.0
Social Security Number	1	0.3
Date of Birth	2	0.5
First Date at MNDOT	4	1.1
Last date at MNDOT	1	0.3
TOTAL	8	0.2

Table 3-6. Comparison of Work Records Abstracted at MNDOT (St. Paul) to District Records

District*	Number of Records		
	Found	Not Found	Updated
1A	128	156	57
1B	104	122	53
2A	93	67	16
2B	35	91	41
3A	107	62	41
3B	13	206	05
4A	87	89	29
4B	70	63	37
5A	403	299	78
6A	132	112	46
6B	130	149	10
7A	61	162	08
7B	32	172	06
8A	30	144	03
8B	75	77	16
9A	304	304	28
Total** (%)	1804(39.6)	2275(50.0)	474(10.4)

* See Table 3-2 for Name of Districts
** This number does not represent the entire cohort.

Table 3-7. Number of MNDOT Workers Abstracted from the MSRS and Located in MNDOT Personnel Records - for Workers Leaving State Service 1945-1984 and who Worked One or More Years (MSRS Department Code = 79)#

Total Work Time (Years)	Found in the MNDOT Records		
	Yes	No	Percent Found
1 - 2	3	4	43
2 - 5	7	1	88
5 - 10	7	2	78
10 +	44	2	96
Total	61	9	87

At the MSRS, no method existed to distinguish between workers who were HMWs and those employed in other jobs.

Table 3-8. Summary Standardized Mortality Ratios (SMR) and Proportional Mortality Ratios (PMR)

	Cause of Death	Number of Deaths	SMR	PMR	Adjusted PMR*
(99)+	Tuberculosis	5	0.79	1.07	0.97
(100)	Cancer of Mouth and Pharynx	7	0.88	0.95	0.86
(8)	Stomach Cancer	23	0.91	1.04	0.95
(9)	Intestinal Cancer	30	0.86	0.93	0.85
(13)	Pancreatic Cancer	17	0.89	0.96	0.87
(101)	All Gastrointestinal Cancer	90	0.82	0.91	0.83
(16)	Cancer of Lung and Bronchus	54	0.69	0.73	0.66
(102)	All Respiratory Cancer	57	0.69	0.73	0.63
(23)	Prostatic Cancer	38	1.00	1.08	0.98
(105)	All Male Genital Cancer	41	1.04	1.12	1.02
(27)	Bladder Cancer	12	1.09	1.19	1.08
(106)	All Urinary Cancer	19	0.92	1.00	0.91
(35)	Soft and Connective Tissue Cancer	2	1.41	1.48	1.35
(39)	Leukemia	17	1.07	1.16	1.06
(108)	All Hemolymphatic Cancer	34	0.95	1.02	0.93
(127)	**All Cancer**	278	0.84	0.91	0.83
(45)	Diabetes Mellitus	30	1.20	1.31	1.19
(111)	Anemias	5	1.14	1.24	1.13
(50)	Alcoholism	4	0.96	1.05	0.96
(54)	Rheumatic Heart Disease	14	0.91	1.06	0.96
(55)	Ischemic Heart Disease	601	0.96	1.05	0.96
(56)	Chronic Endocardial Disease	10	1.62	1.88	1.71
(114)	All Heart Disease	677	0.93	1.03	0.94
(61)	Cerebrovascular Disease	130	0.80	0.89	0.81
(62)	Diseases of Arteries and Veins	37	1.13	1.22	1.11
(66)	Penumonia	41	0.93	1.02	0.93
(67)	Chronic Bronchitis	7	1.47	1.63	1.48
(68)	Emphysema	19	0.94	1.02	0.93
(70)	Fibrotic and Other Lung Diseases	30	1.08	1.13	1.03
(73)	Cirrhosis	19	0.79	0.86	0.78
(76)	Chronic Renal Failure	8	1.06	1.20	1.09
(90)	Transportation Accidents	53	1.38	1.47	1.34
(92)	Accidental Falls	13	0.83	0.92	0.85
(93)	Other Accidents	44	1.05	1.41	1.28
(95)	Suicide	15	0.59	0.64	0.58
(125)	**All Causes of Death**	1530	0.91	1.00	0.91

+ N.O.R.T.AL. Code. See Appendix A-3.

* PMR for all causes of death must be 1.00. For comparison to SMR, PMR must be adjusted by multiplying PMR by 0.91.

Table 3-9. Summary Observed to Expected Ratios for Selected* Causes of Death, Minnesota Highway Maintenance Workers (HMW) 1945-1984

Cause of Death	Observed to Expected Mortality Ratios					
	All Workers++			HMW Only++		
	State (N=4849)	Urban (N=1508)	Rural (N=3541)	State (N=2094)	Urban (N=818)	Rural (N=1276)
(99)# Tuberculosis	0.79(5)**	0.00(0)	1.20(5)	0.39(1)	0.00(0)	0.63(1)
(100) Cancer of Mouth and Pharynx	0.88(7)	0.42(1)	1.22(6)	0.86(3)	0.00(0)	1.52(3)
(8) Stomach Cancer	0.91(23)	0.85(4)	0.92(19)	1.06(12)	1.10(3)	1.04(9)
(9) Intestinal Cancer	0.86(30)	1.39(11)	0.73(19)	1.16(18)	1.52(7)	1.04(11)
(13) Pancreatic Cancer	0.89(17)	1.11(5)	0.85(12)	1.06(9)	0.76(2)	1.23(7)
(101) All Gastrointestinal Cancer	0.82(90)	0.95(23)	0.81(67)	1.09(53)	1.00(14)	1.15(39)
(16) Cancer of Lung and Bronchus	0.69(54)	0.64(14)	0.78(40)	0.85(29)	0.80(10)	0.93(19)
(102) All Respiratory Cancer	0.69(57)	0.60(14)	0.79(43)	0.83(30)	0.75(10)	0.92(20)
(23) Prostatic Cancer	1.00(38)	1.38(10)	0.91(28)	1.20(21)	1.58(7)	1.07(14)
(105) All Male Genital Cancer	1.04(41)	1.32(10)	0.97(31)	1.22(22)	1.52(7)	1.11(15)
(27) Bladder Cancer	1.09(12)	0.82(2)	1.22(10)	1.00(5)	0.68(1)	1.18(4)
(106) All Urinary Cancer	0.92(19)	1.08(5)	0.91(14)	0.65(6)	0.74(2)	0.63(4)
(35) Soft and Connective Tissue Cancer	1.41(2)	0.00(0)	1.91(2)	0.00(0)	0.00(0)	0.00(0)
(39) Leukemia	1.07(17)	1.12(4)	1.07(13)	0.72(5)	0.49(1)	0.81(4)
(108) All Hemolymphatic Cancer	0.95(34)	1.00(8)	0.95(26)	0.70(11)	0.66(3)	0.73(8)
(127) All Cancer	0.84(278)	0.88(69)	0.86(209)	0.94(138)	0.90(41)	0.98(97)
(45) Diabetes Mellitus	1.20(30)	1.90(10)	1.03(20)	1.18(13)	1.65(5)	1.01(8)
(111) Anemias	1.14(5)	1.07(1)	1.16(4)	0.51(1)	1.83(1)	0.00(0)
(50) Alcoholism	0.96(4)	0.80(1)	1.12(3)	1.17(2)	0.00(0)	1.97(2)
(54) Rheumatic Heart Disease	0.91(14)	0.85(3)	0.99(11)	0.61(4)	1.51(3)	0.23(1)
(55) Ischemic Heart Disease	0.96(601)	1.03(141)	0.97(460)	1.00(278)	1.08(86)	0.98(192)
(56) Chronic Endocardial Disease	1.62(10)	1.67(2)	1.61(8)	2.19(6)	1.47(1)	2.43(5)
(114) All Heart Disease	0.93(677)	1.02(158)	0.94(519)	0.98(316)	1.06(96)	0.97(220)
(61) Cerebrovascular Disease	0.80(130)	0.86(25)	0.78(105)	0.90(67)	0.91(16)	0.89(51)
(62) Diseases of Arteries and Veins	1.13(37)	0.61(5)	1.41(32)	0.89(13)	0.41(2)	1.19(11)
(66) Pneumonia	0.93(41)	0.32(3)	1.16(38)	1.00(20)	0.18(1)	1.37(19)
(67) Chronic Bronchitis	1.47(7)	0.92(1)	1.72(6)	1.86(4)	0.00(0)	2.78(4)
(68) Emphysema	0.94(19)	1.02(5)	0.98(14)	0.55(5)	0.99(3)	0.34(2)
(70) Fibrotic and Other Lung Diseases	1.08(30)	1.31(9)	1.06(21)	1.13(14)	1.24(5)	1.11(9)
(73) Cirrhosis	0.79(19)	1.04(8)	0.78(11)	0.90(9)	1.23(5)	0.73(4)
(76) Chronic Renal Failure	1.06(8)	1.40(2)	0.97(6)	0.61(2)	1.24(1)	0.40(1)
(90) Transportation Accidents	1.38(53)	2.23(17)	1.13(36)	1.71(27)	3.30(13)	1.18(14)
(92) Accidental Falls	0.83(13)	0.77(3)	0.93(10)	0.57(4)	0.45(1)	0.67(3)
(93) Other Accidents	1.05(44)	0.98(9)	1.07(35)	1.12(20)	1.20(6)	1.09(14)
(95) Suicide	0.59(15)	0.61(4)	0.57(11)	0.77(8)	1.18(4)	0.56(4)
(125) All Causes of Death	0.91(1530)	0.96(354)	0.93(1176)	0.99(732)	1.02(218)	0.99(514)

* See Appendix A-5 for complete summary.

\# M.O.R.T.AL. Code. See Appendix A-3.

++ "All Workers" are HMW that worked in jobs other than those defined as highway maintenance work. "HMW only" are individuals that spent all of their employment in highway maintenance work. See Table 2-2 for detailed definition of job categories.

** Observed Number of deaths.

Table 3-10. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for All Causes

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.8(26)	0.9(43)	0.5(13)**	0.7(82)**	(0.6, 0.7)
1925 - 1934	0.4(1)	0.9(3)	0.7(37)*	0.9(115)	0.8(75)	1.2(21)	0.9(252)*	(0.8, 1.0)
1935 - 1944	1.0(139)	0.8(117)*	0.9(197)	1.1(119)	1.2(33)	0.0(0)	1.0(605)	(0.9, 1.1)
1945 - 1954	0.9(65)	0.8(46)	0.8(85)*	0.7(31)*	0.6(4)	---	0.8(231)**	(0.7, 0.9)
1955 - 1964	1.1(73)	1.0(63)	1.1(86)	1.3(20)	---	---	1.1(242)	(1.0, 1.2)
1965 - 1974	0.9(43)	0.9(34)	1.1(36)	---	---	---	1.0(113)	(0.8, 1.2)
1975 - 1984	1.0(5)	0.0(0)	---	---	---	---	0.8(5)	(0.3, 1.9)
TOTAL	1.0(326)	0.9(263)*	0.9(441)*	0.9(311)	0.9(155)	0.8(34)	0.9(1530)**	
(95% Confidence Interval)	(0.9, 1.1)	(0.8, 1.0)	(0.8, 1.0)	(0.8, 1.0)	(0.8, 1.0)	(0.6, 1.1)	(0.8, 0.9)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-10. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for All Causes

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.8(26)	0.9(43)	0.5(13)**	0.7(82)**	(0.6, 0.7)
1925 - 1934	0.4(1)	0.9(3)	0.7(37)*	0.9(115)	0.9(75)	1.2(21)	0.9(252)*	(0.8, 1.0)
1935 - 1944	1.0(139)	0.8(117)*	0.9(197)	1.1(119)	1.2(33)	0.0(0)	1.0(605)	(0.9, 1.1)
1945 - 1954	0.9(65)	0.8(46)	0.8(85)*	0.7(31)*	0.6(4)	---	0.8(231)**	(0.7, 0.9)
1955 - 1964	1.0(73)	1.1(63)	1.1(86)	1.3(20)	---	---	1.1(242)	(1.0, 1.2)
1965 - 1974	0.9(43)	0.9(34)	1.1(36)	---	---	---	1.0(113)	(0.8, 1.2)
1975 - 1984	1.0(5)	0.0(0)	---	---	---	---	0.8(5)	(0.3, 1.9)
TOTAL	1.0(326)	0.9(263)*	0.9(441)*	0.9(311)	0.9(155)	0.8(34)	0.9(1530)**	
(95% Confidence Interval)	(0.9, 1.1)	(0.8, 1.0)	(0.8, 1.0)	(0.8, 1.0)	(0.8, 1.0)	(0.6, 1.1)	(0.8, 0.9)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-11. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for All Cancers

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.7(4)	0.4(4)	0.6(3)	0.5(11)*	(0.2, 0.9)
1925 - 1934	0.0(0)	0.0(0)	0.4(4)	1.0(22)	1.0(19)	0.3(1)	0.8(46)	(0.6, 1.1)
1935 - 1944	1.1(27)	0.6(14)*	0.8(30)	0.9(20)	1.3(9)	0.0(0)	0.9(100)	(0.7, 1.1)
1945 - 1954	0.5(8)	0.4(5)	0.6(14)	1.1(12)	0.5(1)	---	0.7(40)**	(0.5, 1.0)
1955 - 1964	0.9(12)	1.0(13)	1.3(25)	1.2(5)	---	---	1.1(55)	(0.8, 1.4)
1965 - 1974	0.6(6)	0.9(8)	1.3(11)	---	---	---	0.9(25)	(0.6, 1.3)
1975 - 1984	1.1(1)	0.0(0)	---	---	---	---	0.9(1)	(0.0, 5.0)
TOTAL	0.8(54)	0.7(40)*	0.9(84)	1.0(63)	0.9(33)	0.4(4)	0.8(278)**	
(95% Confidence Interval)	(0.6, 1.0)	(0.5, 1.0)	(0.7, 1.1)	(0.8, 1.3)	(0.6, 1.3)	(0.1, 1.0)	(0.7, 0.9)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-12. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Cancer of Mouth, Pharyngal Cavity

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	20.6(2)**	4.8(2)	(0.6, 17.3)
1925 - 1934	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1935 - 1944	1.7(1)	0.0(0)	1.3(1)	0.0(0)	0.0(0)	0.0(0)	0.8(2)	(0.1, 2.9)
1945 - 1954	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	---	0.0(0)	(---)
1955 - 1964	2.7(1)	0.0(0)	1.9(1)	0.0(0)	---	---	1.4(2)	(0.2, 5.0)
1965 - 1974	3.4(1)	0.0(0)	0.0(0)	---	---	---	1.2(1)	(0.0, 6.7)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	1.8(3)	0.0(0)	0.9(2)	0.0(0)	0.0(0)	11.1(2)*	0.9(7)	
(95% Confidence Interval)	(0.4, 5.3)	(---)	(0.1, 3.2)	(---)	(---)	(1.3, 40.1)	(0.4, 1.8)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-13. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Cancer of Digestive System

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.9(2)	0.0(0)	0.0(0)	0.3(2)*	(0.0, 1.1)
1925 - 1934	0.0(0)	0.0(0)	0.3(1)	1.4(11)	0.9(5)	0.0(0)	0.9(17)	(0.5, 1.4)
1935 - 1944	1.1(10)	0.7(7)	0.7(9)	0.8(6)	1.0(2)	0.0(0)	0.8(34)	(0.6, 1.1)
1945 - 1954	0.6(3)	0.5(2)	0.7(5)	0.9(3)	0.0(0)	---	0.7(13)	(0.4, 1.2)
1955 - 1964	1.0(4)	1.0(4)	0.9(5)	1.7(2)	---	---	1.0(15)	(0.6, 1.6)
1965 - 1974	0.7(2)	0.8(2)	2.2(5)	---	---	---	1.2(9)	(0.6, 2.3)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	0.9(19)	0.8(15)	0.8(25)	1.1(24)	0.6(7)	0.0(0)	0.8(90)	
(95% Confidence Interval)	(0.5, 1.4)	(0.4, 1.3)	(0.5, 1.2)	(0.7, 1.6)	(0.2, 1.2)	(---)	(0.6, 1.0)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-14. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Intestinal Cancer

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1925 - 1934	0.0(0)	0.0(0)	0.0(0)	2.4(6)	0.0(0)	0.0(0)	1.0(6)	(0.4, 2.2)
1935 - 1944	1.1(3)	0.7(2)	0.7(3)	0.8(2)	1.4(1)	0.0(0)	0.9(11)	(0.4, 1.6)
1945 - 1954	0.7(1)	0.8(1)	0.9(2)	0.0(0)	0.0(0)	---	0.6(4)	(0.2, 1.5)
1955 - 1964	0.8(1)	0.8(1)	1.0(2)	4.8(2)	---	---	1.2(6)	(0.4, 2.6)
1965 - 1974	0.0(0)	1.2(1)	2.3(2)	---	---	---	1.1(3)	(0.2, 3.2)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	0.8(5)	0.8(5)	0.9(9)	1.4(10)	0.3(1)	0.0(0)	0.9(30)	
(95% Confidence Interval)	(0.3, 1.9)	(0.2, 1.9)	(0.4, 1.7)	(0.7, 2.6)	(0.0, 1.7)	(---)	(0.6, 1.3)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-15. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Latency for Intestinal Cancer, Urban Workers

	Latency (years)								
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40 - 49	50+	Total	(95% Confidence Interval)
1900 - 1924	---	---	---	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1925 - 1934	---	---	0.0(0)	0.0(0)	3.8(1)	0.0(0)	0.0(0)	1.2(1)	(0.0, 6.7)
1935 - 1944	0.0(0)+	0.0(0)	2.2(1)	0.0(0)	0.0(0)	14.9(3)**	---	2.1(4)	(0.6, 5.4)
1945 - 1954	0.0(0)	0.0(0)	0.0(0)	1.4(1)	3.7(1)	---	---	1.2(2)	(0.1, 4.3)
1955 - 1964	0.0(0)	3.5(1)	1.0(1)	1.9(1)	---	---	---	1.6(3)	(0.3, 4.7)
1965 - 1974	0.0(0)	0.0(0)	1.2(1)	---	---	---	---	0.7(1)	(0.0, 3.9)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	---	0.0(0)	(---)
TOTAL	0.0(0)	1.1(1)	1.1(3)	1.0(2)	1.8(2)	5.8(3)*	0.0(0)	1.4(11)	
(95% Confidence Interval)	(---)	(0.0, 6.1)	(0.2, 3.2)	(0.1, 3.6)	(0.2, 6.5)	(1.2, 17.0)	(---)	(0.7, 2.5)	

\+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-16. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Cancer of the Respiratory System

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1925 - 1934	0.0(0)	0.0(0)	0.0(0)	0.2(1)	1.1(5)	0.9(1)	0.6(7)	(0.2, 1.2)
1935 - 1944	0.9(5)	1.2(5)	0.7(5)	1.2(7)	0.4(1)	0.0(0)	0.9(23)	(0.6, 1.4)
1945 - 1954	0.5(2)	0.4(1)	0.6(3)	1.1(4)	0.0(0)	---	0.6(10)	(0.3, 1.1)
1955 - 1964	0.8(3)	0.5(2)	0.9(6)	0.7(1)	---	---	0.8(12)	(0.4, 1.4)
1965 - 1974	0.3(1)	1.0(3)	0.0(0)	---	---	---	0.4(4)	(0.1, 1.0)
1975 - 1984	3.8(1)	0.0(0)	---	---	---	---	3.0(1)	(0.1, 16.7)
TOTAL	0.7(12)	0.8(11)	0.6(14)*	0.8(13)	0.6(6)	0.4(1)	0.7(57)**	
(95% Confidence Interval)	(0.4, 1.2)	(0.4, 1.4)	(0.3, 1.0)	(0.4, 1.4)	(0.2, 1.3)	(0.0, 2.2)	(0.5, 0.9)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-17. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Cancer of the Male Genital Organs

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	1.2(1)	1.4(2)	0.0(0)	1.0(3)	(0.2, 2.9)
1925 - 1934	0.0(0)	0.0(0)	0.0(0)	0.9(3)	0.8(2)	0.0(0)	0.7(5)	(0.2, 1.6)
1935 - 1944	0.6(2)	0.0(0)	0.9(5)	1.0(3)	1.4(1)	0.0(0)	0.7(11)	(0.4, 1.3)
1945 - 1954	1.4(2)	0.7(1)	0.7(2)	1.0(1)	0.0(0)	---	0.9(6)	(0.3, 2.0)
1955 - 1964	2.0(2)	2.5(3)	4.6(7)**	3.8(1)	---	---	3.3(13)**	(1.8, 5.6)
1965 - 1974	0.0(0)	4.1(2)	2.0(1)	---	---	---	1.8(3)	(0.4, 5.3)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	1.0(6)	0.9(6)	1.3(15)	1.0(9)	1.0(5)	0.0(0)	1.0(41)	
(95% Confidence Interval)	(0.4, 2.2)	(0.3, 2.0)	(0.7, 2.1)	(0.4, 2.1)	(0.3, 2.3)	(---)	(0.7, 1.4)	

\+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-18. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Prostate Cancer

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	1.2(1)	1.4(2)	0.0(0)	1.0(3)	(0.2, 3.0)
1925 - 1934	0.0(0)	0.0(0)	0.0(0)	0.9(3)	0.8(2)	0.0(0)	0.7(5)	(0.2, 1.6)
1935 - 1944	0.7(2)	0.0(0)	0.7(4)	1.0(3)	1.4(1)	0.0(0)	0.6(10)	(0.3, 1.1)
1945 - 1954	1.5(2)	0.8(1)	0.7(2)	1.0(1)	0.0(0)	---	0.9(6)	(0.3, 2.0)
1955 - 1964	1.1(1)	1.8(2)	4.8(7)**	4.0(1)	---	---	3.0(11)**	(1.5, 5.4)
1965 - 1974	0.0(0)	4.7(2)	2.2(1)	---	---	---	2.2(3)	(0.4, 6.4)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	0.9(5)	0.8(5)	1.2(14)	1.1(9)	1.1(5)	0.0(0)	1.0(38)	
(95% Confidence Interval)	(0.3, 2.1)	(0.3, 1.9)	(0.7, 2.0)	(0.5, 2.1)	(0.4, 2.6)	(---)	(0.7, 1.4)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-19. Ratio of Observed Deaths to Expected Number of Deaths by Age Started Work and Year Started Work for Prostate Cancer

	Age					
Year Started	0 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	1.2(2)	0.9(1)	0.0(0)	1.0(3)	(0.2, 2.9)
1925 - 1934	0.0(0)	0.5(1)	0.9(3)	0.6(1)	0.7(5)	(0.2, 1.6)
1935 - 1944	0.0(0)	1.4(1)	1.4(3)	0.5(6)*	0.6(10)	(0.3, 1.1)
1945 - 1954	0.0(0)	0.0(0)	0.0(0)	1.1(6)	0.9(6)	(0.3, 2.0)
1955 - 1964	0.0(0)	0.0(0)	3.8(1)	2.9(10)**	3.0(11)**	(1.5, 5.4)
1965 - 1974	0.0(0)	0.0(0)	0.0(0)	2.2(3)	2.2(3)	(0.4, 6.4)
1975 - 1984	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
TOTAL	0.0(0)	0.9(4)	1.0(8)	1.0(26)	1.0(38)	
(95% Confidence Interval)	(---)	(0.2, 2.3)	(0.4, 2.0)	(0.6, 1.5)	(0.7, 1.4)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-20. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Cancer of the Urinary Organs

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1925 - 1934	0.0(0)	0.0(0)	1.5(1)	1.3(2)	0.9(1)	0.0(0)	1.1(4)	(0.3, 2.8)
1935 - 1944	1.8(3)	0.6(1)	1.2(3)	0.0(0)	5.2(2)	0.0(0)	1.2(9)	(0.6, 2.3)
1945 - 1954	0.0(0)	0.0(0)	0.7(1)	3.2(2)	0.0(0)	---	0.8(3)	(0.2, 2.3)
1955 - 1964	0.0(0)	0.0(0)	0.0(0)	4.8(1)	---	---	0.4(1)	(0.0, 2.2)
1965 - 1974	2.0(1)	0.0(0)	2.3(1)	---	---	---	1.4(2)	(0.2, 5.0)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	1.0(4)	0.3(1)	1.0(6)	1.2(5)	1.3(3)	0.0(0)	0.9(19)	
(95% Confidence Interval)	(0.3, 2.6)	(0.0, 1.7)	(0.4, 2.2)	(0.4, 2.8)	(0.3, 3.8)	(---)	(0.5, 1.4)	

\+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-21. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Latency for Cancer of Urinary Organs

	Latency (years)								
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40 - 49	50+	Total	(95% Confidence Interval)
1900 - 1924	---	---	---	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1925 - 1934	---	---	0.0(0)	1.4(1)	0.9(1)	1.7(2)	0.0(0)	1.1(4)	(0.3, 2.8)
1935 - 1944	0.0(0)+	1.9(1)	1.2(2)	0.0(0)	0.4(1)	6.6(5)**	---	1.2(9)	(0.6, 2.3)
1945 - 1954	0.0(0)	0.0(0)	0.0(0)	1.4(2)	1.1(1)	---	---	0.8(3)	(0.2, 2.3)
1955 - 1964	0.0(0)	0.0(0)	0.0(0)	1.2(1)	---	---	---	0.4(1)	(0.0, 2.2)
1965 - 1974	0.0(0)	0.0(0)	2.4(2)	---	---	---	---	1.4(2)	(0.2, 5.0)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	---	0.0(0)	(---)
TOTAL	0.0(0)	0.6(1)	0.8(4)	0.7(4)	0.6(3)	2.9(7)*	0.0(0)	0.9(19)	
(95% Confidence Interval)	(---)	(0.0, 3.3)	(0.2, 2.0)	(0.2, 1.8)	(0.1, 1.8)	(1.2, 6.0)	(---)	(0.5, 1.4)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-22. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Latency for Kidney Cancer

	Latency (years)								
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40 - 49	50+	Total	(95% Confidence Interval)
1900 - 1924	---	---	---	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1925 - 1934	---	---	0.0(0)	0.0(0)	2.1(1)	4.5(2)	0.0(0)	1.9(3)	(0.4, 5.6)
1935 - 1944	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	3.5(1)	---	0.3(1)	(0.0, 1.7)
1945 - 1954	0.0(0)	0.0(0)	0.0(0)	0.0(0)	2.6(1)	---	---	0.6(1)	(0.0, 3.3)
1955 - 1964	0.0(0)	0.0(0)	0.0(0)	0.0(0)	---	---	---	0.0(0)	(---)
1965 - 1974	0.0(0)	0.0(0)	2.0(1)	---	---	---	---	1.2(1)	(0.0, 6.7)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	---	0.0(0)	(---)
TOTAL	0.0(0)	0.0(0)	0.4(1)	0.0(0)	1.0(2)	3.3(3)	0.0(0)	0.6(6)	
(95% Confidence Interval)	(---)	(---)	(0.0, 2.2)	(---)	(0.1, 3.6)	(0.7, 9.6)	(---)	(0.2, 1.3)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-23. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Latency for Bladder Cancer

	Latency (years)								
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40 - 49	50+	Total	(95% Confidence Interval)
1900 - 1924	---	---	---	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1925 - 1934	---	---	0.0(0)	3.1(1)	0.0(0)	0.0(0)	0.0(0)	0.5(1)	(0.0, 2.8)
1935 - 1944	0.0(0)+	3.9(1)	2.3(2)	0.0(0)	0.7(1)	6.4(3)*	---	1.6(7)	(0.6, 3.3)
1945 - 1954	0.0(0)	0.0(0)	0.0(0)	2.5(2)	0.0(0)	---	---	1.0(2)	(0.1, 3.6)
1955 - 1964	0.0(0)	0.0(0)	0.0(0)	2.4(1)	---	---	---	0.8(1)	(0.0, 4.4)
1965 - 1974	0.0(0)	0.0(0)	3.0(1)	---	---	---	---	1.9(1)	(0.0, 10.6)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	---	0.0(0)	(---)
TOTAL	0.0(0)	1.5(1)	1.3(3)	1.4(4)	0.4(1)	2.0(3)	0.0(0)	1.1(12)	
(95% Confidence Interval)	(---)	(0.4, 8.3)	(0.3, 3.8)	(0.4, 3.6)	(0.0, 2.2)	(0.4, 5.8)	(---)	(0.6, 1.9)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-24. Detailed Description of 19 Deaths Due to Cancer of the Urinary Organs in Highway Maintenance Workers

Death Certificate Cause of Death	Year Started	Year Ended	Years Worked	Date of Death	Age at Death
Carcinoma of Urethra	1935	1974	39	1978	67
Transitional Cell Carcinoma of Bladder	1939	1975	36	1982	71
Hypernephroma	1927	1960	33	1960	65
Kidney Cancer	1934	1964	30	1978	79
Hypernephroma	1946	1975	29	1976	61
Cancer of Bladder	1945	1973	28	1973	64
Carcinoma of Bladder	1932	1958	26	1958	65
Hypernephroma	1934	1960	26	1977	79
Cancer of Bladder	1962	1983	21	1984	64
Carcinoma of Bladder	1942	1961	19	1961	56
Hypernephroma	1965	1980	15	1982	64
Transitional Cell Cancer of the Bladder	1943	1958	15	1978	85
Cancer of Bladder	1942	1955	13	1984	95
Carcinoma of Bladder	1946	1957	11	1968	76
Papillary Carcinoma of Bladder	1942	1951	9	1958	74
Hypernephroma	1939	1946	7	1980	58
Cancer of Bladder	1942	1946	4	1951	53
Transitional Cell Carcinoma of Bladder	1942	1946	4	1984	76
Carcinoma of Urinary Bladder	1966	1967	1	1980	75

Table 3-25. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Connective and Soft Tissue Cancer#

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1925 - 1934	0.0(0)	0.0(0)	0.0(0)	0.0(0)	15.4(1)	0.0(0)	5.0(1)	(0.1, 27.8)
1935 - 1944	0.0(0)	0.0(0)	6.7(1)	0.0(0)	0.0(0)	0.0(0)	2.4(1)	(0.1, 13.3)
1945 - 1954	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	---	0.0(0)	(---)
1955 - 1964	0.0(0)	0.0(0)	0.0(0)	0.0(0)	---	---	0.0(0)	(---)
1965 - 1974	0.0(0)	0.0(0)	0.0(0)	---	---	---	0.0(0)	(---)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	0.0(0)	0.0(0)	2.4(1)	0.0(0)	7.5(1)	0.0(0)	1.4(2)	
(95% Confidence Interval)	(---)	(---)	(0.1, 13.3)	(---)	(0.2, 41.7)	(---)	(0.2, 5.0)	

\+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$
\# See also Table 3-26

Table 3-26. Detailed Description of 2 Deaths Incorrectly Coded to Cancer of Connective Tissue in Highway Maintenance Workers

Death Certificate Cause of Death	Year Started	Year Ended	Years Worked	Date of Death	Age at Death
Mesothelioma of the Pericardium, Pleura, Mediastinum and Heart	1927	1960	33	1969	77
Fibrous Mesothelioma	1939	1955	16	1955	45

Table 3-27. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Neoplasms of the Lymphatic and Hematopoietic Systems

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	2.0(2)	0.0(0)	0.9(2)	(0.1, 3.2)
1925 - 1934	0.0(0)	0.0(0)	1.0(1)	1.2(3)	2.1(4)	0.0(0)	1.4(8)	(0.6, 2.8)
1935 - 1944	0.4(1)	0.0(0)	0.8(3)	0.8(2)	4.5(3)	0.0(0)	0.8(9)	(0.4, 1.5)
1945 - 1954	0.6(1)	0.8(1)	0.8(2)	1.8(2)	0.0(0)	---	0.9(6)	(0.3, 2.0)
1955 - 1964	0.6(1)	1.4(2)	0.5(1)	0.0(0)	---	---	0.7(4)	(0.2, 1.8)
1965 - 1974	0.7(1)	1.0(1)	3.5(3)	---	---	---	1.5(5)	(0.5, 3.5)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	0.5(4)	0.6(4)	1.0(10)	1.0(7)	2.4(9)*	0.0(0)	1.0(34)	
(95% Confidence Interval)	(0.1, 1.3)	(0.2, 1.5)	(0.5, 1.8)	(0.4, 2.1)	(1.1, 4.6)	(---)	(0.7, 1.4)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-28. Ratio of Observed Deaths to Expected Number of Deaths by Age and Calendar Year for Leukemia

Age at Death	Calendar Years of Death					
	1945 - 1954	1955 - 1964	1965 - 1974	1975 - 1984	Total	(95% Confidence Interval)
0 - 19	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
20 - 24	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
25 - 29	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
30 - 34	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
25 - 39	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
40 - 44	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
45 - 49	0.0(0)	0.0(0)	0.0(0)	6.2(1)	1.5(1)	(0.0, 8.3)
50 - 54	0.0(0)	0.0(0)	3.8(1)	0.0(0)	1.0(1)	(0.0, 5.6)
55 - 59	0.0(0)	0.0(0)	2.4(1)	0.0(0)	0.7(1)	(0.0, 3.9)
60 - 64	0.0(0)	0.0(0)	3.4(2)	1.9(1)	1.5(3)	(0.3, 4.4)
65 - 69	0.0(0)	0.0(0)	1.2(1)	1.3(1)	0.8(2)	(0.1, 2.9)
70 - 74	0.0(0)	0.0(0)	0.0(0)	2.4(2)	0.8(2)	(0.1, 2.9)
75 - 79	0.0(0)	0.0(0)	2.2(2)	2.8(3)	2.1(5)	(0.7, 4.9)
80 - 84	0.0(0)	0.0(0)	2.1(1)	1.0(1)	1.3(2)	(0.2, 4.7)
85+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
TOTAL	0.0(0)	0.0(0)	1.5(8)	1.5(9)	1.1(17)	
(95% Confidence Interval)	(---)	(---)	(0.6, 3.0)	(0.7, 2.8)	(0.6, 1.8)	

+ Number in parentheses is the number of observed deaths

* $p < 0.05$

** $p < 0.01$

Table 3-29. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Leukemia

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	2.2(1)	0.0(0)	1.0(1)	(0.0, 5.6)
1925 - 1934	0.0(0)	0.0(0)	2.0(1)	1.7(2)	4.8(4)*	0.0(0)	2.6(7)*	(1.0, 5.4)
1935 - 1944	0.0(0)	0.0(0)	0.0(0)	1.0(1)	7.3(2)	0.0(0)	0.5(3)	(0.1, 1.5)
1945 - 1954	0.0(0)	1.7(1)	1.0(1)	0.0(0)	0.0(0)	---	0.7(2)	(0.1, 2.5)
1955 - 1964	0.0(0)	3.3(2)	1.3(1)	0.0(0)	---	---	1.3(3)	(0.3, 3.8)
1965 - 1974	0.0(0)	2.4(1)	0.0(0)	---	---	---	0.8(1)	(0.0, 3.9)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	0.0(0)	1.4(4)	0.7(3)	1.0(3)	4.2(7)**	0.0(0)	1.1(17)	
(95% Confidence Interval)	(---)	(0.4, 3.6)	(0.1, 2.0)	(0.2, 2.9)	(1.7, 8.7)	(---)	(0.6, 1.8)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-30. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Leukemia, Urban Workers

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1925 - 1934	0.0(0)	0.0(0)	0.0(0)	0.0(0)	14.5(2)*	0.0(0)	5.5(2)	(0.7, 19.8)
1935 - 1944	0.0(0)	0.0(0)	0.0(0)	0.0(0)	28.4(1)	0.0(0)	1.2(1)	(0.0, 6.7)
1945 - 1954	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	---	0.0(0)	(---)
1955 - 1964	0.0(0)	3.3(1)	0.0(0)	0.0(0)	---	---	1.1(1)	(0.0, 6.1)
1965 - 1974	0.0(0)	0.0(0)	0.0(0)	---	---	---	0.0(0)	(---)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	0.0(0)	1.1(1)	0.0(0)	0.0(0)	16.0(3)**	0.0(0)	1.1(4)	
(95% Confidence Interval)	(---)	(0.0, 6.1)	(---)	(---)	(3.3, 46.8)	(---)	(0.3, 2.8)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-31. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Leukemia, Rural Workers

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	2.2(1)	0.0(0)	1.1(1)	(0.0, 6.1)
1925 - 1934	0.0(0)	0.0(0)	2.3(1)	2.0(2)	2.9(2)	0.0(0)	2.2(5)	(0.7, 5.1)
1935 - 1944	0.0(0)	0.0(0)	0.0(0)	1.2(1)	4.3(1)	0.0(0)	0.4(2)	(0.0, 1.4)
1945 - 1954	0.0(0)	2.6(1)	1.4(1)	0.0(0)	0.0(0)	---	1.0(2)	(0.1, 3.6)
1955 - 1964	0.0(0)	3.3(1)	1.9(1)	0.0(0)	---	---	1.5(2)	(0.0, 8.3)
1965 - 1974	0.0(0)	5.4(1)	0.0(0)	---	---	---	1.6(1)	(0.0, 8.9)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	0.0(0)	1.5(3)	0.9(3)	1.2(3)	2.8(4)	0.0(0)	1.1(13)	
(95% Confidence Interval)	(---)	(0.3, 4.4)	(0.2, 2.6)	(0.2, 3.5)	(0.8, 7.2)	(---)	(0.6, 1.9)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-32. Ratio of Observed Deaths to Expected Number of Deaths by Latency and Number of Years Worked for Leukemia

Latency (years)	Number of Years Worked						Total	(95% Confidence Interval)
	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+		
0 - 4	0.0(0)+	---	---	---	---	---	0.0(0)	(---)
5 - 9	0.0(0)	1.2(1)	---	---	---	---	0.7(1)	(0.0, 3.9)
10 - 19	0.0(0)	2.8(3)	1.0(2)	---	---	---	1.3(5)	(0.4, 3.0)
20 - 29	0.0(0)	0.0(0)	0.0(0)	0.0(0)	---	---	0.0(0)	(---)
30 - 39	0.0(0)	0.0(0)	0.0(0)	2.5(3)	5.1(3)*	---	1.8(6)	(0.7, 3.9)
40 - 49	0.0(0)	0.0(0)	6.5(1)	0.0(0)	2.7(2)	0.0(0)	1.8(3)	(0.4, 5.3)
50+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	6.5(2)	0.0(0)	2.9(2)	(0.4, 10.5)
TOTAL	0.0(0)	1.4(4)	0.7(3)	1.0(3)	4.2(7)**	0.0(0)	1.1(17)	
(95% Confidence Interval)	(---)	(0.4, 3.6)	(0.1, 2.0)	(0.2, 2.9)	(1.7, 8.7)	(---)	(0.6, 1.8)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-33. Detailed Description of the Seventeen Leukemia Deaths in Highway Maintenance Worker Cohort (1945 - 1984)

Leukemia Type	Year Started	Year Ended	Years Worked	Date of Death	Age at Death	Included in Wheaton Report
Chronic Lymphocytic	1922	1959	37	1978	80	No
Lymphocytic	1927	1964	37	1966	63	No
Chronic Myelogenous	1939	1975	36	1979	66	No
Chronic Lymphocytic	1930	1974	44	1983	74	No
Lymphocytic	1932	1966	34	1967	67	No
Chronic Myelogenous	1939	1973	34	1976	64	No
Chronic Myelogenous	1933	1965	32	1979	76	No
Chronic Lymphocytic	1933	1961	28	1975	78	Yes
Acute Lymphocytic	1934	1958	24	1968	75	No
Chronic Myelogenous	1933	1956	23	1972	84	No
Chronic Myelogenous	1938	1959	21	1977	73	Yes
Chronic Lymphocytic	1953	1965	12	1971	60	No
Acute Myelogenous	1963	1975	12	1982	72	Yes
Acute Myelogenous	1964	1975	11	1975	48	No
Chronic Myelogenous	1965	1974	9	1974	54	Yes
Chronic Myelogenous	1951	1956	5	1970	57	No
Acute Myelogenous	1960	1965	5	1972	76	No

Table 3-34. Estimated Minimum# Observed/Expected Deaths (SMR) Among HMWs with 30-39 Years of Experience by Year Started with Follow-Up Through December 1986: All Leukemias

Year Started	Observed to Expected Ratio	95% Confidence Interval
1900 - 1924	2.2(1)+	(0.1, 12.2)
1925 - 1934	4.7(4)*	(1.3, 12.0)
1935 - 1944	6.2(2)	(0.8, 22.4)
1945 - 1954	9.1(1)	(0.2, 50.6)
TOTAL	4.5(8)**	(1.9, 8.8)

\# Assumes all workers alive as of December 31, 1984 were also alive on December 31, 1986
\+ Number of leukemia deaths observed
* $p < 0.05$
** $p < 0.01$

Table 3-35. Ratio of Observed Deaths to Expected Number of Deaths by Age and Calendar Year for Diabetes

	Calendar Years of Death					
Age at Death	1945 - 1954	1955 - 1964	1965 - 1974	1975 - 1984	Total	(95% Confidence Interval)
0 - 19	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
20 - 24	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
25 - 29	0.0(0)	0.0(0)	24.4(1)	0.0(0)	9.4(1)	(0.2, 52.2)
30 - 34	21.1(1)	0.0(0)	0.0(0)	0.0(0)	3.3(1)	(0.1, 18.3)
35 - 39	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
40 - 44	0.0(0)	0.0(0)	7.4(1)	0.0(0)	2.0(1)	(0.0, 11.1)
45 - 49	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
50 - 54	0.0(0)	3.1(1)	3.1(1)	0.0(0)	1.4(2)	(0.2, 5.0)
55 - 59	0.0(0)	1.9(1)	0.0(0)	1.9(1)	0.9(2)	(0.1, 3.2)
60 - 64	3.3(2)	0.0(0)	2.5(2)	1.2(1)	1.6(5)	(0.5, 3.7)
65 - 69	1.9(1)	0.0(0)	0.0(0)	2.1(2)	0.8(3)	(0.2, 2.3)
70 - 74	0.0(0)	0.0(0)	2.9(5)	0.0(0)	1.2(5)	(0.4, 2.8)
75 - 79	0.0(0)	0.0(0)	2.7(4)	0.7(1)	1.4(5)	(0.4, 3.3)
80 - 84	0.0(0)	3.8(1)	4.1(4)*	0.0(0)	1.9(5)	(0.6, 4.4)
85+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
TOTAL	1.3(4)	0.6(3)	2.1(18)**	0.6(5)	1.2(30)	
(95% Confidence Interval)	(0.4, 3.3)	(0.1, 1.8)	(1.2, 3.3)	(0.2, 1.4)	(0.8, 1.7)	

+\ Number in parentheses is the number of observed deaths

* $p < 0.05$

** $p < 0.01$

Table 3-36. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Diabetes

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	2.6(2)	0.0(0)	1.2(2)	(0.1, 4.3)
1925 - 1934	0.0(0)	0.0(0)	1.1(1)	1.6(3)	0.8(1)	0.0(0)	1.1(5)	(0.4, 2.6)
1935 - 1944	1.9(4)	1.3(3)	1.2(4)	0.0(0)	0.0(0)	0.0(0)	1.1(11)	(0.6, 2.0)
1945 - 1954	0.8(1)	1.1(1)	1.3(2)	1.6(1)	0.0(0)	---	1.2(5)	(0.4, 2.8)
1955 - 1964	2.0(2)	1.2(1)	1.9(2)	0.0(0)	---	---	1.6(5)	(0.5, 3.7)
1965 - 1974	0.0(0)	3.8(2)	0.0(0)	---	---	---	1.2(2)	(0.1, 4.3)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	1.3(7)	1.5(7)	1.2(9)	0.8(4)	1.2(3)	0.0(0)	1.2(30)	
(95% Confidence Interval)	(0.5, 2.7)	(0.6, 3.1)	(0.6, 2.3)	(0.2, 2.0)	(0.2, 3.5)	(---)	(0.8, 1.7)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-37. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Diseases of the Blood-forming Organs

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1925 - 1934	0.0(0)	0.0(0)	0.0(0)	0.0(0)	4.0(1)	0.0(0)	1.3(1)	(0.0, 7.2)
1935 - 1944	2.8(1)	0.0(0)	1.7(1)	6.7(2)	0.0(0)	0.0(0)	2.3(4)	(0.6, 5.9)
1945 - 1954	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	---	0.0(0)	(---)
1955 - 1964	0.0(0)	0.0(0)	0.0(0)	0.0(0)	---	---	0.0(0)	(---)
1965 - 1974	0.0(0)	0.0(0)	0.0(0)	---	---	---	0.0(0)	(---)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	1.2(1)	0.0(0)	0.8(1)	2.3(2)	2.1(1)	0.0(0)	1.1(5)	
(95% Confidence Interval)	(0.0, 6.7)	(---)	(0.0, 4.4)	(0.3, 8.3)	(0.0, 11.7)	(---)	(0.4, 2.6)	

\+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-38. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Diseases of the Nervous System and Sense Organs

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1925 - 1934	0.0(0)	0.0(0)	0.0(0)	0.9(1)	0.0(0)	0.0(0)	0.4(1)	(0.0, 2.2)
1935 - 1944	3.0(4)	0.8(1)	1.1(2)	0.0(0)	0.0(0)	0.0(0)	1.2(7)	(0.5, 2.5)
1945 - 1954	0.0(0)	1.6(1)	1.8(2)	1.9(1)	0.0(0)	---	1.2(4)	(0.3, 3.1)
1955 - 1964	0.0(0)	0.0(0)	1.1(1)	0.0(0)	---	---	0.4(1)	(0.0, 2.2)
1965 - 1974	1.6(1)	0.0(0)	0.0(0)	---	---	---	0.7(1)	(0.0, 3.9)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	1.3(5)	0.7(2)	1.0(5)	0.6(2)	0.0(0)	0.0(0)	0.8(14)	
(95% Confidence Interval)	(0.4, 3.0)	(0.1, 2.5)	(0.3 2.3)	(0.1, 2.2)	(---)	(---)	(0.4, 1.3)	

\+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-39. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Diseases of the Heart

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.8(12)	0.8(17)	0.7(8)	0.8(37)	(0.6, 1.0)
1925 - 1934	0.0(0)	2.1(3)	0.8(20)	0.9(50)	0.9(35)	2.0(15)*	1.0(123)	(0.8, 1.2)
1935 - 1944	0.9(52)	0.9(58)	0.9(81)	1.2(58)	1.3(16)	0.0(0)	1.0(265)	(0.9, 1.1)
1945 - 1954	0.9(30)	0.7(17)	0.9(44)	0.7(13)	0.7(2)	---	0.8(106)*	(0.6, 1.0)
1955 - 1964	1.5(40)*	1.2(32)	0.8(27)	1.2(8)	---	---	1.2(107)	(1.0, 1.4)
1965 - 1974	0.7(13)	0.6(9)	1.3(17)	---	---	---	0.9(39)	(0.6, 1.2)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	1.0(135)	0.9(119)	0.9(189)	1.0(141)	0.9(70)	1.2(23)	0.9(677)	
(95% Confidence Interval)	(0.8, 1.2)	(0.7, 1.1)	(0.8, 1.0)	(0.8, 1.2)	(0.7, 1.1)	(0.8, 1.8)	(0.8, 1.0)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-40. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Ischemic Heart Disease

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.9(11)	0.8(16)	0.8(8)	0.8(35)	(0.6, 1.1)
1925 - 1934	0.0(0)	2.5(3)	0.9(18)	0.9(44)	0.9(30)	2.2(14)*	1.0(109)	(0.8, 1.2)
1935 - 1944	0.9(43)	1.0(51)	0.9(71)	1.1(48)	1.3(14)	0.0(0)	1.0(227)	(0.9, 1.1)
1945 - 1954	1.0(28)	0.7(15)	1.0(40)	0.8(13)	0.4(1)	---	0.9(97)	(0.7, 1.1)
1955 - 1964	1.5(36)	1.2(28)	0.8(25)	1.4(8)	---	---	1.2(97)	(1.0, 1.5)
1965 - 1974	0.6(10)	0.7(9)	1.5(17)	---	---	---	0.9(36)	(0.6, 1.2)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	1.0(117)	0.9(106)	0.9(171)	1.0(124)	0.9(61)	1.3(22)	1.0(601)	
(95% Confidence Interval)	(0.8, 1.2)	(0.7, 1.1)	(0.8, 1.0)	(0.8, 1.2)	(0.7, 1.2)	(0.8, 2.0)	(0.9, 1.1)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-41. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Chronic Endocardial Disease

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1925 - 1934	0.0(0)	0.0(0)	2.9(1)	0.0(0)	3.8(1)	0.0(0)	1.7(2)	(0.2, 6.1)
1935 - 1944	1.4(1)	0.0(0)	3.6(3)	3.2(1)	0.0(0)	0.0(0)	1.9(5)	(0.6, 4.4)
1945 - 1954	0.0(0)	4.6(1)	6.5(2)	0.0(0)	0.0(0)	---	3.1(3)	(0.6, 9.1)
1955 - 1964	0.0(0)	0.0(0)	0.0(0)	0.0(0)	---	---	0.0(0)	(---)
1965 - 1974	0.0(0)	0.0(0)	0.0(0)	---	---	---	0.0(0)	(---)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	0.8(1)	0.8(1)	3.4(6)*	0.9(1)	1.9(1)	0.0(0)	1.6(10)	
(95% Confidence Interval)	(0.0, 4.4)	(0.0, 4.4)	(1.2, 7.4)	(0.0, 5.0)	(0.0, 10.6)	(---)	(0.8, 2.9)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-42. Detailed Description of 10 Deaths from Chronic Diseases of the Endocardium in Highway Maintenance Workers

Death Certificate Cause of Death	Year Started	Year Ended	Years Worked	Date of Death	Age at Death
Valvular Heart Disease	1932	1969	37	1981	77
Pericarditis; Aortic Stenosis	1939	1968	29	1982	78
Myocarditis; Chronic Valvular Heart Disease	1942	1958	16	1969	77
Chronic Valvular Heart Disease	1933	1948	15	1948	65
Aortic Stenosis	1942	1953	11	1955	70
Aortic Stenosis with Calcification	1952	1963	11	1963	54
Valvular Heart Disease	1949	1960	11	1967	72
Aortic Stenosis	1942	1952	10	1953	64
Aortic Valvular Disease, 1st degree AV Block	1953	1962	9	1964	59
Probably Aortic Regurgitation; Heart Lesion	1942	1945	3	1961	68

Table 3-43. Ratio of Observed Deaths to Expected Number of Deaths by Age Started Work and Latency for Chronic Endocardial Disease

Latency (years)	Age Started Work				Total	(95% Confidence Interval)
	0 - 19	20 - 29	30 - 39	40+		
0 - 4	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
5 - 9	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
10 - 19	0.0(0)	0.0(0)	0.0(0)	5.1(7)**	4.1(7)**	(1.6, 8.4)
20 - 29	0.0(0)	0.0(0)	0.0(0)	1.1(1)	0.7(1)	(0.0, 3.9)
30 - 39	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
40 - 49	0.0(0)	5.8(1)	4.2(1)	0.0(0)	3.7(2)	(0.4, 13.4)
50+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
TOTAL	0.0(0)	1.2(1)	0.7(1)	2.0(8)	1.6(10)	
(95% Confidence Interval)	(---)	(0.0, 6.7)	(0.0, 3.9)	(0.9, 4.0)	(0.8, 2.9)	

\+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-44. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Other Diseases of the Circulatory System

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.6(3)	0.8(7)	0.0(0)	0.6(10)	(0.3, 1.0)
1925 - 1934	4.0(1)	0.0(0)	0.8(6)	1.0(20)	0.5(6)	1.5(3)	0.8(36)	(0.6, 1.1)
1935 - 1944	1.0(18)	0.7(17)	1.1(40)	1.0(15)	0.3(1)	0.0(0)	0.9(91)	(0.7, 1.1)
1945 - 1954	0.9(8)	0.9(7)	0.5(8)	0.2(1)	0.0(0)	---	0.7(24)*	(0.4, 1.0)
1955 - 1964	0.8(5)	0.8(5)	1.1(8)	3.7(4)	---	---	1.1(22)	(0.7, 1.7)
1965 - 1974	0.6(2)	0.8(2)	0.9(2)	---	---	---	0.7(6)	(0.2, 1.5)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	0.9(34)	0.7(31)	1.0(64)	0.9(43)	0.6(14)*	0.5(3)	0.8(189)*	
(95% Confidence Interval)	(0.6, 1.2)	(0.5, 1.0)	(0.8, 1.3)	(0.6, 1.2)	(0.3, 1.0)	(0.1, 1.5)	(0.7, 0.9)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-45. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Latency for Diseases of Arteries and Veins

	Latency (years)								
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40 - 49	50+	Total	(95% Confidence Interval)
1900 - 1924	---	---	---	0.0(0)	0.0(0)	0.0(0)	4.2(4)*	1.8(4)	(0.5, 4.6)
1925 - 1934	---	---	0.0(0)	0.0(0)	0.6(1)	1.8(4)	1.1(1)	1.0(6)	(0.4, 2.2)
1935 - 1944	0.0(0)+	0.0(0)	1.6(3)	1.9(7)	1.2(5)	0.7(1)	---	1.4(16)	(0.8, 2.3)
1945 - 1954	0.0(0)	0.0(0)	0.7(1)	1.9(5)	0.0(0)	---	---	1.0(6)	(0.4, 2.2)
1955 - 1964	0.0(0)	0.0(0)	1.4(3)	1.4(2)	---	---	---	1.1(5)	(0.4, 2.6)
1965 - 1974	0.0(0)	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	---	0.0(0)	(---)
TOTAL	0.0(0)	0.0(0)	1.0(7)	1.6(14)	0.7(6)	1.1(5)	2.7(5)	1.1(37)	
(95% Confidence Interval)	(---)	(---)	(0.4, 2.1)	(0.9, 2.7)	(0.2, 1.5)	(0.4, 2.6)	(0.9, 6.3)	(0.8, 1.5)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-46. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Diseases of the Respiratory System

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)*	0.0(0)	0.0(0)	0.5(1)	2.3(8)	0.4(1)	1.3(10)	(0.6, 2.4)
1925 - 1934	0.0(0)	0.0(0)	0.7(2)	1.2(10)	0.9(6)	0.8(1)	1.0(19)	(0.6, 1.6)
1935 - 1944	1.4(11)	1.1(10)	1.3(19)	1.0(8)	1.0(2)	0.0(0)	1.2(50)	(0.9, 1.6)
1945 - 1954	0.7(3)	1.0(4)	0.6(5)	0.3(1)	2.7(1)	---	0.7(14)	(0.4, 1.2)
1955 - 1964	0.3(1)	0.3(1)	1.8(8)	0.0(0)	---	---	0.8(10)	(0.4, 1.5)
1965 - 1974	1.4(3)	0.6(1)	0.0(0)	---	---	---	0.8(4)	(0.2, 2.0)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	1.0(18)	0.9(16)	1.1(34)	0.9(20)	1.4(17)	0.6(2)	1.0(107)	
(95% Confidence Interval)	(0.6, 1.6)	(0.5, 1.5)	(0.8, 1.5)	(0.5, 1.4)	(0.8, 2.2)	(0.1, 2.2)	(0.8, 1.2)	

\+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-47. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Fibrotic and Other Lung Diseases

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	4.2(3)	0.0(0)	1.7(3)	(0.4, 5.0)
1925 - 1934	0.0(0)	0.0(0)	0.0(0)	0.6(1)	1.5(3)	2.0(1)	1.0(5)	(0.3, 2.3)
1935 - 1944	1.7(3)	1.3(2)	0.7(2)	0.9(2)	2.4(2)	0.0(0)	1.2(11)	(0.6, 2.1)
1945 - 1954	0.9(1)	3.2(3)	1.4(3)	0.0(0)	0.0(0)	---	1.3(7)	(0.5, 2.7)
1955 - 1964	1.1(1)	0.9(1)	1.1(2)	0.0(0)	---	---	1.0(4)	(0.3, 2.6)
1965 - 1974	0.0(0)	0.0(0)	0.0(0)	---	---	---	0.0(0)	(---)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	1.1(5)	1.4(6)	0.9(7)	0.5(3)	2.1(8)	0.8(1)	1.1(30)	
(95% Confidence Interval)	(0.4, 2.6)	(0.5, 3.0)	(0.4, 1.8)	(0.1, 1.5)	(0.9, 4.1)	(0.0, 4.4)	(0.7, 1.6)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-48. Detailed Description of 30 Deaths Due to Fibrotic and Other Lung Diseases

Death Certificate Cause of Death	Year Started	Year Ended	Years Worked	Date of Death	Age at Death
Chronic Obstructive Lung Disease	1927	1970	43	1977	73
Chronic Obstructive Pulmonary Disease	1922	1965	43	1981	81
Severe Pulmonary Fibrosis	1936	1974	38	1981	72
Acute & Chronic Obstructive Pulmonary Disease	1922	1959	37	1973	82
Chronic Obstructive Lung Disease	1922	1958	36	1975	82
Chronic Obstructive Lung Disease	1925	1961	36	1976	78
Chronic Obstructive Pulmonary Disease	1932	1967	35	1976	77
Severe Endstage Chronic Obstructive Pulmonary Lung Disease	1933	1967	34	1982	79
Interstitial Pneumonitis	1936	1967	31	1983	80
Chronic Obstructive Pulmonary Disease	1939	1964	25	1981	80
Chronic Lung Disease	1932	1956	24	1982	84
Chronic Obstructive Pulmonary Disease	1942	1965	23	1979	82
Chronic Obstructive Pulmonary Disease	1958	1975	17	1982	72
Chronic Obstructive Pulmonary Disease	1943	1958	15	1979	90
Severe Chronic Obstructive Lung Disease	1951	1966	15	1978	68
Acute Respiratory Infection	1942	1955	13	1978	87
Chronic Obstructive Pulmonary Disease	1962	1975	13	1982	72
Chronic Obstructive Pulmonary Disease	1954	1966	12	1978	78
Pulmonary Fibrosis	1942	1953	11	1963	70
Pulmonary Fibrosis	1947	1958	11	1982	89
Chronic Obstructive Pulmonary Disease	1950	1959	9	1977	80
Chronic Bronchietasis and Emphysema	1941	1948	7	1959	53
Chronic Obstructive Pulmonary Disease	1942	1949	7	1971	91
Chronic Obstructive Pulmonary Disease	1942	1948	6	1984	86
Prior Chronic Obstructive Pulmonary Disease	1957	1963	6	1979	81
Pulmonary Edema and Congestion, Etiology Unknown	1953	1959	6	1959	39
Severe Chronic Obstructive Lung Disease	1948	1954	6	1975	76
Severe Chronic Obstructive Pulmonary Disease	1942	1945	3	1982	81
Massive Chronic Obstructive Lung Disease	1952	1954	2	1979	64
Chronic Obstructive Lung Disease	1963	1964	1	1976	51

Table 3-49. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Diseases of the Digestive System

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	3.3(4)	0.6(1)	0.0(0)	1.3(5)	(0.4, 3.0)
1925 - 1934	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.4(1)	0.0(0)	0.1(1)**	(0.0, 0.6)
1935 - 1944	1.4(7)	1.2(6)	0.7(5)	2.4(9)*	1.0(1)	0.0(0)	1.2(28)	(0.8, 1.7)
1945 - 1954	1.2(4)	0.4(1)	0.3(1)	0.0(0)	0.0(0)	---	0.5(6)	(0.2, 1.1)
1955 - 1964	0.3(1)	0.4(1)	1.2(4)	1.4(1)	---	---	0.7(7)	(0.3, 1.4)
1965 - 1974	0.0(0)	2.8(5)	0.6(1)	---	---	---	1.1(6)	(0.4, 2.4)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	0.9(12)	1.1(13)	0.6(11)	1.2(14)	0.5(3)	0.0(0)	0.8(53)	
(95% Confidence Interval)	(0.5, 1.6)	(0.6, 1.9)	(0.3, 1.1)	(0.6, 2.0)	(0.1, 1.5)	(---)	(0.6, 1.0)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-50. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Diseases of the Genito-urinary System

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	1.3(1)	0.0(0)	0.6(1)	(0.0, 3.3)
1925 - 1934	0.0(0)	0.0(0)	3.5(3)	0.5(1)	0.9(1)	0.0(0)	1.2(5)	(0.4, 2.8)
1935 - 1944	1.0(2)	1.2(3)	0.3(1)	0.7(1)	0.0(0)	0.0(0)	0.7(7)	(0.3, 1.4)
1945 - 1954	1.0(1)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	---	0.3(1)	(0.0, 1.7)
1955 - 1964	0.0(0)	0.0(0)	3.4(2)	0.0(0)	---	---	1.0(2)	(0.1, 3.6)
1965 - 1974	2.9(1)	0.0(0)	0.0(0)	---	---	---	1.4(1)	(0.0, 7.8)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	1.0(4)	0.7(3)	0.9(6)	0.4(2)	0.9(2)	0.0(0)	0.8(17)	
(95% Confidence Interval)	(0.3, 2.6)	(0.1, 2.0)	(0.3, 2.0)	(0.0, 1.4)	(0.1, 3.2)	(---)	(0.5, 1.3)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-51. Ratio of Observed Deaths to Expected Number of Deaths by Latency and Number of Years Worked for Chronic Renal Failure

Latency (years)	Number of Years Worked						Total	(95% Confidence Interval)
	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+		
0 - 4	0.0(0)+	---	---	---	---	---	0.0(0)	(---)
5 - 9	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
10 - 19	5.3(2)	0.0(0)	0.0(0)	---	---	---	1.1(2)	(0.0, 4.4)
20 - 29	0.0(0)	0.0(0)	1.5(1)	0.0(0)	---	---	0.6(1)	(0.0, 4.4)
30 - 39	0.0(0)	0.0(0)	2.1(1)	2.1(1)	0.0(0)	---	1.3(2)	(0.0, 3.9)
40 - 49	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
50+	0.0(0)	0.0(0)	NC#(1)	0.0(0)	9.7(2)*	0.0(0)	6.6(3)*	(1.4, 19.9)
TOTAL	1.2(2)	0.0(0)	1.4(3)	0.7(1)	2.9(2)	0.0(0)	1.1(8)	
(95% Confidence Interval)	(0.0, 3.9)	(---)	(0.1, 4.3)	(0.0, 4.4)	(0.4, 11.6)	(---)	(0.4, 2.2)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$
# NC - SMR was not calculated. Expected number of deaths was less than 0.02.

Table 3-52. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Latency for Chronic Renal Failure, Rural Workers

	Latency (years)								
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40 - 49	50+	Total	(95% Confidence Interval)
1900 - 1924	---	---	---	0.0(0)	0.0(0)	0.0(0)	4.3(1)	1.8(1)	(0.0, 10.0)
1925 - 1934	---	---	0.0(0)	0.0(0)	4.1(1)	0.0(0)	9.5(2)*	2.4(3)	(0.5, 7.0)
1935 - 1944	0.0(0)+	0.0(0)	1.4(1)	0.0(0)	0.0(0)	0.0(0)	---	0.4(1)	(0.0, 2.2)
1945 - 1954	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	---	---	0.0(0)	(---)
1955 - 1964	0.0(0)	0.0(0)	0.0(0)	8.1(1)	---	---	---	2.1(1)	(0.0, 11.7)
1965 - 1974	0.0(0)	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	---	0.0(0)	(---)
TOTAL	0.0(0)	0.0(0)	0.8(1)	0.8(1)	0.7(1)	0.0(0)	6.8(3)*	1.0(6)	
(95% Confidence Interval)	(---)	(---)	(0.0, 4.4)	(0.0, 4.4)	(0.0, 3.9)	(---)	(1.4, 19.6)	(0.4, 2.2)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-53. Detailed Description of 8 Deaths Due to Chronic Renal Failure

Death Certificate Cause of Death	Year Started	Year Ended	Years Worked	Date of Death	Age at Death
Renal Failure	1926	1962	36	1984	86
Chronic Renal Failure	1921	1953	32	1978	92
Coronary Infarct, Chronic Renal Disease	1934	1960	26	1969	64
Uremia, Chronic Renal Failure Chronic Glomerulonephritis	1929	1955	26	1982	92
Uremia, Chronic Nephritis	1934	1953	19	1969	82
Intracerebral Hemorrhage, Chronic Renal Failure	1956	1974	18	1978	64
Uremia, Chronic Glomerulonephritis	1944	1948	4	1956	53
Chronic Renal Failure	1968	1972	4	1982	79

Table 3-54. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Diseases of Muskuloskeletal System and Connective Tissue

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	17.5(1)	4.8(1)	(0.1, 26.7)
1925 - 1934	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1935 - 1944	0.0(0)	0.0(0)	2.7(1)	4.4(1)	0.0(0)	0.0(0)	1.7(2)	(0.2, 6.1)
1945 - 1954	0.0(0)	0.0(0)	0.0(0)	9.5(1)	0.0(0)	---	1.6(1)	(0.0, 8.9)
1955 - 1964	0.0(0)	0.0(0)	0.0(0)	0.0(0)	---	---	0.0(0)	(---)
1965 - 1974	0.0(0)	0.0(0)	13.1(1)	---	---	---	3.8(1)	(0.1, 21.1)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	0.0(0)	0.0(0)	2.1(2)	3.1(2)	0.0(0)	10.4(1)	1.5(5)	
(95% Confidence Interval)	(---)	(---)	(0.2, 7.6)	(0.4, 11.2)	(---)	(0.3, 57.8)	(0.5, 3.5)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-55. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Accidents

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	1.3(2)	0.0(0)	0.6(2)	(0.1, 2.2)
1925 - 1934	0.0(0)	0.0(0)	0.4(1)	0.9(4)	1.6(4)	2.3(1)	1.0(10)	(0.5, 1.8)
1935 - 1944	0.8(5)	0.4(2)	0.7(5)	0.6(2)	2.7(2)	0.0(0)	0.7(16)	(0.4, 1.1)
1945 - 1954	0.8(4)	2.4(7)	1.9(8)	0.6(1)	0.0(0)	---	1.4(20)	(0.8, 2.2)
1955 - 1964	1.2(8)	1.6(6)	2.1(8)	3.1(2)	---	---	1.6(24)*	(1.0, 2.4)
1965 - 1974	1.7(12)	1.7(6)	1.5(3)	---	---	---	1.7(21)*	(1.0, 2.6)
1975 - 1984	3.3(4)	0.0(0)	---	---	---	---	2.8(4)	(0.8, 7.2)
TOTAL	1.2(33)	1.3(21)	1.2(25)	0.8(9)	1.6(8)	0.9(1)	1.2(97)	
(95% Confidence Interval)	(0.8, 1.7)	(0.8, 2.0)	(0.8, 1.8)	(0.4, 1.5)	(0.7, 3.2)	(0.0, 5.0)	(1.0, 1.5)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-56. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Transportation Accidents

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	1.7(1)	0.0(0)	0.7(1)	(0.0, 3.9)
1925 - 1934	0.0(0)	0.0(0)	0.0(0)	1.8(3)	3.2(3)	0.0(0)	1.4(6)	(0.5, 3.0)
1935 - 1944	1.4(4)	0.4(1)	0.7(2)	0.0(0)	7.4(2)	0.0(0)	0.9(9)	(0.4, 1.7)
1945 - 1954	0.0(0)	2.1(3)	2.2(4)	0.0(0)	0.0(0)	---	1.0(7)	(0.4, 2.1)
1955 - 1964	1.0(4)	1.6(3)	1.6(3)	3.6(1)	---	---	1.4(11)	(0.7, 2.5)
1965 - 1974	1.8(8)	2.0(4)	3.0(3)	---	---	---	2.0(15)*	(1.1, 3.3)
1975 - 1984	4.9(4)*	0.0(0)	---	---	---	---	4.2(4)*	(1.1, 10.7)
TOTAL	1.4(20)	1.4(11)	1.4(12)	0.9(4)	3.2(6)*	0.0(0)	1.4(53)*	
(95% Confidence Interval)	(0.8, 2.2)	(0.7, 2.5)	(0.7, 2.4)	(0.2, 2.3)	(1.2, 7.0)	(---)	(1.0, 1.8)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-57. Detailed Description* of 53 Deaths Due to Transportation Accidents

Death Certificate Cause of Death	Year Started	Date Ended	Years Worked	Date of Death	Time of Death	Day of Death	Died on The Job
Motor vehicle accident	1926	1969	43	1983	na+	na	no
One car rollover	1935	1973	38	1974	na	na	no
Over yellow line	1934	05/02/69	35	05/02/69	9:35a	Fri.	yes
Automobile accident	1922	07/25/53	31	07/25/53	7:30a	Sat.	no
Passenger of automobile struck in rear by a truck	1933	11/30/64	31	12/18/64	na	na	no
Struck by automobile	1938	1969	31	1972	na	na	no
Two automobile collision, skidded on icy road	1958	11/08/84	26	11/23/84	na	na	no
Automobile accident	1934	08/15/59	25	08/15/59	na	Sat.	yes
Automobile left road and turned over	1932	1955	23	1958	na	na	no
Automobile left road, rolled on victim	1934	11/09/56	22	11/11/56	na	na	no
Head-on collision between two automobiles	1963	01/28/82	19	01/28/82	9:30a	Thu.	yes
Automobile accident	1947	1965	18	1979	na	na	no
Truck collision	1935	07/06/51	16	07/06/51	10:30a	Fri.	no
Boat capsized	1945	08/25/61	16	08/25/61	9:15p	Fri.	no
Automobile accident; burned	1965	04/25/80	15	04/25/80	na	na	no
Automobile overturned after missing curve	1939	01/28/55	16	01/31/55	na	na	no
Boat capsized	1944	06/20/58	14	06/21/58	na	na	no
Snowmobile collided with train engine	1954	02/08/68	14	02/09/68	na	na	no
Passenger of automobile, struck by another car	1962	1976	14	1983	na	na	no
Automobile accident	1953	10/21/66	13	10/23/66	na	na	no
Automobile accident	1952	10/30/64	12	10/30/64	6:45p	Fri.	no
Passenger in autombile; struck by another vehicle	1966	06/09/78	12	06/10/78	na	na	no
Drove off into ditch and struck access road	1967	10/12/78	11	10/13/78	4:15a	Fri.	yes
Automobile/train collision	1947	03/01/57	10	03/02/57	na	na	no
Boat swamped	1959	1969	10	1970	na	na	no
Riding lawn tractor and was hit by truck	1968	06/05/78	10	06/10/78	na	Sat.	yes
Two car accident, man thrown from automobile	1956	08/22/65	9	08/22/65	5:15p	Sun.	no
Pedestrian involved in collision with truck	1967	05/12/76	9	05/12/76	11:20a	Wed.	yes

Table 3-57. Detailed Description of 53 Deaths Due to Transportation Accidents (continued)

Death Certificate Cause of Death	Year Started	Date Ended	Years Worked	Date of Death	Time of Death	Day of Death	Died on The Job
Walked into path of oncoming automobile	1942	02/22/50	8	02/22/50	3:30p	Wed.	NL++
Pedestrian struck by automobile	1954	1962	8	1970	na	na	no
One car accident	1964	07/03/72	8	07/03/72	10:45p	Mon.	no
Driving DOT truck, ran off road, reason not known	1967	07/16/75	8	07/16/75	4:00p	Wed.	yes
Highway maintenance worker hit by a truck	1972	04/05/79	7	04/05/79	9:15a	Thu.	yes
Two vehicle collision	1962	04/26/68	6	04/26/68	6:20p	Fri.	no
Motorcycle hit truck	1974	04/20/79	5	04/21/79	na	na	no
Collision-automobile and motorcycle	1975	1980	5	1981	na	na	no
Automobile collision	1942	01/21/46	4	01/21/46	2:28p	Mon.	NL
Automobile collision	1942	08/28/46	4	08/28/46	11:30a	Wed.	yes
Passenger in automobile; hit head-on by another car	1943	1947	4	1976	na	na	no
Head-on collision between two automobiles	1965	1969	4	1974	na	na	no
Automobile collided with semi-truck	1972	1975	3	1982	na	na	no
Motorcyclist left road, struck telephone pole	1976	06/15/79	3	06/18/79	na	na	no
Pedestrian struck by a truck	1975	08/24/78	3	08/24/78	9:36a	Thu.	yes
Struck by automobile	1965	01/12/68	3	01/12/68	10:05a	Fri.	yes
Road sweeper struck from rear by a truck	1957	09/27/60	3	09/27/60	9:40a	Tue.	yes
Truck ran off road	1963	1965	2	1982	na	na	no
Struck by oncoming automobile; burned by hot tar from repair truck and gasoline explosion	1963	08/11/65	2	08/11/65	na	Wed.	yes
Automobile-train collision	1965	1967	2	1971	na	na	no
Highway accident	1978	05/22/80	2	05/29/80	na	na	no
Motorcyclist in automobile collision	1962	1963	1	1972	na	na	no
Two vehicle accident	1967	11/06/68	1	11/08/68	na	na	no
Automobile accident	1966	12/07/67	1	12/07/67	8:00a	Thu.	yes
Automobile left highway	1974	05/02/75	1	05/04/75	na	na	no

* When a worker died the same year he quit working at MNDOT, the full dates were given. When the worker died on the same day he quit working at MNDOT, the day and time of death are given.

\+ Not applicable.

++ Not Listed entries.

Table 3-58. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Transportation Accidents, Urban Workers

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1925 - 1934	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1935 - 1944	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1945 - 1954	0.0(0)	3.4(1)	0.0(0)	0.0(0)	0.0(0)	---	0.9(1)	(0.0, 5.0)
1955 - 1964	2.6(3)	3.9(2)	5.5(2)	0.0(0)	---	---	3.4(7)*	(1.4, 7.0)
1965 - 1974	2.8(4)	3.2(2)	0.0(0)	---	---	---	2.5(6)	(0.9, 5.5)
1975 - 1984	16.8(3)**	0.0(0)	---	---	---	---	14.7(3)**	(3.0, 43.0)
TOTAL	2.8(10)**	2.7(5)	1.3(2)	0.0(0)	0.0(0)	0.0(0)	2.2(17)**	
(95% Confidence Interval)	(1.3, 5.1)	(0.8, 6.3)	(0.2, 4.7)	(---)	(---)	(---)	(1.3, 3.5)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-59. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Transportation Accidents, Urban Highway Maintenance Workers Only

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1925 - 1934	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1935 - 1944	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1945 - 1954	0.0(0)	5.4(1)	0.0(0)	0.0(0)	0.0(0)	---	1.4(1)	(0.0, 7.8)
1955 - 1964	2.6(2)	0.0(0)	8.3(1)	0.0(0)	---	---	2.6(3)	(0.5, 7.6)
1965 - 1974	4.7(4)*	8.0(2)	0.0(0)	---	---	---	5.0(6)**	(1.8, 10.9)
1975 - 1984	24.1(3)**	0.0(0)	---	---	---	---	21.4(3)**	(4.4, 62.6)
TOTAL	3.9(9)**	3.4(3)	1.6(1)	0.0(0)	0.0(0)	0.0(0)	3.3(13)**	
(95% Confidence Interval)	(1.8, 7.4)	(0.7, 9.9)	(0.0, 8.9)	(---)	(---)	(---)	(1.8, 5.6)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-60. Ratio of Observed Deaths to Expected Number of Deaths by Age Started Work and Year Started Work for Other Accidents

Year Started	Age 0 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	1.4(1)	0.0(0)	0.4(1)	(0.0, 2.2)
1925 - 1934	2.5(1)	0.5(1)	0.4(1)	0.8(1)	0.6(4)	(0.2, 1.5)
1935 - 1944	0.0(0)	0.0(0)	1.6(4)	0.3(3)*	0.5(7)	(0.2, 1.0)
1945 - 1954	0.0(0)	0.7(1)	3.5(6)*	1.5(6)	1.8(13)	(1.0, 3.1)
1955 - 1964	2.9(1)	2.5(3)	1.2(2)	1.9(7)	1.9(13)*	(1.0, 3.2)
1965 - 1974	2.5(1)	1.4(2)	1.0(1)	0.9(2)	1.2(6)	(0.4, 2.6)
1975 - 1984	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
TOTAL	1.6(3)	0.8(7)	1.4(15)	0.9(19)	1.0(44)	
(95% Confidence Interval)	(0.3, 4.7)	(0.3, 1.6)	(0.7, 2.3)	(0.5, 1.4)	(0.7, 1.3)	

\+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-61. Ratio of Observed Deaths to Expected Number of Deaths by Latency and Number of Years Worked for Other Accidents

Latency (years)	Number of Years Worked						Total	(95% Confidence Interval)
	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+		
0 - 4	1.4(6)+	---	---	---	---	---	1.4(6)	(0.5, 3.0)
5 - 9	0.8(2)	2.5(8)*	---	---	---	---	1.7(10)	(0.8, 3.1)
10 - 19	1.2(3)	0.3(1)	1.5(9)	---	---	---	1.2(13)	(0.6, 2.0)
20 - 29	1.4(2)	0.7(1)	0.9(3)	1.0(3)	---	---	1.0(9)	(0.4, 1.9)
30 - 39	0.0(0)	0.0(0)	0.0(0)	0.8(2)	0.0(0)	---	0.3(2)	(0.0, 1.1)
40 - 49	0.0(0)	0.0(0)	2.9(1)	0.0(0)	1.6(2)	0.0(0)	0.9(3)	(0.2, 2.6)
50+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	2.4(1)	0.8(1)	(0.0, 3.9)
TOTAL	1.1(13)	1.2(10)	1.2(13)	0.7(5)	0.6(2)	1.4(1)	1.0(44)	
(95% Confidence Interval)	(0.6, 1.9)	(0.6, 2.2)	(0.6, 2.0)	(0.2, 1.6)	(0.1, 2.2)	(0.0, 7.8)	(0.5, 3.0)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-62. Detailed Description [a] of 44 Deaths Due to Other (Non-Transportation Related) Accidents

Death Certificate Cause of Death	Year Started	Date Ended	Years Worked	Date of Death	Time of Death	Day of Death	Age Death	Died on The Job
Fall from ladder	1929	1975	46	1983	na+	na	70	no
Fell downstairs	1923	1961	38	1968	na	na	76	no
Shot; walked in front of a deer target	1925	1956	31	1966	na	na	71	NL++
Intra-operative death	1949	1977	28	1978	na	na	64	NL
Roof collapsed	1960	6/22/84	24	6/22/84	na	Fri.	43	yes (farm)
Fell downstairs	1932	1954	22	1960	na	na	77	no
Putting out a fire on an electric range stovetop	1942	1964	22	1977	na	na	78	no
Was cutting ice off roof of home when fell to ground	1939	1969	30	1970	na	na	62	no
Aspiration of meat	1951	1970	19	1975	na	na	56	NL
Fell off back steps of home and suffered a hematoma	1952	9/04/70	18	9/08/70	na	na	50	no
Road packer overturned, crushing deceased	1961	8/17/79	18	8/17/79	3:00p	Fri.	57	yes
Tractor tipped over	1942	9/10/59	17	9/10/59	11:00a	Thu.	56	yes
Severe thermal injury	1950	1965	15	1979	na	na	83	no
Home caught fire; unable to get out	1957	1972	15	1973	na	na	60	no
Froze to death	1958	1972	14	1975	na	na	60	no
Pinned under automobile	1933	10/24/46	13	10/24/46	10:20p	Thu.	41	yes
Fracture of left hip	1942	1954	12	1982	na	na	90	NL
Fall striking back of head	1942	1953	11	1967	na	na	81	NL
Safety rim of tire exploded, penetrating skull	1959	1971	12	1978	na	na	46	yes (city)
Heat stroke	1962	8/30/73	11	08/30/73	1:35p	Thu.	33	NL
Cave-in of 8 foot deep trench while laying water pipe for village of Beaver Bay	1948	1958	10	1959	na	na	41	yes (city)
Fell from ladder on roof	1951	1960	9	1969	na	na	79	NL
Drowned	1946	1955	9	1972	na	na	60	NL
Strangulation on bite of food	1958	1/04/67	9	4/29/67	na	na	49	NL
Ingested large quantities of cocaine and valium	1972	1980	8	1981	na	na	30	no

Table 3-62. Detailed Description of 44 Deaths Due to Other (Non-Transportation Related) Accidents (continued)

Death Certificate Cause of Death	Year Started	Date Ended	Years Worked	Date of Death	Time of Death	Day of Death	Age Death	Died on The Job
Accidental electrocution	1974	8/19/82	8	8/19/82	9:00p	Thu.	36	no
Car jack slipped and car fell across chest	1942	1949	7	1962	na	na	57	yes (farm)
Stepped on nail; anaphylactic shock from tetanus shot	1943	1950	7	1952	na	na	46	yes (State)
Shot by another deer hunter	1951	10/31/58	7	11/08/58	na	na	50	no
Intractable post-operative shock; injured when wrench the was using to work on large tires for MNDOT slipped and injured right arm (7/20/61)	1953	10/07/60	7	7/21/61	na	na	66	yes
Fell 14 feet from bridge abatement	1964	7/09/70	6	7/09/70	na	Thu.	55	yes
Accidentally shot by a deer hunter	1956	11/15/63	7	11/16/63	na	na	56	no
Carbon monoxide poisoning	1949	1953	4	1963	na	na	45	no
Caught under heavy "front loader"	1957	11/01/61	4	11/01/61	9:45a	Wed.	34	yes
Run over by tractor pulling mower	1965	6/26/69	4	6/26/69	11:00a	Thu.	36	yes
Asphyxia due to smoke inhalation	1962	1965	3	1978	na	na	61	no
Hit head on dock while diving to retrieve drifting boat	1962	8/27/65	3	9/06/65	na	na	37	no
Fell 12 feet from combine - landed on chest	1945	1947	2	1970	na	na	67	yes (farm)
Fall	1953	1955	2	1973	na	na	87	NL
Fell approximately 25 - 30 feet over cliff (9/12/68)	1966	11/24/68	2	11/24/68	na	Sun.	57	yes
Found on floor (in hospital, rails up)	1970	1972	2	1975	na	na	55	no
Drowned	1953	1954	1	1960	na	na	30	NL
State highway tractor overturned in ditch. Caught under tractor as he catapulted from right of way	1960	8/02/61	1	8/02/61	2:30p	Wed.	28	yes
Putting up a highway sign when hit by a high voltage wire	1969	12/04/70	1	12/04/70	11:00a	Fri.	20	yes

* When a worker died the same year he quit working at MNDOT, the full dates were given. When the worker died on the same day he quit working at MNDOT, the day and time of death are given.
\+ Not applicable.
++ Not listed entries.

Table 3-63. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Violence

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	(---)
1925 - 1934	0.0(0)	0.0(0)	0.0(0)	1.6(2)	1.4(1)	0.0(0)	0.9(3)	(0.2, 2.6)
1935 - 1944	0.9(2)	0.6(1)	0.5(1)	0.0(0)	0.0(0)	0.0(0)	0.6(4)	(0.2, 1.5)
1945 - 1954	1.2(2)	1.0(1)	0.0(0)	0.0(0)	0.0(0)	---	0.6(3)	(0.1, 1.8)
1955 - 1964	0.9(2)	0.7(1)	0.6(1)	0.0(0)	---	---	0.7(4)	(0.2, 1.8)
1965 - 1974	0.8(2)	0.0(0)	0.0(0)	---	---	---	0.4(2)	(0.0, 1.4)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	0.9(8)	0.5(3)	0.3(2)	0.5(2)	0.7(1)	0.0(0)	0.6(16)*	
(95% Confidence Interval)	(0.4, 1.7)	(0.1, 1.5)	(0.0, 1.1)	(0.1, 1.8)	(0.0, 3.9)	(---)	(0.3, 1.0)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-64. Ratio of Observed Deaths to Expected Number of Deaths by Year Started Work and Number of Years Worked for Tuberculosis

	Number of Years Worked							
Year Started	0 - 4	5 - 9	10 - 19	20 - 29	30 - 39	40+	Total	(95% Confidence Interval)
1900 - 1924	0.0(0)+	0.0(0)	0.0(0)	3.3(1)	0.0(0)	0.0(0)	1.9(1)	(0.0, 10.6)
1925 - 1934	0.0(0)	0.0(0)	0.0(0)	2.2(1)	0.0(0)	0.0(0)	0.7(1)	(0.0, 3.9)
1935 - 1944	1.8(2)	0.0(0)	1.3(1)	0.0(0)	0.0(0)	0.0(0)	1.0(3)	(0.2, 2.9)
1945 - 1954	0.0(0)	0.0(0)	0.0(0)	0.0(0)	0.0(0)	---	0.0(0)	(---)
1955 - 1964	0.0(0)	0.0(0)	0.0(0)	0.0(0)	---	---	0.0(0)	(---)
1965 - 1974	0.0(0)	0.0(0)	0.0(0)	---	---	---	0.0(0)	(---)
1975 - 1984	0.0(0)	0.0(0)	---	---	---	---	0.0(0)	(---)
TOTAL	1.1(2)	0.0(0)	0.6(1)	2.0(2)	0.0(0)	0.0(0)	0.8(5)	
(95% Confidence Interval)	(0.1, 4.0)	(---)	(0.2, 3.3)	(0.2, 7.2)	(---)	(---)	(0.2, 1.9)	

+ Number in parentheses is the number of observed deaths
* $p < 0.05$
** $p < 0.01$

Table 3-65. Results of Environmental Monitoring Conducted by MNDOT and/or MN OSHA, 1981-1985

				Substance and Concentration					
				Petroleum Distillates (mg/m3)	Xylene ppm	Total Hydrocarbons n-Hexane ppm	Benzene ppm	Hexane ppm	Toluene ppm
			OSHA Standard	2000	100	50	10	500	200
Sample Date	Duration of Sample	Type of Sample	Activity						
July 1981	not indicated	BZ#	silk screen	8	2				
July 1981	not indicated	BZ	silk screen	41	4				
July 1981	not indicated	BZ	silk screen	16	28				
Aug. 1984	not indicated	BZ	paving			3.6			
Aug. 1984	not indicated	BZ	paving			3.5			
Nov.-Dec. 1984	not indicated	NS	crack filling				< 0.01		
Nov.-Dec. 1984	not indicated	NS##	crack filling				< 0.01		
March 1985	90 minutes	Area	asphalt heating	1107	23.0		0.05	2.0	5.0
March 1985	not indicated	BZ	crack filling	< 0.12	< 0.02		< 0.05	< 0.03	< 0.02
March 1985	not indicated	BZ	crack filling	< 0.12	< 0.02		< 0.05	< 0.03	< 0.02
March 1985	not indicated	BZ	crack filling	< 0.20	< 0.03		< 0.08	< 0.06	< 0.04
March 1985	not indicated	BZ	crack filling	< 0.54	< 0.08		< 0.22	< 0.15	< 0.09
March 1985	not indicated	Area*	distributor hatch	861.00 mg/m3	18.00		2.00	4.00	8.00

\# BZ = Breathing Zone
\## NS = Area sample not specified
* Area = sampled at hatch opening

Table 3-66. Environmental Monitoring During Road Repair: March 27, 1986

Sampling Period	Area Sampled	Activity	Benzene (ppm)	Hexane (ppm)	Petroleum Distillates (ppm)	Toluene (ppm)	Xylene (ppm)
1015-1150	BZ#	Oil application from tar kettle	N.D.##	N.D.	11	0.25	0.51
1018-1154	BZ	Shoveling from patching trailer	N.D.	N.D.	1.5	0.06	0.22
1023-1212	Area	Hatch opening on patching trailer	N.D.	N.D.	20	N.D.	N.D.
1026-1154	BZ	Raking mix	N.D.	N.D.	N.D.	N.D.	N.D.
1215-1332	Area	Hatch opening on patching trailer	N.D.	N.D.	92	N.D.	N.D.
1234-1344	BZ	Shoveling from patching trailer	N.D.	N.D.	2.0	0.05	0.40
1235-1350	BZ	Raking mix	N.D.	N.D.	2.0	N.D.	0.30
1236-1354	BZ	Oil application from tar kettle	N.D.	N.D.	2.4	0.05	0.20
1332-1416	Area	Hatch opening on patching trailer	N.D.	N.D.	282	N.D.	N.D.
1344-1416	BZ	Shoveling from patching trailer	N.D.	N.D.	12	0.30	N.D.
1350-1416	BZ	Raking mix	N.D.	N.D.	N.D.	N.D.	N.D.
1354-1416	BZ	Oil application from tar kettle	N.D.	N.D.	N.D.	N.D.	N.D.

\# Breathing zone
None detected

Table 3-67. Time Weighted Average Exposures for Road Repairs: March 27, 1986

Number of Samples	Sampling Period	Employee Sampled	Activity	Petroleum Distillates (ppm)	Xylene TWA (ppm)	Toluene TWA (ppm)
3	195 min.	BZ#	Oil application from tar kettle	6.3	0.33	0.14
3	198 min.	BZ	Shoveling from patching trailer	3.4	0.25	0.10
3	189 min.	BZ	Raking mix	0.79	0.12	
3	230 min.	General air	Hatch opening on patching trailer	94		

Breathing zone

Table 3-68. **Air Contaminants Collected in Worker Breathing Zones: March 27, 1986**

Sampling Period	Description	Air Concentration Total Particulate mg/m^3
1015-1150	Oil application from tar kettle	0.64
1018-1154	Shoveling from patching trailer	0.99
1023-1212	Hatch opening on patching trailer	3.4
1026-1154	Raking mix	1.1
1215-1332	Hatch opening on patching trailer	7.7
1234-1344	Shoveling from patching trailer	1.9
1235-1350	Raking mix	1.0
1236-1354	Oil application from tar kettle	0.70
1332-1416	Hatch opening on patching trailer	37.2
1344-1416	Shoveling from patching trailer	5.0
1350-1416	Raking mix	4.8
1354-1416	Oil application from tar kettle	4.7

Table 3-69. Eight-Hour Time Weight Average Exposures for Breathing Zone Samples: March 27, 1986

Number of Samples	Sampling Period	Activity	Substance	Total Particulate TWA* (mg/m3)
3	195 min.	application from tar kettle	Total particulate	1.1
3	198 min.	Shoveling from patching trailer	Total particulate	2.0
3	189 min.	Raking mix	Total particulate	1.6
3	230 min.	Hatch opening on patching trailer	Total particulate	11

* Unsampled workshift exposure time considered as zero exposure.

Table 3-70. Breathing Zone Samples Collected During Sign Shop Silk Screening: August 1986

Duration of Sampling	Petroleum Distillates (ppm)	Xylene (ppm)
9:46 - 11:34	4.0	0.42
9:48 - 11:40	4.9	1.0

Table 3-71. Breathing Zone Samples Collected During a Paving Operation: August 1986

Duration of Sample	Activity	Toluene (ppm)	Xylene (ppm)	Petroleum Distillates (ppm)
8:29 - 11:52	screen operator	ND	0.04	0.3
8:29 - 14:51	screen operator	ND	ND	ND
8:23 - 11:50	paving operator	0.04	0.06	0.4
11:52 - 14:51	paving operator	ND	0.02	0.2
11:50 - 14:50	paving operator	0.03	0.07	0.2
8:23 - 14:51	paving operator	ND	ND	ND

Table 3-72. **MNDOT Bulk Samples for Benzene and Hexane: December 1984**

Description	Benzene* (ug/g)	Hexane* (ug/g)
Ashland Cutter Stock (for MC cutbacks)	19	2.8
Ashland Cutback Asphalt MC-70	16	9.0
Ashland Asphalt AC-1 120/150	0.4	0.08
Trumbull Asphalt AC-3 Crackfiller	0.8	0.6
Koch Cutback Asphalt RC/250	188	45
Koch Asphalt AC-1 120-150	3.5	1.1
Koch Cutback Asphalt MC/250	24	3.5
Murphy Asphalt AC-1 120/150	3.0	0.5
Murphy Cutback Asphalt MC/250	6.4	3.4
Murphy Cutback Asphalt RC/250	61	7.5

* Lower detectable limit for benzene = 0.03 ug/g; for hexane = 0.02 ug/g.

4. DISCUSSION

INTRODUCTION AND OVERVIEW: This section integrates the results of this study with the relevant medical and epidemiologic literature about the causes of death (diseases) that appear to be elevated among the HMWs. This includes discussion of the low SMR for all causes -- often called the healthy worker effect; a synopsis of criteria used to interpret elevated SMRs; an evaluation of alcohol and smoking related mortality in the HMW cohort; and finally, a discussion of the findings that leads to the recommendations given in the next section.

The lower overall mortality (SMR = 0.91) for HMWs may be explained by what is called the healthy worker effect. In this study, MNDOT workers were compared with all Minnesotans of the same age, race, time period, and region of the state. These two groups are not strictly comparable (i.e., one group is employed and the other consists of all Minnesota residents). Because a person must be in relatively good health to start working and to remain working, workers will, in general, experience less mortality than the population as a whole which also includes persons too ill to work.

The healthy worker effect is thought to play a much smaller role (if any) for cancers than for "all" causes of mortality or diseases of the heart. The all cause deficit of 146 deaths (SMR = 0.91) in this cohort was primarily due to a decrease in 50 deaths (SMR = 0.93) from all heart disease and 32 deaths from cerebrovascular diseases (SMR = 0.80). The overall decrease in cancer mortality accounted for 54 fewer deaths than expected (SMR = 0.84). The significantly reduced mortality for all cancer was unusual because those factors that are thought to influence cancer mortality do not usually affect employment ability before disease onset (Monson, 1986; Wen, 1983).

The existence of a healthy worker effect does not mean that the incorrect comparison population was used. A comparison population in a study such as this must be large. In this instance, the expected number was computed from 1,300,000 deaths that occurred over a 40 year period in Minnesota. Because Minnesotans tend to live longer than Americans in general, comparison to United States mortality data would have spuriously decreased most of the SMRs. Thus, results must be interpreted as relative to other Minnesotans of the same age, sex, race, and time periods.

The baseline rates from which the expected number of deaths was calculated were relatively stable. The observed deaths were often small in number and subject to much more variability. Using a large comparison population, however, did not account for the fact that there were several thousand comparisons. When conducting thousands of statistical tests as was done in this study, many (approximately 2.5%) will be significantly elevated due to chance alone (assuming 95% confidence limits). It is often difficult to dissect this "multiple comparison" problem out of inferential associations. A priori hypotheses, strength of the association, biologic plausibility, and consistency are often used to refine inferences drawn from observational studies. For this reason, interpretation of data cannot be confined to an isolated test result. Both high and low SMRs must be interpreted in relation to these criteria.

Prior to the onset of the HMW study, several causes of death were identified as being of interest. These included: 1) leukemia and other hematopoietic disorders; 2) transportation accidents; 3) pneumoconioses; 4) lead related disorders; and 5) soft-tissue sarcomas. Because these causes were defined prior to the study (a priori) it may be argued that they should not be evaluated as part of a spectrum of multiple statistical comparisons.

Even after considering multiple statistical comparisons, the magnitude of the SMR, and statistical significance, no conclusion may be made about causality. What may be said is that a group of workers, all of whom had a certain degree of experience in common, had an SMR that was less than, equal to, or greater than expected. Except in specific circumstances (e.g., injury), etiology cannot be determined. The etiology of acute traumatic events such as falling off a bridge are often associated with other specific events even if the factors leading to the event are unclear.

Interpretation of this and other studies that rely on death certificate data is also made difficult due to several problems related to death certificate data: physicians have little or no training on completing death certificates; the data available at death may be incomplete; death certificates are often hastily completed in order to expedite funeral arrangements; amendments to the original entry are infrequent even when new information becomes available (e.g., autopsy results); and diagnoses used on death certificates are often difficult to code (Comstock, 1986).

Regardless of these problems, a cohort mortality study represents the best means by which to evaluate a large and previously unstudied group of workers. In addition, the coding of cause of death for cancer generally tends to be better than the coding for non cancer deaths (Percy, 1981). Because injuries are acute events, it might be expected that the data for transportation and other forms of death from injury were also likely to be accurate.

Even though errors may exist in certification and coding of death certificates, there is no reason to suspect that the deaths of HMWs were processed differently than those of other Minnesotans. Therefore, it is

unlikely that the elevated (or lowered) mortality for specific causes of death identified in the study were due to differences in death certification and nosologic coding.

An overview of the interpretation of cohort mortality data has been given by Monson (1985). These criteria will be described and then discussed in the context of HMW study.

Consistency: It is useful to know if the findings of a specific study are consistent with the findings in similar occupational groups. A slightly elevated SMR may mean more than a large SMR if the former is supported by multiple studies and the latter is inconsistent with previous epidemiologic work. The absence of consistency leaves doubt with regard to etiology, and its presence creates a stronger argument for a causal association.

Specificity: An interpretation of causation is favored when the association links the exposure to a single disease rather than some broad spectrum of diseases. An example of high specificity is the association between occupational exposure to vinyl chloride and angiosarcoma (a rare form of liver cancer). The high specificity, as well as the strength of this association leaves little doubt as to its causative nature.

A lack of specificity, however, does not necessarily argue against causality. For example, cigarette smoking has been associated with a wide range of diseases. In fact, the smoking history of study subjects (when available) is always considered in well-designed studies. This lack of specificity, although still sometimes raised in arguments by the tobacco industry, is not particularly troublesome to epidemiologists since a great many components have been identified in tobacco smoke, and many of these components can be transported through the body to different sites.

Strength of Association: It is useful to examine the magnitude of an association, (e.g., SMRs of 10 vs. SMRs of 1.5). However, the magnitude of an SMR may be misleading. An SMR of 5 may have resulted from 1 case (e.g., 1/0.2) and an SMR of 1.5 from 150 cases (e.g., 150/100). Clearly the former is much less stable than the latter.

Dose-Response: Exposure may be graded by intensity, duration or both. When a substance (e.g., cigarette smoke) places a person at risk for lung cancer, then more intense or longer use of that substance might be expected to increase that risk. The presence of a dose-response relationship is strong evidence in support of a relationship between the disease of interest and the exposure(s) or occupation under study. For example, it would be unusual to find lung cancer increased in those with 5 years of work and not in those with 30 years of work if the cancer was being caused by an ongoing job related exposure.

Biologic Plausability: A causal hypothesis is supported when an association is consistent with or supported by other known facts and observations. For example, a causative hypothesis is favored if there is some demonstrated or potential biological mechanism by which the effect can be explained. The cellular effects of ionizing radiation have long been recognized and offer a clear explanation for the health hazards of radiation.

In the case of cigarette smoking, laboratory studies have identified a variety of organic compounds in inhaled smoke; a number of these compounds have been shown to cause cancer in animal studies. These findings are thus consistent with the human epidemiologic evidence.

The absence of a recognized biological mechanism is not necessarily contradictory to a causative interpretation. The lack of an apparent mechanism may only reflect an early stage of investigation.

Temporal Relationship: It is also useful to examine the time relationship between the disease of interest and the exposure of interest. Obviously, it is important to ascertain whether the disease or exposure occurred first. If the exposure was first, it must be determined if there was enough time (i.e., latency) for the disease to occur. As an example, mesothelioma rarely develops until 30-40 years after exposure to asbestos.

ALCOHOL AND TOBACCO: Before examining cause specific mortality, it is important to examine mortality from alcohol and tobacco related experiences. These substances are known to influence mortality for numerous causes of death, and their combined effect is known to affect other causes.

Alcohol use has been strongly associated with deaths due to injuries, cirrhosis, pancreatitis, and oral and laryngeal cancers. In the case of oral and laryngeal cancer, alcohol acts largely in combination with tobacco smoke (Parker, 1985). Table 4-1 shows the SMRs and percent of deaths attributable to alcohol for selected causes of death associated with alcohol consumption. It appears from these data that there was a deficit in alcohol-related mortality in the HMW cohort. Aggregating the 5 causes of death gave an SMR of 0.7. These observations suggest, but do not prove, that alcohol use was less among HMWs than among Minnesotans in general.

Table 4-2 shows the SMRs and percent of deaths attributable to smoking for selected causes of death. Clearly, lung cancer was significantly reduced among HMWs. This is unusual because "blue collar" populations usually have higher smoking rates. Lower rates of lung cancer mortality

are very often the result of decreased smoking. In aggregate, there was no reduction in other smoking related causes of death (i.e., excluding lung cancer) (SMR = 1.0). The findings of substantially reduced lung cancer mortality in the face of nominal mortality for other smoking related causes of death is at this time unexplained.

It may be concluded that mortality from both smoking and alcohol related causes was equal to, if not less than, mortality from these causes for all Minnesotans. These data are useful when examining the increase in mortality due to injuries and certain cancers (e.g., leukemia and bladder cancer).

LEUKEMIA: There were 17 deaths from leukemia during the 40 year follow-up of this study. The largest elevation was in those workers with 30-39 years of experience (SMR = 4.2). Epidemiologically, the high risk leukemia mortality profile did not include the Wheaton cluster. Therefore, the Wheaton cluster may represent the common finding of spatial and temporal clustering of leukemia with no apparent etiology.

There have been two descriptive studies of transportation workers. Maizlesh (personal communication) studied the proportional mortality from 1507 death certificates of California highway maintenance workers. Specific job classifications and duration of work were not available . An overall PMR of 1.6 was found for all lymphopoietic cancers; those workers who died after retiring had a PMR of 2.3 for these cancers. Milham (personal communication) found an overall leukemia PMR of 1.1 for highway maintenance related workers in the state of Washington. These figures are consistent with data from the current study.

The SMR of 4.2 in the Minnesota study for workers with 30-39 years of experience was based on 7 deaths. A usual (but arbitrary) requirement for interpreting an SMR is for three or more deaths to have occurred. In this case, one more or one less leukemia death would not qualitatively change the interpretation. The finding of an additional leukemia death after December 31, 1984 supports the plausibility of an association between leukemia mortality and the life long experience of this cohort. Since this death occurred in a worker with 30-39 years of experience, attention to this subgroup is justified and makes this specific finding (SMR = 4.5) less likely to be due to chance.

It was not possible in this instance to examine a specific dose-response relationship for leukemia mortality. Air monitoring data and work histories lacked the detail required for such estimates. Though no time trend was seen, the increased SMRs were found only in those with 30 or more years of experience. Because of the difficulty in examining a dose-response relationship, it is important to examine the risk factors associated with leukemia in order to more carefully examine possible causes of these elevated SMRs.

The following is a brief summary of the vast literature on the epidemiology of leukemia.

Radiation: High to moderate levels of ionizing radiation can cause leukemia. This conclusion is based on the high incidence of leukemia among survivors of the atomic bomb blasts in Hiroshima and Nagasaki (Bizzozero, 1966), and the reports by Brown (1965) of patients receiving therapeutic radiation for ankylosing spondylitis. Increased risk for leukemia has been found for radium workers with significant lifetime exposures to radium isotopes (Rowland, 1970), and patients therapeutically exposed to radiation

for conditions such as menorrhagia (Alderson, 1971) and polycythemia vera (Modan, 1965).

Gibson (1972) found an association between both chronic and acute myelogenous leukemia (CML and AML) in men due to diagnostic radiation. Graham (1966) found an increased risk for leukemia in children associated with preconceptional diagnostic radiation of either parent. Diagnostic radiation during pregnancy also increased the risk of leukemia in children. The incidence of acute leukemia was increased for patients receiving diagnostic x-rays using thorotrast (daSilva, 1974). Gunz (1964) also found a significant association between diagnostic x-rays and AML. Other reports concerning leukemia risk from diagnostic x-rays are controversial and inconclusive.

Smoking: Cigarette smoke is not generally recognized as a risk factor for leukemia. The lack of recognition of smoking as a risk factor is curious since many studies have reported this association. The relative risks for leukemia in smokers have, however, been much smaller than those reported for other cancers. Based on the results of two large cohort studies in the United States, smokers had relative risks of 1.2-1.5 (20-50% excesses) for leukemia mortality compared to nonsmokers (Rogot, 1974; Hammond, 1966). Since the relative risk for lung cancer in smokers compared to nonsmokers is 8 to 10 times larger, it is understandable why the leukemia findings have not been emphasized. Small quantities of many substances potentially capable of causing leukemia are present in cigarette smoke in either the gas or particulate phase (DHEW, 1979). These substances include benzene, urethane, naphthalene, nitrosamines, PAHs and radioactive compounds. Although the relative risk for leukemia associated with cigarette smoking is small, the population attributable risk (which is a measure of the

amount of leukemia that can be attributed to smoking) may be large because of the large number of smokers.

Viruses: Other environmental factors are far less clear in their involvement in the etiology of leukemia. Because of their influence on leukemia in laboratory animals, and the recent discovery of an association between HTLV-I and a rare form of human leukemia (Gallo, 1985), viruses are a concern in the development of leukemia in man. While the appearance of so-called "micro-epidemics" and clusters of leukemia lend credence to the possibility of infectious spread of leukemia, studies have yielded inconsistent results and have demonstrated the need for caution before attributing any consequence to these clusters (see Perspectives on Wheaton and other cancer clusters in section 1).

Chemicals and Occupation

1. Drugs: Many chemicals are suspect as possible leukemia causing agents. Most have the ability to suppress the growth of cells in animal and human bone marrow. A group of chemicals under suspicion are therapeutic drugs, including chloramphenicol (Cohen, 1973) and phenylbutazone (Hart, 1964), which may be involved in the development of aplastic anemia. Other drugs are also suspected as being associated with leukemia.

2. Benzene: The chemical with the most evidence of causing leukemia is the aromatic hydrocarbon benzene, a common industrial solvent (Infante, 1977). It also has the ability to induce aplastic anemia (Askoy, 1962). Benzene's leukemogenic action has long been suspected. The first case of benzene-associated leukemia was described by Delore and Borgomano in 1928. Since that time hundreds of cases of leukemia have been attributed to benzene. The presence of benzene in petroleum products such as gasoline

and oils make its role as a factor in leukemia etiology of particular interest in this study of highway maintenance workers (see Appendix A-6 for a detailed discussion of benzene, solvents, and leukemia).

3. Other Occupational Exposures: Increased leukemia risk has been reported for a number of other industries and occupations involving chemical exposures. Numerous case-reports have linked leukemia and exposure to chlordane and heptachlor (Infante, 1978). Ott (1974) reported an increased risk for all hematopoietic cancers in workers in arsenical pesticide formulating plants. Two other studies of workers exposed to heptachlor and chlordane were negative (Wang, 1979). Milham (1979) found a small nonsignificant increase in leukemia deaths for aluminum reduction workers as well as a 30% excess of leukemia deaths for pavers, graders, and excavators. Within the later group, HMWs in the state of Washington had a 13% excess for all leukemia deaths (Milham, personal communication).

Several studies have suggested that workers with presumed exposure to electromagnetic fields may have a modestly elevated risk of acute leukemia. However, these studies have not characterized actual exposures to electromagnetic fields, and other types of exposures in these diverse occupations cannot be ruled out. Thus, no causal association has been established (Savitz and Calle, 1987).

Many studies have found that leukemia mortality is higher in rural areas with large agricultural industries than in the rest of the United States. There is a broad band of increased leukemia mortality from Texas through the Dakotas and Wisconsin (Blair, 1980). In Iowa (1973-1977) for example, the mortality for all forms of leukemia was 7.3 per 100,000, a 10%

increase over the entire SEER program (a federally funded cancer registration system). Over the past 40 years, Minnesota's overall leukemia mortality was approximately 15% higher than the rest of the country.

Several investigators have suggested that this increased leukemia mortality was associated with agricultural practices (Blair, 1985). One of the hypotheses was that the bovine leukemia virus which is widely prevalent in dairy herds in this country is associated with the development of human leukemia (Donham, 1977). Data from a recent study, however, indicates that this possibility is extremely unlikely (Bender, 1987). Farming does confer substantial exposure to many substances such as pesticides. One recent study linked exposure to certain pesticides and specific forms of lymphoreticular malignancies (Hoar, 1986).

Host Factors: Host factors appear to be important in leukemia development. There is increasing evidence of the influence of genetic factors in human leukemia. A number of inherited abnormalities have been described as potentiating the development of leukemia. These illnesses include Down's, Klinefelter's, Turner's, Bloom's, and Fanconi's syndromes as well as ataxia telangiectasia (Fraumeni, 1969; Pierre, 1974).

Gunz (1970) describes a threshold effect involving the interaction of multiple genes and environmental factors, which he proposed as a model for human leukemia. Identical twin studies described by Gunz found that if a twin sibling had previously developed acute leukemia, the other twin had at least a 25% chance of developing the disease.

It is improbable that most of the above factors influenced leukemia mortality of the cohort. There is no reason to suspect viral infections, radiation, drug, and host factors. Three factors however, require further discussion: smoking, chemicals, and farming.

The relationship between smoking and leukemia appears to be weak but consistently positive. However, lung cancer mortality is substantially reduced in this cohort (SMR = 0.69). This makes it unlikely that smoking could account for the increased leukemia risk seen. Environmental exposures to this cohort remain enigmatic. As discussed above, several studies have shown a relationship between herbicide exposure and leukemia. In this study, the largest SMR was 16.0 for urban workers with 30-39 years of experience compared to 2.8 for rural workers. The overall SMR for urban workers was 1.12 compared to 1.07 for rural workers. This indicates that it is unlikely that farming, most commonly associated with rural life, played a significant role in the etiology of leukemia deaths in this cohort. This does not mean, however, that urban workers did not use herbicides in the maintenance of roads.

Extensive data have also been gathered on current exposures to benzene by HMWs. Recent exposures have been well below the threshold limit value (TLV). However, no data were available on past exposures to benzene. Acute myelogenous leukemias are most commonly associated with benzene exposure, and chronic myelogenous leukemias are least commonly associated with benzene exposure. In many cases in the literature, leukemia followed benzene exposure by less than 15 years. There have also been reports of a relationship between lymphocytic leukemia and solvent exposure.

As seen in Table 3-33, 10 out of 17 leukemia deaths were coded on the death certificate as nonlymphocytic leukemia, and 7 out of 17 worked 30 or more years. These data, combined with the monitoring data showing little evidence of benzene exposure, leaves in question the possibility of exposure to other leukemogens either on and/or off the job.

Because of the magnitude of the increases in leukemia mortality with no apparent explanation, these observations require further exploration: 1) Case-control studies within the existing record systems may be useful to further refine which components (if any) of maintenance work were associated with the increased leukemia risk; 2) Continued environmental monitoring using more sophisticated protocols to ensure that exposures to known carcinogens are not occurring; and 3) Cytogenetic testing of high risk groups as measures of present and/or historical exposures to cytotoxic agents. Cytogenetic techniques have been demonstrated to be sensitive indicators of both in vitro and in vivo induced DNA damage. It would be useful to investigate these chromosomal changes in peripheral blood lymphocytes of HMWs and matched controls. This information will help to interpret the leukemia risk to HMWs as well as to assist in evaluating the efficacy of environmental monitoring. (See next section for more detail on these recommendations.)

TRANSPORTATION AND OTHER ACCIDENTS: As shown in summary Table 4-3, the overall SMR for transportation accidents was 1.4. The SMR was higher for the all urban compared with the all rural subgroup. The overall SMRs for these groups were 2.2 and 1.1, respectively. The SMRs for urban and rural "HMWs only" were 3.3 and 1.2, respectively.

The overall SMR increased with later years of starting work. This trend was dramatic for urban HMWs (Table 4-3). No trend was seen for age started work. For rural HMWs, the SMR increased with increasing years of work experience (summary Table 4-4).

Part of this increasing SMR in later years may be accounted for by the decrease in age adjusted mortality from transportation accidents for white male Minnesotans. As seen in Figure 4-1, age adjusted mortality increased

slightly between 1945-1954 and 1965-1974. However, age adjusted mortality decreased from 44/100,000 in 1965-1974 to 30/100,000 in 1975-1984. The SMRs for these four periods for all state workers were 1.0, 1.4, 2.0, and 4.2, respectively.

Table 3-57 lists the cause of death for each worker killed in transportation accidents. A total of 14 workers died while at work based on death certificate information. For 2 additional workers, it could not be determined from the death certificate if they died at work with MNDOT. No specific type of injury was apparent from this list. Though the SMRs for "other" accidents were not increased as seen in Table 3-61, there were 10 MNDOT work related deaths. Four of these ten were the result of mishaps with equipment and two were the result of falls.

In summary, the SMRs for transportation accidents have been increasing steadily over time in this cohort. Urban workers were affected more than rural workers, and "HMW only" workers more than all workers. HMWs were at increased risk of dying from transportation accidents and this risk has been increasing relative to other Minnesotans. The cause for this increase in not apparent. There was also several injurious deaths at the workplace from other causes. The risk conferred by both on the job and off the job activities needs to be evaluated further. The overall contribution of occupation to this increase cannot be evaluated at this time.

There have been studies of safety practices in highway construction zones (Hargroves, 1978 and Davis, 1982). These studies, however, examine risk factors related to public motoring in roadway repair zones and not to specific work practices.

As is often the case with injurious death, mortality may reflect only a small portion of total morbidity. Most injuries do not result in mortality. For example, in 1983 in Minnesota, there were 481 fatalities

but 39,103 personal injuries due to automobile accidents. This means nonfatal injuries outnumbered fatal injuries 80 to 1 for motor vehicular crashes. During the same year, there were 48 road maintenance vehicle crashes and none of these were fatal (Crash Facts, 1983). It seems unlikely that alcohol played a major role in this cohort because there was no indication that other alcohol-related deaths were greater than expected in relation to Minnesotans in general. This is important because of the known connection between traffic safety, injury, and alcohol use (NHTSA, 1984).

Table 4-5 lists the principal compensated work injuries for MNDOT over a three year period. These data were compiled on all MNDOT employees, not just HMWs. However, as seen in this table, there were 236 injuries related to trucks and/or tractors and/or other vehicles and 301 injuries related to falls. The severity of these injuries cannot be determined from these data. Table 4-6 lists the area of the body injured. Back, finger, knee, and eye injuries represent the most common injury sites. Once again, severity cannot be determined. Data gathered on these events were not sufficient to evaluate risk factors for injuries. The acquision of more and better data is a prerequisite to the study of injuries. In general, there is a lack of detailed information on the groups susceptible to injuries. Furthermore, continuous and systematic data collection is essential for planning and evaluation of preventive programs, both within and outside the workplace (Injury in America, 1985). The risk factors for fatal injuries may also be elucidated by the case-control studies recommended in the next section.

CANCER OF THE URINARY ORGANS: There was increased mortality from cancers of the urinary organs for workers with 40-49 years of latency (SMR of 2.9, $p < .05$). This increase was due primarily to kidney and bladder cancer. No strong trend was found for either cause when examined by total years of work. Of the 19 deaths from cancer of the urinary organs, 12 were due to bladder cancer, 6 were due to kidney cancer, and 1 was due to urethral cancer (Table 3-22).

a. Bladder Cancer: There are multiple risk factors for these cancers (renal pelvis, ureter, bladder, and urethra). The dye industry has long been implicated in bladder cancer. Benzidene and beta-naphthylamine have been identified as potent bladder carcinogens. In addition, a relationship has been found between several trades and bladder cancer. These trades include rubber, leather, and textile workers, hairdressers, and construction workers. Numerous studies also suggest a relationship between bladder cancer and tobacco, cyclamates, and phenacetin. Cole found increased cancer risk in five occupational categories: dyestuffs, rubber, leather, painting, and organic chemicals (Morrison, 1982).

It is typical to have long induction periods for bladder cancer especially with weaker cancer causing agents. This is consistent with the elevation seen in this study. The largest increase was seen in those with a latency of 40-49 years. The increase found from bladder cancer (Table 3-23) was the result of 3 deaths. There was, however, a total of 12 bladder or urethral cancer deaths.

Given the overall decrease in smoking related lung cancer, it is unlikely that tobacco contributed substantially to the excess cases of bladder cancer. Several occupations have previously been found to be associated with bladder cancer; thus, an occupational etiology cannot be

ruled out. For these reasons, bladder cancer should be included in the case-control studies.

b. Kidney Cancer: As seen in Table 3-22, there was an SMR of 0.6 for kidney cancer based on 6 cases. Most of these cases occurred in workers with 40-49 years of experience. Although both the incidence and mortality from kidney cancer has been steadily increasing during this century, it is still a relatively rare cancer, comprising less than 5% of all cancers diagnosed on an annual basis. The risk factors for this cancer are poorly understood.

Perhaps the most clearly established risk factor for kidney cancer is smoking. Both British and American studies of cohorts of smokers have demonstrated elevated kidney cancer rates in comparison to nonsmoking cohorts (Schottenfeld and Fraumeni, 1982). This association has also been noted in case-control studies. A recent large population-based, case-control study reported that men who smoked cigarettes had a relative risk of 1.7 for developing kidney cancer and women who smoked had a relative risk of 1.9 (McLaughlin, 1984). The risk increased with duration of smoking. Another smaller study did not find this same association, but did report an increased risk with chewing tobacco, particularly in conjunction with heavy cigarette smoking (Goodman, 1986). Relative obesity has also been implicated as a risk factor for developing kidney cancer for women (McLaughlin, 1984) and more recently for men (Goodman, 1986).

A variety of other risk factors have been suggested, including phenacetin use, previous history of kidney stones and infections, German and Scandinanian ethnicity, and meat consumption. Coffee and alcohol consumption do not seem to be related. Further research is needed to clarify the role of these putative risk factors.

An association between exposure to petroleum and petroleum products and kidney cancer has been suggested in both cohort and case-control studies. Studies of cohorts of both coke-oven workers (Redmond, 1972) and petroleum refinery workers (Thomas, 1982; Hanis, 1982; Waxweiler, 1983) have demonstrated increased risk of kidney cancer, although interpretation of these findings is limited by lack of any estimates of exposure. However, in the studies of refinery workers, lung cancer incidence has been less than expected, suggesting that the increased kidney cancer incidence is not due to smoking. An association between kidney cancer and self-reported exposure to petroleum, tar, and pitch products has also been noted in a case-control study, although no association was found when jobs were categorized according to their potential for exposure to petroleum products (McLaughlin, 1985).

The lack of specific exposure data, again, points to the need for further exploration of possible etiologies and exposure monitoring. Initially, careful and detailed analysis of job histories, through case-control studies, may be useful to further evaluate mortality due to kidney cancer.

OTHER CANCERS: Several other cancers need to be discussed. Cancer of the mouth and pharynx had an overall SMR of 0.9. Workers with 40 or more years of experience who started work between 1900 and 1924 had an SMR of 20.6. However, this was based on only 2 deaths, and no increase was seen in workers who had 40 or more years of experience and started between 1925-1944. Major risk factors for these cancers are alcohol, tobacco, and race. The only occupational factors that have been related to these cancers are wood dusts and radiation -- in particular, sunlight has been associated with increased cancer of the lip. The small number of cases of oral-

pharyngeal cancers, the failure to find an increase in workers who started in 1925-1944, and the number of non-occupational risk factors associated with these cancers lead to the conclusion that further evaluation of these deaths would not be useful.

Cancer of the digestive tract had an SMR of 0.82. Rural workers had an SMR of 0.81 and urban workers an SMR of 0.95. Urban workers who started between 1935-1944 and worked 40-49 years had an SMR of 14.9 (3 cases). These three workers had cancer of the colon. Coke-plant workers employed in the steel industry may be at excess risk of digestive cancer (NAS, 1983). There is also some indication that cancer of the colon may be increased in machinists (Schottenfeld, 1982). In general, however, cancer of the large intestine is not thought to be an occupationally related disease. Risk factors for colon cancer include inflammatory bowel disease, hereditary factors, diet, and race. The multifactorial nature of these cancers combined with the fact that an increase was seen in only those workers who started in 1935-1944 leave doubt about the utility of further evaluation of this cause of death. These results, however, should be carefully considered in future updates of this cohort.

Cancer of the male genital organs had an SMR of 1.0. There was an SMR of 3.2 for men who started between 1955-1964. This increase was due to prostatic cancer among men who started work at MNDOT at an older age. Cancer of the prostate is one of the most common malignancies in the United States. Approximately 0.48 men per 100 develop prostatic cancer before the age of 65 and 3.48 men per 100 by the age of 85.

Several occupational studies of prostatic cancer have been reported. Many of these studies implicate cadmium exposure from welding, electroplating and alkaline battery production. Data from the Third National Cancer Survey showed prostatic cancer to be elevated among

ministers, plumbers, rubber workers, and coal miners. In addition, prostatic cancer may be related to sexual activity, dietary factors, race, religion, and socioeconomic status (Greenwald, 1982).

It is also noteworthy that there is a known inverse relationship between alcoholic cirrhosis and the development of prostatic cancer. This "protective" effect of alcohol is thought to result from the hyperestrogenism caused by excess alcohol use. Theoretically, the decrease in alcohol related mortality in this cohort could relate to the increase in prostatic cancer in some groups. This is purely speculative with regard to this specific cohort. Regardless, the endocrinologic parameters surrounding prostatic cancer increase the difficulty of studying this disease. This combination of factors makes the study of prostatic cancer extremely difficult. It is unlikely that further evaluation of prostatic cancer in this cohort would be useful.

There were 2 cancer deaths coded as resulting from soft tissue cancer. These deaths were miscoded and were actually both mesotheliomas that should have been coded to the respiratory cancer. Exposure to asbestos is the only known risk factor for mesotheliomas. This makes these cases sentinel events that should be investigated on an individual basis.

OTHER NONCANCER DEATHS: A total of 30 deaths resulted from diabetes. The overall SMR for diabetes was 1.2. A statistically significant increase was seen in those who started work 1965-1974. The increase in these years was seen for both rural and urban workers. Several chemical agents are known to cause diabetes. These substances include alloxan, streptozotoxin, and, as a secondary effect, alcohol.

Diabetes is a disease that has not been commonly associated with work. Reports from early this century indicated that diabetes was more common among the "learned professions," occupations exposed to alcohol (e.g., brewers), butchers, and perhaps, commercial clerks. Diabetes was negatively associated with hard labor of all kinds. Later reports indicated that there may have been differences in the prevalence of diabetes in different occupational groups. Those differences, however, have not been well defined (West, 1978).

Diabetes is a complex illness influenced by many factors such as heredity, race, geography, parity, exercise, nutrition, socioeconomic status, and infection to name a few. In light of the above factors, specific study of diabetes in this cohort is unwarranted.

Diseases of the heart are the most common cause of mortality in the U.S. and Minnesota. The greatest elevation seen in this cohort was for chronic disease of the endocardium. The SMR for HMWs who worked 10-19 years was 3.4. The urban and rural patterns were the same. Table 3-42 lists these deaths by cause. Almost all of these deaths were the result of cardiac valvular lesions. The SMR for diseases of the circulatory system was 0.8. There was an increase in vascular lesions in those workers who had 50 or more years of latency and started work between 1900-1924. There was a total of 4 deaths in this group.

Though many environmental exposures are known to induce cardiac disease (e.g., cobalt, carbon monoxide, carbon disulfide, cadmium, and trichloroethylene) none of these substances exerts its effect by causing valvular lesions. Thus, it seems very unlikely that valvular disease found in this cohort was the result of an occupational exposure. The final caveat in interpreting cardiovascular mortality is that these deaths were, and are, poorly coded on death certificates. Small fluctuations in these

rates are, therefore, difficult to evaluate. Further follow-up of these deaths is not warranted.

Diseases of the respiratory system were generally decreased in this cohort. For the category of fibrotic and other lung disease, the SMR was 1.1. Three of these deaths were due to pulmonary fibrosis. There are many occupational causes (e.g., silicosis, asbestosis) and non-occupational causes (e.g., sarcoidois, scleroderma, rheumatoid arthritis) of pulmonary fibrosis. Because the occupational causes may be considered sentinel events, these cases should be evaluated on an individual basis.

There was an overall deficit of digestive diseases. The SMR for these causes was 2.4 for the group that started 1935-1944 and had 20-29 years of experience. No trend was seen with latency or the number of years worked and the overall SMR was 0.8. This category of diseases does not appear to need further evaluation.

Diseases of the genito-urinary system had an overall SMR of 0.8. There was, however, an SMR of 6.6 for chronic renal failure for workers with 50 or more years of latency (Table 3-51). Many chemicals such as heavy metals and organic solvents may cause renal failure. In addition, there are dozens of metabolic and physiologic causes of renal dysfunction -- these causes range from heart failure to pregnancy.

Table 3-53 lists all cases of chronic renal failure in this cohort as well as underlying medical conditions. Underlying pathology could not be adequately explained from data contained on the death certificates of these individuals. Because there are several occupational exposures (such as lead) that might result in renal disease (and these may be germane to this cohort), it would be prudent to further evaluate this cause of mortality as part of the follow-up case-control studies.

Diseases of the musculoskeletal system had an SMR of 1.5. The SMR had a tendency to increase with an increasing number of years worked. The total number of deaths, however, was 5. No category had more than 2 deaths. All of these cases appeared to be the result of an underlying immunologic disorder. It is unlikely that further evaluation of these deaths would be useful.

SUMMARY: The HMW cohort had a deficit of 169 deaths. Most of this deficit came from the three major categories of death: cancer, heart, and cerebrovascular related mortality. Despite the favorable overall mortality experience among highway maintenance workers, several findings raise serious questions about the health and safety of these workers. Most important among these are increased risks of leukemia among long-term workers and accidental deaths among short-term workers. Also of potential concern are deaths from urinary cancers and chronic renal failure. Though in some instances, elevations were found for other causes of mortality (e.g., endocardial diseases, prostatic cancer, and diabetes), there does not appear to be a coherent biologic reason to evaluate these further. Two other causes of mortality, mesothelioma and pulmonary fibrosis, should be evaluated further through case history studies. Cancer of the colon should be evaluated further in future studies.

ENVIRONMENTAL MONITORING: Exposure monitoring conducted to date has failed to reveal an excessive worker exposure to petroleum products, benzene, or PAHs. Analysis of bulk samples revealed 13,100 ppm dodecane in MC-70 tack coat, and 188 ppm in Koch RC/250 cutback asphalt.

The failure to detect PAHs in breathing zone and asphalt samples is difficult to evaluate. These data are inconsistent with other findings (Brandt, 1985) and raises questions about the sampling and analytic

procedures. The assessment of exposure to PAHs contained in bituminous materials is not straightforward and stringent criteria must be used in data collection and evaluation. Dodecane is an aliphatic hydrocarbon with 10 carbons. Dodecane and larger aliphatic materials are thought to act as co-carcinogens (i.e., enhance other carcinogenic substances). Dodecane is being considered by NIOSH as a possible indicator substance when evaluating exposure to asphalt fumes.

The earliest historic data available on herbicide use dates back to 1952. At that time, 2,4-D (2,4 diclorophenoxy acetic acid) and 2,4,5-T (2,4,5 trichlorophenoxy acetic acid) were used for the control of weeds and brush. The first records indicating the use of other herbicides was in 1963. There was, however, a large gap in the records retained.

In 1964, 15 herbicides were being used by MNDOT. The majority of spraying was done with 2,4,-D, followed by Ureabor, then 2,4,5-T. In addition, a variety of pesticides of other types were in use. Although the use of 2,4,5-T was discontinued in 1978, a large number of other pesticides continues to be used. The development of a complete listing of materials by decade would be a difficult task of doubtful value.

To date, despite efforts by MN OSHA and the MNDOT, the environmental exposures of HMWs have not been well characterized. It is important at this time to identify those areas most in need of evaluation and the best means of assessing any potential problems.

Figure 4-1. Transportation Accident Mortality Rate Among All Minnesota White Males by Time Period.

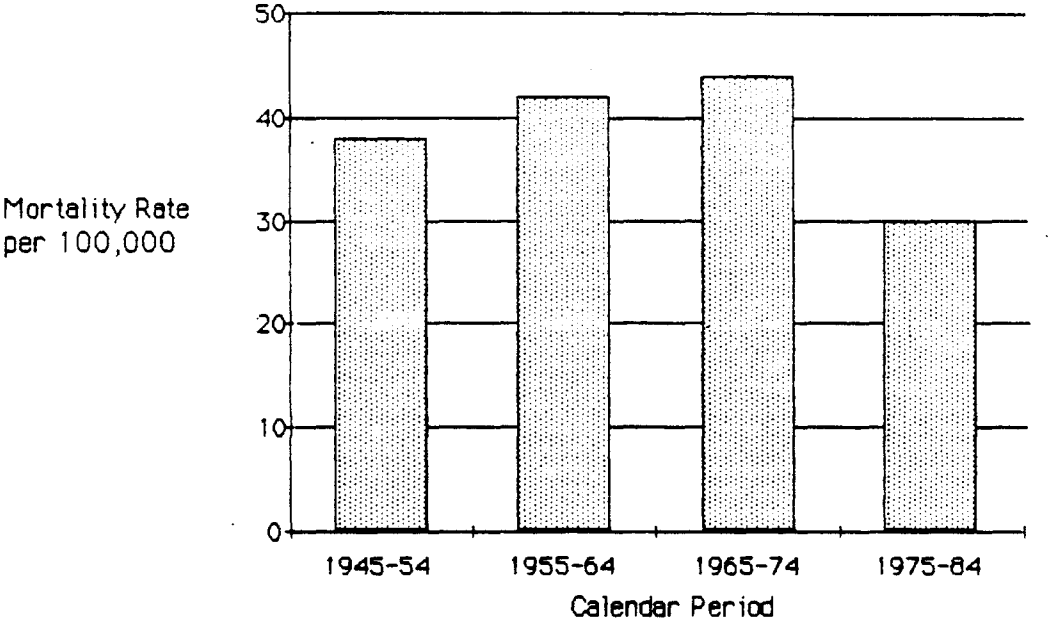


Table 4-1. SMRs for Selected Alcohol Related Causes of Death

Cause of Death	Number of Deaths	SMR	Percent of Deaths Attributed to Alcohol#
Accidental Falls	13	0.8	41
Suicide	15	0.6	26
Cirrhosis	19	0.8	80
Alcoholism	4	1.0	100
Cancer of the Mouth & Pharynx	7	0.9	48
Total	58	0.7	--

Source: The Social and Economic Cost of Alcohol Abuse in Minnesota, 1985

Table 4-2. SMRs for Selected Smoking Related Causes of Death

Cause of Death #	Number of Deaths	SMR	Percent of Deaths Attributed to Smoking##
Cancer of Lung & Bronchus	54	0.7	85
Chronic Bronchitis	7	1.5	90
Emphysema	19	0.9	90
Cancer of Mouth & Pharynx	7	0.9	52
Kidney & Bladder Cancers	19	1.0	20
Total	136	0.8	--
Total (excluding lung cancer)	82	1.0	--

An additional 30 deaths from chronic obstructive pulmonary disease occurred in this cohort. The SMR for "other" respiratory diseases which included these 30 cases was 1.1

Source: Minnesota Center for Nonsmoking & Health, 1985.

Table 4-3. Transportation Accident Mortality for SMRs for State, Urban, and Rural HMWs by Year Started Work

Year Started	State		Urban		Rural	
	HMW# ONLY	ALL WORKERS	HMW ONLY	ALL WORKERS	HMW ONLY	ALL WORKERS
1925 - 1934	0.0	1.4	0.0	0.0	0.0	1.5
1935 - 1944	1.1	1.9	0.0	0.0	1.2	1.0
1945 - 1954	1.3	0.9	1.4	9.0	1.2	1.0
1955 - 1964	1.4	1.4	2.6	3.4*	0.8	.7
1965 - 1974	2.7*	2.0*	5.0**	2.5	1.4	1.8
1975 - 1984	8.3**	4.2*	21.4**	14.7**	3.0	1.3
Total	1.7*	1.4*	3.3**	2.2*	1.2	1.1

HMW Only: HMWs with only highway maintenance worker experience
* $P < .05$
** $p < .01$

Table 4-4. SMRs for State, Urban, and Rural HMWs by Number of Years Worked for Transportation Accidents

Years Worked	State		Urban		Rural	
	HMW# ONLY	ALL WORKERS	HMW ONLY	ALL WORKERS	HMW ONLY	ALL WORKERS
0 - 4	1.9**	1.4	3.9*	2.8	1.2	.9
5 - 9	1.5	1.4	3.4	2.7	0.8	1.0
10 - 19	1.3	1.4	1.6	1.3	1.2	1.3
20 - 29	1.3	0.9	0.0	0.0	1.4	.9
30 - 39	8.2	3.2**	---	---	8.7	3.2
40 +	---	0.0	---	---	---	0.0
Total	1.7	1.4**	3.3	2.2*	1.2	1.1

HMW only: HMWs with only highway maintenance worker experience
* $p < .05$
** $p < .01$

Table 4-5. First Report of Injury by Cause for all MNDOT Employees: 1984-1986.

Categories	Number	Percent
Strain/Sprain/Muscle Pull	394	21.1
Struck/Caught	392	21.0
Slip/Fall/Fell	301	16.2
Cut(s)/Puncture	289	15.5
Car/Auto/Vehicle Truck/Tractor	236	12.7
Burn(s)	73	3.9
Bite(s)	8	0.4
Cart	5	0.3
Saw	25	1.3
Infection	8	0.4
Athletic Games	0	0.0
Machine	6	0.3
Chemical	4	0.2
Bee/Wasp	11	0.6
Rash	9	0.5
Heart Attack	8	0.4
Wheelchair	0	0.0
TB Exposure	0	0.0
Stress	0	0.0
Carpal Tunnel	2	0.1
Elevator	1	0.1
Hearing	4	0.2
Asbestos	0	0.0

Source: Denise Fleury, Minnesota Department of Labor and Industry, March 2, 1987

Table 4-6. First Report of Injury by Anatomic Site for all MNDOT Employees: 1984-1986

Site	Number	Percent
Back	414	22.2
Finger	163	8.7
Knee	111	6.0
Multiple	106	5.7
Eye	160	8.6
Hand	98	5.3
Arm	75	4.0
Head	86	4.6
Neck	55	3.0
Ankle	67	3.6
Shoulder	50	2.7
Thumb	50	2.7
Wrist	37	2.0
Leg	79	4.2
Foot	63	3.4
Elbow	59	3.2
Toe	26	1.4
Rib	22	1.2
Face	34	1.8
Hip	9	0.5
Nose	6	0.3
Chest	16	0.9
Groin	17	0.9
Abdomen	61	3.3
Ear	18	1.0
Stomach	10	0.5

Source: Denise Fleury, Minnesota Department of Labor and Industry, March 2, 1987.

5. RECOMMENDATIONS

1. The mortality experience of highway maintenance workers should be periodically updated. In addition, the cancer morbidity experience of these workers should be addressed if, and when, sufficient data are available from the statewide cancer surveillance system.

The present and future cohort of HMWs should have periodic follow-up. The purpose of the continued follow-up is to assist in the determination of the nature of causality and in targeting and evaluating programmatic interventions. Partial incomplete follow-up for an additional 2 years provided enough data to indicate that leukemia mortality in workers with 30-39 years has remained elevated. The next recommended update and complete follow-up should be scheduled for 1990. The MDH should work with the MNDOT and the DOER to ensure that appropriate records are maintained and to facilitate follow-up and tracing. Future follow-up should be relatively simple since most of the HMW cohort has been assembled. The cohort should be updated on a yearly basis. This update would include addition of new members (e.g., new workers with one year of experience) as well as an update of mortality.

At the end of 1989, a listing of cohort members will be sent to the SSA for complete follow-up. Tracing will be minimized because all workers without a SSN have been traced and found. Programs that have been compiled at the MDH for the present study will be used in future studies with little modification. By that time, it should also be possible to evaluate the cancer morbidity of HMWs through the use of the Minnesota Cancer Surveillance System.

2. Case-control studies should be conducted to further characterize any specific highway maintenance activities that may be associated with increased mortality risk.

Although many potential causes of concern have been ruled out by this study, several causes of death warrant further investigation. Case-control studies should be conducted in order to identify any specific types of HMW experience that may be associated with specific causes of death. These studies should be conducted for leukemia, urinary system cancers, renal diseases, and injuries. Case reviews should be conducted for those who died of fibrotic lung diseases and mesotheliomas. At this time, there is only a crude definition of HMW experience and (if possible) these definitions need refinement. The case-control format will involve existing record systems only for leukemia, urinary cancers, and chronic renal disease. Deaths due to injuries may require personal interviews.

In these studies, cases will be cohort members who died of the causes of interest (e.g., leukemia, urinary system cancers, injury, or renal disease). Controls will be matched to cases in a four-to-one ratio. Controls will be frequency matched from the cohort by the year a case started work with MNDOT as well as for urban or rural residence. Controls may be either alive or deceased. Deceased controls will have had to die from a cause unrelated to the cause of death of the case. For example, cancer cases will not be matched to cancer controls.

Because of problems encountered interviewing next of kin, case-control studies for cancer and other causes of death will only involve a detailed review of work histories. Detailed work histories will be abstracted from the record sources described earlier. Because of the length of work records, this was impossible to do for the entire cohort. Based on detailed abstracts, more refined job classifications will be created.

These classifications will then be evaluated for a possible relationship between the outcome(s) of interest and specific job classifications.

3. A pilot study for injury surveillance should be conducted.

A pilot study for injury surveillance should be conducted. Mortality due to injuries may be a small portion of the injury experience of HMWs. If this is true, then programs for reduction of morbidity and mortality need to be developed. The first step in this process is a study to determine the feasibility of statewide injury surveillance within the MNDOT. This pilot study should be conducted through existing MNDOT safety processes with assistance from the MDH.

In order to evaluate injury related mortality, it will be necessary to create a systematic method of data collection. This process should include the administration of questionnaires to all HMWs and other MNDOT employees. These questionnaires will evaluate possible risk factors to serve as predictors of future injury. These factors may include tobacco use, alcohol use, education, attendance in safety classes, previous injuries, and distance commuting each day.

Following the collection of these data, a computerized algorithm should be developed to evaluate the type, cause, and outcome of specific injuries. The type and cause of injuries may be coded through the use of ICD codes. This process, however, will require the collection of additional data by the MNDOT. A measure of injury severity will need to be developed. This measure might include a final disability rating, total lost work, cost or a combination of these factors.

These data will allow a detailed evaluation of the circumstances surrounding injuries sustained by MNDOT employees. The present data only allow a crude categorization of events.

4. There should be additional environmental monitoring for suspected exposures to hazardous agents.

Environmental monitoring for suspected toxic exposures needs to be continued. The purpose of the monitoring is to develop better insights into current exposures for purposes of understanding continuing elevations (if any) of mortality and to ensure that risks to known toxic substances are minimized. A part of the monitoring program must include a quality control program to ensure that the latest technology and procedures are used.

NIOSH has been evaluating several methods with which to study exposure to asphalt fumes. Future environmental monitoring for asphalt should be done with technical advice and/or assistance from NIOSH. In addition, more data on the exposure of HMWs to herbicides, dusts, lead, and solvents should be collected.

5. A pilot study should be conducted using cytogenetic assays to assess personal exposures to mutagenic substances.

A pilot study for cytogenetic screening should be conducted. The current study indicated that the greatest risk was among workers with 30 or more years experience. As of December 31, 1984, 359 HMWs had worked 30-39 years and 72 HMWs had worked more than 40 years. Targeting these groups would facilitate evaluation of the utility of cytogenetic screening for monitoring exposure. Since these tests provide evidence of both recent and long term exposure, cytogenetic screening may be useful for both directing environmental monitoring as well as interpreting the findings of the

mortality studies. If environmental monitoring continues to be negative and cytogenetic screening is positive, this will be a strong indication that environmental monitoring is misdirected or inadequate to measure a potentially important exposure.

Cytogenetic techniques, in particular the measurement of chromosomal aberrations and sister chromatid exchange (SCE), have been demonstrated to be sensitive indicators of both in vitro and in vivo induced DNA damage. It would be useful to investigate these chromosomal changes in peripheral blood lymphocytes of 30 individuals, 15 of whom have been selected as a possible "exposed" group based on job descriptions and length of employment, and 15 control individuals matched for age, sex, and smoking history.

By analyzing 50 cells per individual for SCE frequencies, this proposed sample size of 15 individuals per group would provide adequate statistical power to detect a 15% or greater increase in SCE rates in the exposed group compared to the controls (Hirsch, 1984). For chromosome aberrations, 200 cells will be anlayzed per individual, thus providing sufficient statistical power to detect biologically meaningful differences in aberration frequencies between the two groups. The data from this study will determine whether or not cytogenetic assays will provide useful tools for monitoring possible exposures to this selected population.

To complete the cytogenetic profile, in vivo mutation frequency assay is required. This test has been developed to measure the in vivo mutation frequency in somatic cells of humans. This mutation test allows the determination of the frequency of mutations in a specific gene present in the T-lymphocytes in samples of peripheral blood. This is an important companion test to the measurement of sister chromatid exchange frequencies

and chromosome aberrations in these human blood cells. These two tests provide information on chromosome damage at the microscopic level, while the mutation test measures effects at the single gene and molecular level. As such, it serves as a measure of the genetic consequences of DNA damage and it is the only assay which can provide this needed information for human genetic monitoring.

The above mentioned tests are technically demanding and must be conducted by a scientist certified by the American College of Medical Genetics.

6. The potentially hazardous nature of the materials and some workplace practices utilized in highway maintenance requires continuing efforts on the part of both management and labor to reduce worker exposures to harmful agents and activities.

HMWs should use their protective equipment and follow recommended safety procedures. Until (and if) the etiology of the increased mortality due to leukemia and urinary cancers are understood, it is prudent to be as cautious as possible. It may turn out that these increases in mortality are not directly associated with the HMW experience but until that time, the union and the MNDOT should use this study as a vehicle to enforce these safety measures.

When not already being done on an ongoing basis, there should be a review of work practices related to protective equipment. This review should include policies concerning helmets, protective eye wear, hearing protection, respirators, reflective vests, and safety shoes. Safety efforts should also be coordinated with construction engineers on an ongoing basis.

BUDGET: A budget has been developed for the implementation of the recommendations outlined above. Some funding has already been provided by the National Institute of Occupational Safety and Health (NIOSH). NIOSH has awarded the MDH $60,000 over the next two years to continue some study and follow-up of highway maintenance workers. Through existing staff support, the MDH can contribute another $40,000. An additional $170,000 (not including environmental monitoring or in-house MNDOT contributions) will be required over the next two years to begin implementation of these recommendations.

REFERENCES

Alderson M, Jackson S. (1971). Long term follow-up of patients with menorrhagia treated by irradiation. British Journal of Radiology; 44:295-298.

Aldrich TE, Nash R. (1981). Occupational clustering of cancer. Archives of Dermatology; 117:1-2

Askoy M, Dincol K, Erdem S. (1962). Acute leukemia due to chronic exposure to benzene. American Journal of Medicine; 52:160-166.

Askoy M, Erdem S, Dincol G. (1974). Leukemia in shoe workers chronically exposed to benzene. Blood; 44:837-841.

Askoy M, Erdem S, Dincol G. (1976). Types of leukemia in chronic benzene poisoning. A study of thirty-four patients. Acta Haematologica; 55:65-79.

Axelson O, et al. (1980). Herbicide exposure and tumor mortality. An updated epidemiological investigation on Swedish railroad workers. Scandinavian Journal of Work Environment and Health; 6:73-79.

Bailar JC, Ederer F. (1964). Significance factors for the ratio of a Poisson variable to its expectation. Biometrics; 20:639-643.

Belinky B, Cooper CV, Niemier RN. (1973). Fractionation and analysis of asphalt fumes for carcinogenicity testing. Personal communication.

Bender AP, et al. (1987). Unpublished manuscript.

Bizzozero O, Johnson K, Ciocco A. (1966). Radiation-related leukemia in Hiroshima and Nagasaki, 1946-1964. I. Distribution, incidence, and appearance time. New England Journal of Medicine; 274:1074.

Blair A, Fraumeni JF, Jr, Mason TJ. (1980). Geogrpahic patterns of leukemia in the United States. Journal of Chronic Disease; 33:521-526.

Blair A, White DW. (1985). Leukemia cell types and agricultural practices in Nebraska. Archives of Environmental Health; 40:211-214.

Brandt HC, et al. (1985). Sampling and analysis of bitumen fumes. Annals of Occupational Hygiene; 29(1):27-80.

Brandt L, Nilsson PG, Mitelman F. (1978). Occupational exposure to petroleum products in men with acute nonlymphocytic leukemia. British Journal of Medicine; 4:553-557.

Breslow NE, Liang KY. (1982). The variance of the Mantel-Haenszel estimator. Biometrics; 38:943-952.

Brief RS, et al. (1980). Benzene in the workplace. American Industrial Hygiene Association Journal; 4:616-623.

Brown BW, Hollander M. (1977). Statistics: A Biomedical Introduction. New York; J. Wiley and Sons.

Caldwell GG, Heath CW. (1976). Case clustering in cancer. Southern Medical Journal; 69:1598-1602.

Cartwright RA, Miller JG. (1984). Lymphoid and haematopoietic malignancy case occurrence in UK, 1984. Lancet; 3:1270-1271.

Checkoway H, et al. (1984). An evaluation of the associations of leukemia and rubber industry solvent exposures. American Journal of Industrial Medicine; 5:239-249.

Comstock GW, Markush RE. (1986). Further problems on death certification. American Journal of Epidemiology; 124:180-181.

Court Brown W, Doll R. (1965). Mortality from cancer and other causes after radiotherapy for ankylosing spondylitis. British Medical Journal; 2:1327.

daSilva Horta J, daMotta LC, Tavares MH. (1974). Thorium dioxide effects in man. Environmental Research; 8:131-159.

Davis TD. (1983). Construction zone safety and delineation study. New Jersey Department of Transportation. (Publication No. FHWA/NJ-83/005.)

Dean B. (1979). Genetic toxicology of benzene, toulene, xylene, and phenols. Mutation Research; 47:75-89.

Department of Public Safety. (1983). Motor Vehicle Crash Facts. St. Paul, Minnesota Department of Public Safety.

Donham KJ, et al. (1977) Sero epidemiologic studies on the relationship of human and bovine leukemia in Iowa. Journal of the National Cancer Institute; 59:851-857.

Enterline PE, Vinen J. (1985). The epidemiologic evidence for an association between gasoline and kidney cancer. Environmental Health Perspectives; 62:303-312.

Environmental Protection Agency. (1984). Creosote Special Review Position Document 2/3. Office of Pesticides and Toxic Substances, EPA, Washington, D.C.

Eriksson M, et al. (1981). Soft-tissue sarcomas and exposure to chemical substances: A case-referent study. British Journal of Industrial Medicine; 38:27-33.

Fishbein L. (1984). An overview of environmental and toxicological aspects of aromatic hydrocarbons. I. Benzene. Science of the Total Environment; 40:189-218.

Fleiss JL. (1981). Statistical Methods for Rates and Proportions, 2nd ed. New York: J Wiley and Sons.

Fraumeni J. (1969). Clinical epidemiology of leukemia. Seminars in Haematology; 6:250-267.

Gallo RC. (1985). The human T-cell leukemia/lymphotropic retroviruses (HTLV) family: Past, present, and future. Cancer Research; 45:4524-4533.

Garshick E. (1987). Diesel exhaust exposure and lung cancer in U.S. railroad workers (Abstr). Health Effects Institute Annual Conference, February 1987, South Carolina.

Gibson R, et al. (1972). Irradiation in the epidemiology of leukemia among adults. Journal National Cancer Institute; 48:301-311.

Glass AG, Hill JA, Miller RW. (1968). Significance of leukemia clusters. Journal of Pediatrics; 73:101-107.

Goldstein BD. (1977). Hematotoxicity in humans. Journal of Toxicology and Environmental Health; 2:63-68 (suppl).

Goodman MT, Morgenstein H, Wynder EL. (1986). A case-control study of factors affecting the development of renal cell cancer. American Journal of Epidemiology; 124:926-941.

Graham S, et al. (1966). Preconception, intra-uterine, and post-natal irradiation as related to leukemia. National Cancer Institute Monograph; 19:347-371.

Greenwald P. (1982). Prostate. In: Schottenfeld D, Fraumeni JF, eds. Cancer Epidemiology and Prevention. Philadelphia: W.B. Saunders Company.

Guerin MR. (1978). Energy sources of polycyclic aromatic hydrocarbons. IN: Gelboin H and Ts'o P. eds: Polycyclic Hydrocarbons and Cancer, Vol. 1. Academic Press, New York, pp. 3-42.

Gunz F. (1970). Problems in leukemia etiology. Haemotologic and Bluttransfusion; 9:48-62.

Gunz F, Atkinson H. (1964). Medical radiation and leukemia: A retrospective study. British Medical Journal; 1:389-393.

Hammond EC. (1966). Smoking in relation to death rates of one million men and women. National Cancer Institute Monograph; 19:127-204.

Hanis NM, et al. (1982). Epidemiologic study of refinery and chemical workers. Journal of Occupational Medicine; 24:203-212.

Hardell L. (1977). Malignant mesenchymal tumors and exposure to phenoxy acids. A clinical observation (Swed.) Lakartidningen; 74:2753-2754.

Hardell L, Sandstrom A. (1979). Case-control study: Soft-tissue sarcoma and exposure to phenoyxacetic acids or chlorophenols. British Journal of Cancer; 39:711-717.

Hardell L, et al. (1981). Malignant lymphoma and exposure to chemical substances, especially organic solvents, chlorophenols, and phenoxy acids: A case-control study. British Journal of Cancer; 43:169-176.

Hargroves BT. (1978). Vehicle accidents at maintenance and utility work zones. Charlottesville: Virginia Highway and Transportation Research Council. (Publication No. VHTRC 79-R22.)

Hart GD. (1964). Leukemia and phenylbutazone. British Medical Journal; 2:569.

Health Effects Insitute (1985). Gasoline vapor and human cancer: Evaluation of existing scientific information and recommendations for future research. Cambridge, MA.

Heath CW, Hasterlik RJ. (1963). Leukemia among children in a suburban community. American Journal of Medicine; 34:796-812.

Heath CW, Manning MD, Zelkowitz L. (1964). Case clusters in the occurrence of leukemia and congenital malformations. Lancet; 2:136-141.

Higgins I. (1987). Epidemiologic evidence on the toxicity of diesel emissions (abstr.). Health Effects Insitute Annual Conference, February 1987, South Carolina.

Hoar SK, et al. (1986). Agricultural herbicide use and risk of lymphoma and soft-tissue sarcoma. Journal of the American Medical Association; 256(9):1141-1147.

Hogstedt C, Westerlund B. (1980> Cohort study of the causes of death among forestry workers with and without exposure to phenoxy acid preparations (Swedish). Lakartidningen; 77:1828-1831.

Humphreys JB, et al. (1979). Identification of traffic management problems in work zones. Knoxville: Tennessee University. (Publication No. FWHA-RD-79-4.)

Infante PF, et al. (1977). Leukemia in benzene workers. Lancet; 2:76-78.

Infante PF, Epstein SS, Newtoln WA. (1978). Blood dyscrasias and childhood tumors and exposure to chlordane and heptachlor. Scandinavian Journal of Work, Environment and Health; 4: 137-150.

Infante PF, White MC. (1983). Benzene: Epidemiologic observations of leukemia by cell type and adverse health effects associated with low-level exposure. Environmental Health Perspectives; 52:75-82.

International Agency for Research on Cancer. (1983). IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans. Vol. 32. Polynuclear Aromatic Compounds, Part 1, Chemical, Environmental and Experimental Data. Lyon, France.

International Agency for Research on Cancer. (1985). IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans, Vol. 35. Polynuclear Aromatic Compounds, Part 4, Bitumens, Coal-Tars, and Derived Products, Shale oils and Soots. Lyon, France.

Ishimaru T, et al. (1971). Occupational factors in the epidemiology of leukemia in Hiroshima and Nagasaki. American Journal of Epidemiology; 93:157-167.

Lathrop GD, et al. (1984). An epidemiologic investigation of health effects in air force personnel following baseline morbidity study results. USAF School of Aerospace Medicine, Brooks Air Force Base, TX.

MacFarland HN, et al. (1984). A chronic inhalation study with unleaded gasoline vapor. Journal of the American College of Toxicology; 3:231-248.

Mantel N. (1963). Chi square tests with one degree of freedom: extensions of the Mantel-Haenszel procedure. Journal of the American Statistical Association; 58:690-700.

Mantel N, Haenszel W. (1959). Statistical aspects of the analysis of data from retrospective studies of disease. Journal of the National Cancer Institute; 22:719-748.

Mausner JS, Kramer S. (1985). Epidemiology - An Introductory Text. Philadelphia: W.B. Saunders Company.

McLaughlin J, et al. (1983). Etiology of cancer of the renal pelvis. Journal of the National Cancer Institute; 71:287-291.

McLaughlin JK, et al. (1984). A population-based case-control study of renal cell carcinoma. Journal of the National Cancer Institute; 72:275-284.

McLaughlin JK, et al. (1985). Petroleum-related employment and renal cell cancer. Journal of Occupational Medicine; 27:672-674.

McMichael AJ, et al. (1975). Solvent exposure and leukemia among rubber workers. An epidemiologic study. Journal of Occupational Medicine; 17:234-239.

McNeil D. (1983). Tar and pitch. IN: Kirk RE and Othmer DF, eds. Encyclopedia of Chemical Technology, 3rd ed. Vol. 22. New York, Wiley and Sons, pp. 564-600.

Menck HR, Henderson BE. (1976). Occupational differences in rates of lung cancer. Journal of Occupational Medicine; 18:797-801.

Miettinen OS, Wang J. (1981). An alternative to the proportionate mortality ratio. American Journal of Epidemiology; 114:144-148.

Milham S. (1979). Mortality in aluminum reduction plant workers. Journal of Occupational Medicine; 21:475-480.

Milham S. (1983). Occupational Mortality in Washington State, 1950-1979. (Contract No. 210-80-0088), Cincinnatti OH, NIOSH.

Minnesota Department of Health. (1984). The Minnesota plan for nonsmoking and health. Minneapolis, Minnesota: Minnesota Department of Health.

Mitelman F, Brandt L, Nilsson P. (1978). Relation among occupational exposure to potential mutagenic/carcinogenic agents, clinical findings, and bone marrow chromosomes in acute nonlymphocytic leukemia. Blood; 52:1229-1253.

Modan B, Lilienfeld AM, (1965). Polycythemia vera and leukemia - the role of radiation treatment: A study of 1,222 patients. Medicine; 44:305-344.

Monson RR. (1974). Analysis of relative survival and proportional mortality. Computers and Biomedical Research; 7:325-332.

Monson RR. (1978). USDR users guide. Boston: Harvard University unpublished abstract.

Monson RR. (1985). Occupational Epidemiology. Boca Raton: CRC Press.

Monson RR. (1986). Observations of the healthy worker effect. Journal of Occupational Medicine; 25:425-433.

Morrison AS, Cole P. (1982). Urinary tract. In: Schottenfeld D, Fraumeni JF, eds. Cancer Epidemiology and Prevention. Philadelphia: W.B. Saunders Company.

National Academy of Sciences. (1983). Polycyclic aromatic hydrocarbons: Evaluation of sources and effects. Committee on Pyrene and Selected Analogues. Washington D.C.: National Academy of Sciences.

National Highway Traffic Safety Administration. (1985). Alcohol and highway safety 1984: A review of the state of the knowledge. U.S. Department of Transportation. (Publication No. DOT-HS-806-569.)

Ott MG, Holder BB, Gordon HC. (1974). Respiratory cancer and exposure to arsenicals. Archives Environmental Health; 29:250-255.

Ott MG, et al. (1980). A mortality analysis of employees engaged in the manufacture of 2,4,5-trichlorophenoxyacetic acid. Journal of Occupational Medicine; 22:47-50.

Parker DL, Shultz JM, Gertz L. (1985). Review and Cost of Alcohol Abuse in Minnesota. Minneapolis, Minnesota: Minnesota Department of Health.

Percy CP, Stanek E, Gloecker L. (1981). Accuracy of cancer death certificates and its effect on cancer mortality statistics. American Journal of Public Health; 71:242-250.

Pierre R. (1974). Preleukemia states. Seminars in Haematology; 11:73-89.

Pike MC, Henderson BE. (1975). Clustering of Cancer. CA; 25:230-234.

Pike MC, Henderson BE. (1980). Clustering of cancer cases. National Cancer Institute Monograph No. 53:47-50.

Raile GD. (1981). An epidemiologic investigation of a possible relationship between the occurrence of leukemia and occupational exposures of highway maintenance workers. Minnesota Department of Health (unpublished report).

Rogot E. (1974). Smoking and mortality among U.S. veterans. Journal of Chronic Disease; 27:189-203.

Rowland RE. (1970). Dose and damage in long-term radium cases. In: Medical Radionuclides: Radiation Dose and Effects. Atomic Energy Commission Symposium Series; 20:369-386.

Rubin D, et al. (1985). Work Zone Accident Data Process Training Guide. Wheaton: Cosmis Corporation. (Publication No. FHWA/IP-85-4.)

Santodonato J, Howard P, Basu D. (1981). Health and ecological assessment of polynuclear aromatic hydrocarbons. Journal of Environmental Pathology and Toxicology; 5(1):1-364.

Savitz DA, Calle, EE. (1987). Leukemia and occupational exposure to electromagnetic fields: A review of epidemiologic surveys. Journal of Occupational Medicine; 29(1):47-51.

Schottenfeld D, Winawer SJ. (1982). Large Intestine. In: Schottenfeld D, Fraumeni JF, eds. Cancer Epidemiology and Prevention. Philadelphia: W.B. Saunders Company.

Silverman D. (1987). Motor-exposed occupations and bladder cancer (abstr). Health Effects Institute Annual Conference, February 1987, South Carolina.

Snyder R. (1984). The benzene problem in historical perspective. Fundamental and Applied Toxicology; 4:692-699.

Spiegelman D, Wang J, Wegman D. (1983). Interactive electronic computing of the mortality odds ratio. American Journal of Epidemiology; 118:599-607.

Sterling TA, Arundel AV. (1986). Health effects of phenoxy herbicides. Scandinavian Journal of Work, Environment and Health; 12:161-173.

Tessman GF. (1970). Minnesota Highway Maintenance Costs - A Study of Financial Requirements through 1986. Minnesota Department of Highways, Management Services Section.

Theiss AM, et al. (1982). Mortality study of persons exposed to dioxin in a trichlorophenol process accident that occurred in the DASF AG on Novembver 17, 1953. American Journal of Industrial Medicine; 3:179-189.

Thomas RD, Pope AM, Giese L, Grossblatt N. (1985). Injury in America - A Continuing Public Health Problem. Washington, D.C.: National Academy Press.

Thomas TL, et al. (1982). Mortality patterns among workers in three Texas oil refineries. Journal of Occupational Medicine; 24:135-141.

Thorpe JJ. (1974). Epidemiologic survey of leukemia in persons potentially exposed to benzene. Journal of Occupational Medicine; 18:375-382.

U.S. Department of Commerce, Bureau of the Census (1952). U.S. Census of the Population: 1950. General Characteristics, Minnesota. (Publication No. P-B23.)

U.S. Department of Commerce, Bureau of the Census (1961). U.S. Census of the Population: 1960. General Population Characteristics, Minnesota. (Publication No. PC(1)-B25.)

U.S. Department of Commerce, Bureau of the Census (1971). U. S. Census of the Population: 1970. General Population Characteristics, Minnesota. (Publication No. PC(1)-B25).

U.S. Department of Commerce, Bureau of the Census (1982). U.S. Census of the Population: 1980. General Population Characteristics, Minnesota. (Publication No. PC80-1-B25.)

U.S. Department of Health, Education, and Welfare. International Classification of Diseases, adapted for use in the United States, fifth, sixth, seventh, eighth, and ninth revisions; 1939, 1948, 1955, 1967, 1977.

U.S. Department of Health, Education, and Welfare. Office on Smoking and Health. (1979). Smoking and Health. A report of the Surgeon General. DHEW publication 79-50066.

Van Raalte HGS, Grasso P. (1982). Hematological, myelotoxic, clastogenic, carcinogenic, and leukemogenic effects of benzene. Regulatory Toxicology and Pharmacology; 2:153-176.

Vigliani EC, Saita G. (1964). Benzene and leukemia. New England Journal of Medicine; 271:872-876.

Wallcave L, Garcia H, Feldman R, Lijinsky W, Shubik P. (1971). Skin tumorigenesis in mice by petroleum asphalts and coal-tar pitches of known polynuclear aromatic hydrocarbon content. Toxicology and Applied Pharmacology; 18, 41-52.

Wang HH, MacMahon B. (1979). Mortality of workers employed in the manufacture of chlordane and heptachor. Journal of Occupational Medicine; 21:745-748.

Waxweiler RJ, et al. (1983). Mortality from brain tumors and other causes in a cohort of petrochemical workers. Journal of the National Cancer Institute; 70:75-81.

Wen CP, Tsai SP, Gibson RL. (1983). Anatomy of the healthy worker effect. Journal of Occupational Medicine; 25:283-289.

West KM. (1978). Epidemiology of Diabetes and Its Vascular Lesions. NY: Elsevier Press.

Zack JA, Susskind RR. (1980). The mortality experience of workers exposed to tetrachlorodibenzodioxin in a trichlorophenol process accident. Journal of Occupational Medicine; 22:11-14.

GLOSSARY OF ACRONYMS, TERMS, AND ABBREVIATIONS

95% Confidence Interval	A range of values determined by the degree of variability in the data, which is believed to contain the unknown true value with the specified level of confidence (e.g., 95%). Confidence limits are the boundaries of a confidence interval.
AFSCME	American Federation of State, County, and Municipal Employees.
All Workers	A subset of the cohort population comprised of all workers regardless of job classifications.
BaP	Benzo(a)pyrene.
C	Celsius scale for temperature.
Case-control Study	In a case-control study, those with disease are contrasted to those without disease in terms of interaction with potential disease related factors.
Cluster	A closely grouped (in time or space) series of events or cases of disease. The term is normally used to describe aggregation of relatively uncommon events or diseases (e.g., leukemia).
Cohort	A group of individuals who share a common experience within a specified time period.
DMBA	7,12 Dimethylbenz(a)anthracene.
DMV	Department of Motor Vehicles.
DOER	Department of Employee Relations (Minnesota).
EPA	Environmental Protection Agency.
Exp	Expected number of deaths due to specific cause.
F	Fahrenheit scale for temperature.
HEI	Health Effects Institute.
HMW Only	A subset of the cohort population who had only worked in the HMW job classification throughout their employment.
HMW(s)	Highway Maintenance Worker(s) job classification.

IARC	International Agency for Research on Cancer.
ICD	International Classification of Disease.
LEO	Light Equipment Operator job classification.
Latency	Latency represents the amount of time from when an individual first started work until death, loss to follow-up, or termination of the study.
Leukemogen	Leukemia causing agent.
M.O.R.T.AL.	Minnesota Occupational Risk Tabulating Algorithm.
MDH	Minnesota Department of Health.
MDI	Minnesota Death Index.
MNDOT	Minnesota Department of Transportation.
MSRS	Minnesota State Retirement System.
NAS	National Academy of Sciences.
NDI	National Death Index.
NIOSH	National Institute for Occupational Safety and Health.
NTP	National Toxicology Program.
Nosology (nosologic code)	Classification of causes of death into groups based on a specific set of rules.
OSHA	Occupational Safety and Health Administration.
Obs	Observed number of deaths due to specific cause.
Other (workers)	Job classification other than HMW.
P Value	Probability of occurrence.
PAH(s)	Polynuclear aromatic hydrocarbon(s).
PMR	Proportionate Mortality Ratio.
PPM	Parts Per Million.

Person-years	Person-years take into consideration the number of persons and duration of observation of each person. Study participants contribute person-years of observation until death, loss to follow-up, or termination of the study. For example, if an individual leaves the study after one year due to one of the above reasons, that individual contributes one person-year. It is, thus, possible to express in one number the period when varying numbers of persons are at risk of an event.
SCE	Sister Chromatid Exchange.
SMR	Standardized Mortality Ratio.
SSA	Social Security Administration.
SSN	Social Security Number.
Statistically Significant	Statistical methods allow an estimate to be made of the probability of occurrence. From this estimate, in a sample of a given site, the statistical "significance" of a result can be stated. A result is generally said to be statistically significant if the P value is less than .05 or less than .01.
TCDD	2,3,7,8,-tetrachlorodibenzo-para-dioxin.
TLV	Threshold Limit Value.
TWA	Time Weighted Average.
Tr	Trace amount.
Tracing	Following of workers by a variety of methods to ascertain vital status or other information.
Underlying Cause of Death	The underlying cause of death is the disease or injury which initiated the sequence of events which culminated in death, or the circumstances of the event which produced the fatal injury.

Appendix A-1. Description of HMW Abstract Form Data Items and Facsimile of Abstract

File Number:	Each record was given a four digit code for identification purposes. Each data abstracter was given a two digit number for computer identification.
Source:	Each record that was abstracted was given a fiche number or its source identified as inactive, active, or district.
Last Name:	All workers had their last names written into these fields. The first six letters of the last name were sent to the Social Security Administration.
First Name, Middle Name:	Self explanatory.
Last Known Address:	The most recent address listed in MNDOT records was entered here. This was done only for those with no social security number because the data were needed for tracing.
Social Security Number:	When available the nine digit social security number was entered. The tenth entry was for a letter that was used upon rare occasions. The social security number was used for tracing by the Social Security Administration and National Death Index.
Date of Birth:	Self explanatory.
Sex:	Self explanatory.
District Type:	MNDOT district offices were either maintenance or construction. All HMW worked in maintenance offices. This variable was included as a quality control measure during abstracting.
Date Started at MNDOT:	The first date a worker was known to have worked for MNDOT.
First Date of State Service:	The first date a person was known to have worked for the State of Minnesota. Occasionally, this was earlier than the first day at MNDOT.

FILE NUMBER _____ COL 1-4

MINNESOTA HIGHWAY WORKER STUDY

FOR CODING PURPOSES ONLY

	COLUMNS
ABSTRACTOR'S CODE ____	5-6
FICHE # ____ ☐ INACTIVE 70 ☐ ACTIVE 80 ☐ DISTRICT 90	7-8

DEMOGRAPHIC INFORMATION

SSA FIELDS

LAST NAME _____	9-24
FIRST NAME _____	25-40
MIDDLE NAME _____	41-56
LAST KNOWN ADDRESS	
STREET _____	57-72
_____	73-88
CITY _____	89-104
STATE ____	105-106
ZIP _____	107-111
* SOCIAL SECURITY NUMBER ___-__-____	112-121
DATE OF BIRTH ____ (mm dd yy) SEX ☐ M 1 ☐ F 2	122-128
DISTRICT TYPE ☐ MAINTENANCE 1 ☐ ALL OTHER 2	129
DATE STARTED AT MNDOT ____ (mm dd yy)	130-135
FIRST DATE OF STATE SERVICE if different ____ (mm dd yy)	136-141
LAST WORK DATE AT MNDOT ____ (mm dd yy)	142-147
LAST DATE OF STATE SERVICE if different ____ (mm dd yy)	148-153

FILE NUMBER _____ COL 1-4

MINNESOTA HIGHWAY WORKER STUDY

FOR CODING PURPOSES ONLY

	COLUMNS
ABSTRACTOR'S CODE ____	5-6
FICHE # ____ ☐ INACTIVE 70 ☐ ACTIVE 80 ☐ DISTRICT 90	7-8

DEMOGRAPHIC INFORMATION

SSA FIELDS

LAST NAME _____	9-24
FIRST NAME _____	25-40
MIDDLE NAME _____	41-56
LAST KNOWN ADDRESS	
STREET _____	57-72
_____	73-88
CITY _____	89-104
STATE ____	105-106
ZIP _____	107-111
* SOCIAL SECURITY NUMBER ___-__-____	112-121
DATE OF BIRTH ____ (mm dd yy) SEX ☐ M 1 ☐ F 2	122-128
DISTRICT TYPE ☐ MAINTENANCE 1 ☐ ALL OTHER 2	129
DATE STARTED AT MNDOT ____ (mm dd yy)	130-135
FIRST DATE OF STATE SERVICE if different ____ (mm dd yy)	136-141
LAST WORK DATE AT MNDOT ____ (mm dd yy)	142-147
LAST DATE OF STATE SERVICE if different ____ (mm dd yy)	148-153

WORK HISTORY

DISTRICTS

1A=DULUTH	3A=BRAINERD	5A=GOLDEN VALLEY	7B=WINDOM	99=UNKNOWN
1B=VIRGINIA	3B=ST.CLOUD	6A=ROCHESTER	8A=WILMAR	
2A=BEMIDJI	4A=DETROIT LAKES	6B=OWATONA	8B=MARSHALL	
2B=CROOKSTON	4B=MORRIS	7A=MANKATO	9A=OAKDALE	

CODES

1=DIED/DECEASED
2=FIRED/LAYED OFF/QUIT/RESIGNED
3=INJURED/SICK LEAVE/LEAVE OF ABSENCE
4=RETIRED/RET
5=PART-TIME/INTERMITTENT
6=UNEXPLAINED/TIME GAP

	JOB CLASS	DATE STARTED (MM/DD/YR)	DATE ENDED (MM/DD/YR)	DIS-TRICT #	CODE*	COLUMNS
1	1 HMW 2 LEO 3 OTHER					1-16
2	1 HMW 2 LEO 3 OTHER					17-32
3	1 HMW 2 LEO 3 OTHER					33-48
4	1 HMW 2 LEO 3 OTHER					49-64
5	1 HMW 2 LEO 3 OTHER					65-80
6	1 HMW 2 LEO 3 OTHER					81-96
7	1 HMW 2 LEO 3 OTHER					97-112
8	1 HMW 2 LEO 3 OTHER					113-128
9	1 HMW 2 LEO 3 OTHER					129-144
10	1 HMW 2 LEO 3 OTHER					145-160
11	1 HMW 2 LEO 3 OTHER					161-176
12	1 HMW 2 LEO 3 OTHER					177-192

COMMENTS ☐ YES (1) ☐ NO (2) DIED ☐ YES (1) ☐ NO (2) 193-194

DATE OF DEATH
NAME OF SPOUSE
NAME OF CHILD
SOCIAL SECURITY
ADDRESS
OTHER

SHEET NUM. ____ of ____ 195-196

COMPLETENESS ____ 197
1=COMPLETE 2=INCOMPLETE

A-1-4

Appendix A-2. Example of PMR Calculation

$$\text{PMR} = \frac{\text{Observed Deaths in Cohort Due to a Specific Cause Per Unit Time}}{\text{Expected Deaths (Based on Standard Population) Due to the Same Cause Per Unit Time}}$$

Specific Cause of Interest is Lung Cancer

	(A)	(B)	(C)	(D)	(E)	(F) = (C) x (D)
Age Group	Standard Total Deaths	Deaths Due to Lung Cancer in Standard Population	Lung Cancer Death Proportion in Standard Population	Total Deaths in Cohort Population	Observed Deaths Due to Lung Cancer in Cohort Population	Expected Deaths
30-39	600	12	.02	20	2	.40
40-49	1000	60	.06	100	7	6.00
50-59	2400	300	.125	150	31	18.75
60-69	5500	550	.10	275	48	27.50
					Observed = 88	Expected = 52.65

$$\text{PMR} = \frac{\text{Observed}}{\text{Expected}} = \frac{88}{52.65} = 1.67$$

A-2-1

Appendix A-2. Example of SMR Calculation

$$\text{SMR} = \frac{\text{Observed Deaths in Cohort Due to a Specific Cause Per Unit Time}}{\text{Expected Deaths (Based on Standard Population) Due to the Same Cause Per Unit Time}}$$

Specific Cause of Interest is Lung Cancer

Age Group	(A) Rate of Lung Cancer in Standard Population	(B) Person Years for Cohort Population	(C) Observed Deaths Due to Lung Cancer in Cohort Population	(D) = (A) x (B) Expected Deaths
30-39	.00004	15600	2	.624
40-49	.00033	20900	7	6.897
50-59	.00105	22945	31	24.092
60-69	.00268	16300	48	43.684
			Observed = 88	Expected = 75.297

$$\text{SMR} = \frac{\text{Observed}}{\text{Expected}} = \frac{88}{75.297} = 1.17$$

A-2-2

Appendix A-3. International Classification of Disease Categories -- Sixth - Ninth Revisions

CATEGORY NUMBER	TITLE	5th Rev.	1950-1957 6th Rev.	1958-1967 7th Rev.	1968-1978 8th Rev.	1979-1987 9th Rev.	MORTAL Codes
01[a]	TUBERCULOSIS						99
Respiratory Tuberculosis[b]		013	001-008	001-008	010-012	010-012	1
Other Tuberculosis		014-022	010-019	010-019	013-019	013-018	2
02	MALIGNANT NEOPLASMS (MN) OF BUCCAL CAVITY AND PHARYNX						100
MN of Lip		045A	140	140	140	140	3
MN of Tongue		045B	141	141	141	141	4
MN of Other Parts of Buccal Cavity		045C, 045E	142-144	142-144	142-145	142-145	5
MN of Pharynx		045F	145-148	145-148	146-149	146-149	6
03	MN OF DIGESTIVE ORGANS AND PERITONEUM						101
MN of Esophagus		046A	150	150	150	150	7
MN of Stomach		046B	151	151	151	151	8
MN of Intestine Except Rectum		046C, 046E	152,153	152,153	152,153	152,153	9
MN of Rectum		046D	154	154	154	154	10

a Major Category
b Minor Category

MN of Biliary Passages, Liver, and Gall Bladder	046F	155	155	155,156	155.0,155.1, 156	11
MN of Liver not Specified	No Rates	156A	156A	197.8	155.2	12
MN of Pancreas	046G	157	157	157	157	13
MN of Peritoneum and Other and Unspecified of Digestive Organs	046H, 046M	158,159	158,159	158,159	158,159	14
04 MN OF RESPIRATORY SYSTEM						102
MN of Larynx	047A	161	161	161	161	15
MN of Trachea, Bronchus and Lung	047B,C,D, 047E	162,163	162,163	162,163.0	162,163	16
MN of Other Parts of Respiratory	047F, 055D	160,164	160,164	160,163.1 163.9	160,164,165	17
05 MN OF BREAST						103
MN of Breast	050	170	170	174	174,175	18
06 MN OF FEMALE GENITAL ORGANS						104
MN of Cervix Uteri	048A	171	171	180	180	19
MN of Other and Unspecified Parts of Uterus	048B	172-174	172-174	181,182	179,181,182	20
MN of Ovary, Fallopian Tube, and Broad Ligament	049A,B	175	175	183	183	21
MN of Other Female Genital Organs	049C-E	176	176	184	184	22

07	MN OF MALE GENITAL ORGANS					105
MN of Prostate	051B	177	177	185	185	23
MN of Testis	051C	178	178	186	186	24
MN of Other Male Genital Organs	051A,051D, 051E	179	179	172.5,173.5, 187	187	25
08	MN OF URINARY ORGANS					106
MN of Kidney	052A	180	180	189.0-189.2	189.0-189.2	26
MN of Bladder	052B	181.0	181.0	188	188	27
MN of Other and Unspecified Urinary Organs	052C	No Rates	181.7,181.8	189.9	189.3-189.9	28
09	MN OF OTHER AND UNSPECIFIED SITES					107
Malignant Melanoma of Skin	053	190	190	172.0-172.4, 172.6-172.9	172	29
Other MN of Skin	No Rates	191	191	173.0-173.4, 173.6-173.9	173	30
MN of Eye	No Rates	192	192	190	190	31
MN of Brain and Other Parts of Nervous System	054	193	193	191,192	191,192	32
MN of Thyroid Gland	055C	194	194	193	193	33
MN of Bone	045D,055B	196	196	170	170	34
MN of Connective Tissue and Soft Tissue	No Rates	197	197	171	171	35

MN of Other and Unspecified Sites (Minor)	055A,E	156B,165, 195,198,199	156B,165,195, 198,199	194,195,196, 197.0-197.7, 197.9,198,199	194-199	36
10 NEOPLASMS OF LYMPHATIC & HEMATOPOIETIC TISSUE						108
Lymphosarcoma and Reticulosarcoma	No Rates	200	200	200	200	37
Hodgkin's Disease	044B	201	201	201	201	38
Leukemia and Aleukemia	074	204	204	204-207	204-208	39
Multiple Myeloma & Immunoproliferative Neoplasms	No Rates	203	203	203	203	40
Other Neoplasms of Lymphatic & Hematopoietic Tissue	No Rates	202,205	202,205	202	202	41
11 BENIGN AND UNSPECIFIED NATURE NEOPLASMS						109
Benign Neoplasms of the Eye, Brain and Other Parts of Nervous System	056D	223	223	224,225	224,225	42
Neoplasms of Unspecified Nature of Eye, Brain and Other Parts of Nervous System	057D	237	237	238,743.4	237.5-237.9 239.6,239.7	43
Other Benign and Unspecified Nature Neoplasms	056A-C, 056E, 057A-C,057E	210-222, 224-236, 238,239	210-222, 224-236, 238,239	208, 210-223, 226-237, 239	210-223, 226-237.4, 238.0-239.5, 239.8-239.9	44
12 DIABETES MELLITUS						110
Diabetes Mellitus	061	260	260	250	250	45

13	DISEASES OF THE BLOOD AND BLOOD FORMING ORGANS					111
Pernicious Anemias		073A	290	290	281.0 281.9	281.0 281.9	46
Anemias of Other and Unspecified Type		073B-D	291-293	291-293	280,281.1- 281.4, 282-285	280,281.1- 281.8, 282-285	47
Coagulation Defects, Purpura and Other Hemorrhagic Conditions		072	296	296	286,287	286,287	48
All Other Diseases of Blood Forming Organs		075,076	294,295, 297-299	294,295, 297-299	209, 288,289	288,289	49
14	MENTAL, PSYCHONEUROTIC AND PERSONALITY DISORDERS						112
Alcoholism		077	322	322	303	303	50
Other Mental Disorders		079,084	300-321, 323-326	300-321, 323-326	290-302, 304-315	290-302, 304-319	51
15	DISEASES OF THE NERVOUS SYSTEM AND SENSE ORGANS						113
Multiple Sclerosis		087D	345	345	340	340	52
Other Diseases of the Nervous System and Sense Organs		80-82,85, 86,087A, 087B,087C 087E,88,89	340-344, 350-398	340-344, 350-398	320-333, 341-389	320-337, 341-389	53
16	DISEASES OF THE HEART						114
Rheumatic Heart Disease Including Fever		058,090A, 092B,092C, 093C,095B	400-402, 410-416	400-402, 410-416	390-398	390-398	54

A-3-5

Ischemic Heart Disease	093D,094	420	420	410-414	410-414	55
Chronic Disease of Endocardium	091C,092A, 092D,092E	421	421	424	424	56
Other Myocardial Degeneration	093B,093E	422	422	428	429.0,429.1	57
Hypertension with Heart Disease	131A	440-443	440-443	400.1,400.9, 402,404	402,404	58
Other Diseases of the Heart	090B,091A, 091B,093A, 095A,095C	430-434	430-434	420-423, 425-427, 429	420-423, 425-428, 429.2-429.9	59
17 OTHER DISEASES OF CIRCULATORY SYSTEM						115
Hypertension without Heart Disease	102	444-447	444-447	400.0,400.2, 400.3,401, 403	401,403,405	60
Cerebrovascular Disease	083	330-334	330-334	430-438	430-438	61
Diseases of the Arteries, Veins and Pulmonary Circulation	96, 98-101 103	451-468	451-468	441-444.1, 444.3-458	415-417, 441-459	62
Arteriosclerosis	97	450	450	440	440	63
18 DISEASES OF THE RESPIRATORY SYSTEM						116
Acute Respiratory Infections Except Influenza and Pneumonia	104, 105, 106A	470-475,500	470-475,500	460-466	460-466	64
Influenza	33	480-484	480-484	470-474	487	65
Pneumonia (except newborn)	107-109	490-493	490-493	480-486	480-486	66

Chronic and Unspecified Bronchitis	106B,106C	501,502	501,502	490,491	490,491	67
Emphysema	113	527.1	527.1	492	492	68
Asthma	112	241	241	493	493	69
Pneumoconiosis and Other Respiratory Diseases	110,111 114A-E	510-527.0, 527.2	510-527.0, 527.2	500-519	470-478, 494-519	70
19 DISEASES OF THE DIGESTIVE SYSTEM						117
Diseases of the Stomach and Duodenum	117,118	540,541,543	540,541,543	531-537	531-537	71
Hernia and Intestinal Obstruction	122	560,561,570	560,561,570	550-553, 560	550-553, 560	72
Cirrhosis of the Liver	124	581	581	571	571	73
Other Diseases of Digestive System	115,116, 119-121, 123, 125-129	530-539,542, 544,545, 550-553, 571-578, 580,582-587	530-539,542, 544,545, 550-553, 571-578, 580,582-587	444.2, 520-530, 540-543, 561-570, 572-577	520-530, 540-543, 555-558, 562-570, 572-579	74
20 DISEASES OF THE GENITO-URINARY SYSTEM						118
Acute Glomerulonephritis Nephrotic Syndrome and Acute Renal Failure	130	590,591	590,591	580,581	580,581,584	75
Chronic and Unspecified Nephritis and Renal Failure and Other Renal Sclerosis	131B,132	592-594	592-594	582-584	582,583, 585-587	76
Infection of Kidney	133	600	600	590	590	77
Calculi of Urinary System	134	602,604	602,604	592,594	592,594	78

Hyperplasia of Prostate	137A	610	610	600	600	79
Other Diseases of Male Genital Organs	137B, 138	611-617	611-617	601-607	601-608	80
Diseases of the Breast	No Rates	620, 621	620, 621	610, 611	610, 611	81
Diseases of the Female Genital Organs	139 (contains breast disease prior to 1950)	622-637	622-637	612-629	614-629	82
Other Genito-Urinary System Diseases	131A, 135, 136	601, 603, 605-609	601, 603, 605-609	591, 593, 595-599	588, 589, 591, 593, 595-599	83
21 DISEASES OF THE SKIN AND SUBCUTANEOUS TISSUE						119
Infections of the Skin and Subcutaneous Tissue	151, 152	690-698	690-698	680-686	680-686	84
Other Diseases of the Skin and Subcutaneous Tissue	153	700-716	700-716	690-709	690-709	85
22 DISEASES OF THE MUSCULOSKELETAL SYSTEM AND CONNECTIVE TISSUE						120
Arthritis and Spondylitis	59	720-725	720-725	710-715	711-716, 720, 721	86
Osteomyelitis and Periostitis	154	730	730	720	730	87
Other Diseases of MS System	155, 156	726, 727, 731-749	726, 727, 731-749	716-718, 721-738	710, 717-719, 722-729, 731-739	88
23 SYMPTOMS AND ILL-DEFINED CONDITIONS						121
Symptoms and Ill-Defined Conditions	162, 199, 200	780-793, 795	780-793, 795	780-793, 795, 796	780-796, 798, 799	89

24	ACCIDENTS					122
Transportation Accidents		169-173	E800-866	E800-866	E800-845, E940,E941	E800-848, E929.0,E929.1	90
Accidental Poisoning		78, 178,179	E870-895	E870-895	E850-877, E942	E850-869, E929.2	91
Accidental Falls		186A	E900-904	E900-904	E880-887, E943	E880-888, E929.3	92
Other Accidents		174-177, 180-185, 186B-194, 195C,D, 195E	E910-936 E960-962	E910-936 E960-962	E890-929 E944-946	E890-928 E929.4-929.9	93
Medical Complications and Misadventure		195A,B	E940-959	E940-959	E930-936, E947-949	E870-879, E930-949	94
25	VIOLENCE						123
Suicide		163,164	E963, E970-979	E963, E970-979	E950-959	E950-959	95
Homicide		165-168, 198	E964, E980-985	E964, E980-985	E960-978	E960-978	96
26	OTHER CAUSES						124
Residual Causes		All Other Codes	All Other Codes	All Other Codes	All Other Codes	All Other Codes	97
Undefined		Nonexistent Codes	Nonexistent Codes	Nonexistent Codes	Nonexistent Codes	Nonexistent Codes	98

MAJOR CATEGORY	ICD 5	ICD 6	ICD 7	ICD8	ICD 9	MORTAL
All Causes	001-200C	001-999	001-999	000-999	001-999	125
All Infective and Parasitic	001-044A,C,D	001-138	001-138	000-136	001-139	126
All Malignant Neoplasms and Neoplasms of Unspecified Nature	044B,045-055E, 056D,057, 074A,B,	140-205, 223, 230-239	140-207, 223, 230-239	140-209, 225, 230-239	140-208, 225, 230-239	127
Nutritional, Endocrine, Metabolic and Immune	060-071	240-289	240-289	240-279	240-279	128
Blood and Blood Forming	072A-073D 075A-076D	290-299	290-299	280-289	280-289	129
Mental, Psychoneurotic and Personality	077	300-326	300-326	290-315	290-319	130
Nervous System and Sense Organs	080A-082 083C-089B	340-398	340-398	320-389	320-389	131
All Circulatory and Vascular Lesions of the CNS	058A-058F 083A-083B 090A-103	330-334 400-468	330-334 400-468	390-458	390-459	132
All Respiratory Diseases	104A-114E	470-527	470-527	460-519	460-519	133
All Digestive Diseases	115A-129	530-587	530-587	520-577	520-579	134

All Diseases of the Genito-Urinary System	130-139C	590-637	590-637	580-629	580-629	135
All Diseases of the Skin	151-153	690-716	690-716	680-709	680-709	136
All Bone, Organs of Movement, and Connective Tissue	059, 154A-156B	720-749	720-749	710-738	710-739	137
Senility and Ill Defined Conditions	162A,B 199,200	780-795	780-795	780-796	780-799	138
All E Codes	078,079, 163-198	800-999	800-999	800-999	800-999	139
Congenital and Perinatal Conditions	157-161	750-776	750-776	740-779	740-779	140
Complications of Pregnancy, Childbirth and the Puerperium	140-150	640-689	640-689	630-678	630-676	141
Residual and Undefined	All Other Codes	All Other Codes	All Other Codes	All Other Codes	All Other Codes	142

Appendix A-4. M.O.R.T.AL. Computer Program

The computer program M.O.R.T.AL. (Minnesota Occupational Risk Tabulating Algorithm) was written to provide interactive analysis of occupational cohort mortality for the personal computer. Relative mortality in this program is assessed by the observed to expected (O/E) ratio. The O/E ratio is the observed number of deaths among the cohort population (the exposed group) divided by an estimate of the expected number of deaths determined by a standard population (the unexposed group). Certain covariates such as age, time of death, etc., may be confounders in the relationship between the potential hazard and the outcome(s) of interest. Standardizing the O/E ratio for these covariates produces the standardized mortality ratio (SMR). The indirect method of standardization is utilized in analyses run by this program (Fleiss, 1981). Another standardized O/E ratio calculated in this program is the proportionate mortality ratio (PMR) (Mausner, 1985). (A more detailed description of the SMR and PMR appears in the methods section and sample calculations of these statistics appear in Appendix A-2).

The patterns of mortality are presented by combinations of the following variables: age at death, calendar year of death, age started work, year started work, years worked, and latency. For each O/E ratio categorized by these variables, significance levels are displayed. These significance levels are determined by examination of a table of significance factors for the ratio of an observed value of a Poisson variable to its expectation (Bailar, 1964). A companion program provides 95% and 99% confidence limits for any O/E ratio.

In addition, corresponding to the SMR analysis, the Mantel-Haenszel estimate of the odds ratio and the Mantel-Haenszel chi square test statistic are computed (Breslow, 1982; Mantel and Haenszel, 1959; Mantel,

1963). The probability of obtaining the value of the test statistic is computed by an algorithm which approximates the chi square distribution. Both 95% and 99% confidence intervals for the Mantel-Haenszel estimate of the odds ratio are given. When appropriate, only one-tailed upper or lower confidence limits are displayed.

Corresponding to the PMR analysis, the program provides the standardized mortality odds ratio (SMOR) as an estimate of the odds ratio (Spiegelman, 1983; Miettinen, 1981). Both 95% and 99% confidence intervals are given for the SMOR. The Mantel-Haenszel chi square test statistic and its probability are also computed (Mantel and Haenszel, 1959; Mantel, 1963).

Appendix A-5. Summary Observed to Expected Ratios for All Workers 1945 - 1984

	Cause of Death	Observed to Expected Mortality Ratios
(1)+	Respiratory Tuberculosis	0.35(2)
(2)	Other Tuberculosis	4.46(3)
(3)	Lip Cancer	0.00(0)
(4)	Tongue Cancer	1.06(2)
(5)	Other Cancers of Mouth	0.92(2)
(6)	Pharyngeal Cancer	0.85(3)
(7)	Esophageal Cancer	0.50(4)
(8)	Stomach Cancer	0.91(23)
(9)	Intestinal Cancer	0.86(30)
(10)	Rectal Cancer	0.66(8)
(11)	Cancer of Biliary Tract, Liver, and Gallbladder	0.93(6)
(12)	Liver Cancer	0.51(1)
(13)	Pancreatic Cancer	0.89(17)
(14)	Other Digestive Cancer	0.69(1)
(15)	Cancer of Larynx	0.85(3)
(16)	Cancer of Lung and Bronchus	0.69(54)**
(17)	Other Respiratory Cancer	0.00(0)
(23)	Prostatic Cancer	1.00(38)
(24)	Testicular Cancer	2.17(2)
(25)	Other Male Genital Cancer	2.23(1)
(26)	Kidney Cancer	0.63(6)
(27)	Bladder Cancer	1.09(12)
(28)	Other Urinary Cancer	9.95(1)
(29)	Malignant Melanoma	0.00(0)
(30)	Other Skin Cancer	0.77(1)
(31)	Eye Cancer	2.29(1)
(32)	Cancer of Brain and Nervous System	0.66(6)
(33)	Thyroid Cancer	2.81(2)
(34)	Bone Cancer	1.31(2)
(35)	Soft and Connective Tissue Cancer	1.41(2)
(36)	Other Cancer	0.80(12)
(37)	Lympho- and Reticulosarcoma	1.13(7)
(38)	Hodgkin's Disease	0.58(2)
(39)	Leukemia	1.07(17)
(40)	Multiple Myeloma	0.53(3)
(41)	Other Cancer of Blood and Lymph	1.10(5)
(42)	Benign Cancer of Brain, and Nervous System	1.30(1)
(43)	Unspecified Neoplasm of Eye, Brain, and Nervous System	0.00(0)
(44)	Other Benign Neoplasm	1.62(3)
(45)	Diabetes Mellitus	1.20(30)
(46)	Pernicious Anemia	0.00(0)
(47)	Other Anemias	1.13(2)
(48)	Coagulative, Hemorrhagic Conditions	1.48(1)
(49)	Diseases of Blood Forming Organs	1.34(2)
(50)	Alcoholism	0.96(4)

Appendix A-5. Summary Observed to Expected Ratios for All Workers (continued)
1945 - 1984

	Cause of Death	Observed to Expected Mortality Ratios
(51)	Mental Disorders	0.45(2)
(52)	Multiple Sclerosis	0.00(0)
(53)	Other Diseases of Nervous System and Sensory Organs	0.91(14)
(54)	Rheumatic Heart Disease	0.91(14)
(55)	Ischemic Heart Disease	0.96(601)
(56)	Chronic Endocardial Disease	1.62(10)
(57)	Other Myocardial Degeneration	0.19(2)**
(58)	Hypertensive Heart Disease	0.66(13)
(59)	Other Heart Disease	0.82(37)
(60)	Hypertension	0.96(6)
(61)	Cerebrovascular Disease	0.80(130)*
(62)	Diseases of Arteries and Veins	1.13(37)
(63)	Arteriosclerosis	0.74(16)
(64)	Acute Respiratory Infections	1.60(1)
(65)	Influenza	1.37(5)
(66)	Pneumonia	0.93(41)
(67)	Chronic Bronchitis	1.47(7)
(68)	Emphysema	0.94(19)
(69)	Asthma	0.92(4)
(70)	Pneumoconioses	1.08(30)
(71)	Diseases of Stomach and Duodenum	0.53(6)
(72)	Hernia and Obstructive Disease of Intestines	0.89(5)
(73)	Cirrhosis	0.79(19)
(74)	Other Diseases of Digestive System	1.01(23)
(75)	Acute Renal Failure	1.72(2)
(76)	Chronic Renal Failure	1.06(8)
(77)	Kidney Infection	0.31(1)
(78)	Urinary Calculi	0.00(0)
(79)	Hyperplasia of Prostate	0.27(1)
(80)	Other Male Genital Disease	0.00(0)
(83)	Other Genitourinary Disease	1.01(5)
(84)	Skin Infection	0.00(0)
(85)	Other Skin Disease	0.00(0)
(86)	Arthritis	1.19(2)
(87)	Osteomyelitis	0.00(0)
(88)	Other Musculoskeletal Disease	2.09(3)
(89)	Signs and Symptoms	1.04(13)
(90)	Tranportation Accidents	1.38(53)*
(91)	Accidental Poisoning	0.54(2)
(92)	Accidental Falls	0.83(13)
(93)	Other Accidents	1.29(28)
(94)	Medical Complications	1.13(1)
(95)	Suicide	0.59(15)*
(96)	Homicide	0.43(1)

\+ M.O.R.T.AL. Code (See Appendix A-3)
* $p < 0.05$
** $p < 0.01$

Appendix A-5. Summary Observed to Expected Ratios for All Urban Workers

	Cause of Death	Observed to Expected Mortality Ratios
(1)+	Respiratory Tuberculosis	0.00(0)
(2)	Other Tuberculosis	0.00(0)
(3)	Lip Cancer	0.00(0)
(4)	Tongue Cancer	0.00(0)
(5)	Other Cancers of Mouth	0.00(0)
(6)	Pharyngeal Cancer	0.90(1)
(7)	Esophageal Cancer	0.00(0)
(8)	Stomach Cancer	0.85(4)
(9)	Intestinal Cancer	1.39(11)
(10)	Rectal Cancer	0.77(2)
(11)	Cancer of Biliary Tract, Liver, and Gallbladder	0.00(0)
(12)	Liver Cancer	2.75(1)
(13)	Pancreatic Cancer	1.11(5)
(14)	Other Digestive Cancer	0.00(0)
(15)	Cancer of Larynx	0.00(0)
(16)	Cancer of Lung and Bronchus	0.64(14)
(17)	Other Respiratory Cancer	0.00(0)
(23)	Prostatic Cancer	1.38(10)
(24)	Testicular Cancer	0.00(0)
(25)	Other Male Genital Cancer	0.00(0)
(26)	Kidney Cancer	1.38(3)
(27)	Bladder Cancer	0.82(2)
(28)	Other Urinary Cancer	0.00(0)
(29)	Malignant Melanoma	0.00(0)
(30)	Other Skin Cancer	0.00(0)
(31)	Eye Cancer	14.95(1)
(32)	Cancer of Brain and Nervous System	0.00(0)
(33)	Thyroid Cancer	6.73(1)
(34)	Bone Cancer	0.00(0)
(35)	Soft and Connective Tissue Cancer	0.00(0)
(36)	Other Cancer	1.37(5)
(37)	Lympho- and Reticulosarcoma	1.38(2)
(38)	Hodgkin's Disease	0.00(0)
(39)	Leukemia	1.12(4)
(40)	Multiple Myeloma	0.85(1)
(41)	Other Cancer of Blood and Lymph	0.97(1)
(42)	Benign Cancer of Brain, and Nervous System	5.57(1)
(43)	Unspecified Neoplasm of Eye, Brain, and Nervous System	0.00(0)
(44)	Other Benign Neoplasm	0.00(0)
(45)	Diabetes Mellitus	1.90(10)
(46)	Pernicious Anemia	0.00(0)
(47)	Other Anemias	2.68(1)
(48)	Coagulative, Hemorrhagic Conditions	0.00(0)
(49)	Diseases of Blood Forming Organs	0.00(0)
(50)	Alcoholism	0.80(1)

Appendix A-5. Summary Observed to Expected Ratios for All Urban Workers (continued)

	Cause of Death	Observed to Expected Mortality Ratios
(51)	Mental Disorders	0.88(1)
(52)	Multiple Sclerosis	0.00(0)
(53)	Other Diseases of Nervous System and Sensory Organs	0.78(3)
(54)	Rheumatic Heart Disease	0.85(3)
(55)	Ischemic Heart Disease	1.03(141)
(56)	Chronic Endocardial Disease	1.67(2)
(57)	Other Myocardial Degeneration	0.62(1)
(58)	Hypertensive Heart Disease	0.50(2)
(59)	Other Heart Disease	1.05(9)
(60)	Hypertension	1.55(2)
(61)	Cerebrovascular Disease	0.86(25)
(62)	Diseases of Arteries and Veins	0.61(5)
(63)	Arteriosclerosis	0.86(3)
(64)	Acute Respiratory Infections	7.10(1)
(65)	Influenza	0.00(0)
(66)	Pneumonia	0.32(3)*
(67)	Chronic Bronchitis	0.92(1)
(68)	Emphysema	1.02(5)
(69)	Asthma	0.00(0)
(70)	Pneumoconioses	1.31(9)
(71)	Diseases of Stomach and Duodenum	0.39(1)
(72)	Hernia and Obstructive Disease of Intestines.	0.00(0)
(73)	Cirrhosis	1.04(8)
(74)	Other Diseases of Digestive System	0.60(3)
(75)	Acute Renal Failure	4.13(1)
(76)	Chronic Renal Failure	1.40(2)
(77)	Kidney Infection	1.51(1)
(78)	Urinary Calculi	0.00(0)
(79)	Hyperplasia of Prostate	0.00(0)
(80)	Other Male Genital Disease	0.00(0)
(83)	Other Genitourinary Disease	1.86(2)
(84)	Skin Infection	0.00(0)
(85)	Other Skin Disease	0.00(0)
(86)	Arthritis	0.00(0)
(87)	Osteomyelitis	0.00(0)
(88)	Other Musculoskeletal Disease	0.00(0)
(89)	Signs and Symptoms	0.63(3)
(90)	Tranportation Accidents	2.23(17)**
(91)	Accidental Poisoning	1.79(2)
(92)	Accidental Falls	0.77(3)
(93)	Other Accidents	1.03(4)
(94)	Medical Complications	0.00(0)
(95)	Suicide	0.61(4)
(96)	Homicide	0.92(1)

\+ M.O.R.T.AL. Code (See Appendix A-3)
* $p < 0.05$
** $p < 0.01$

Appendix A-5. Summary Observed to Expected Ratios for All Rural Workers

	Cause of Death	Observed to Expected Mortality Ratios
(1)+	Respiratory Tuberculosis	0.55(2)
(2)	Other Tuberculosis	6.22(3)*
(3)	Lip Cancer	0.00(0)
(4)	Tongue Cancer	1.78(2)
(5)	Other Cancers of Mouth	1.52(2)
(6)	Pharyngeal Cancer	0.95(2)
(7)	Esophageal Cancer	0.76(4)
(8)	Stomach Cancer	0.92(19)
(9)	Intestinal Cancer	0.73(19)
(10)	Rectal Cancer	0.65(6)
(11)	Cancer of Biliary Tract, Liver, and Gallbladder	1.27(6)
(12)	Liver Cancer	0.00(0)
(13)	Pancreatic Cancer	0.85(12)
(14)	Other Digestive Cancer	0.86(1)
(15)	Cancer of Larynx	1.38(3)
(16)	Cancer of Lung and Bronchus	0.78(40)
(17)	Other Respiratory Cancer	0.00(0)
(23)	Prostatic Cancer	0.91(28)
(24)	Testicular Cancer	2.76(2)
(25)	Other Male Genital Cancer	2.80(1)
(26)	Kidney Cancer	0.42(3)
(27)	Bladder Cancer	1.22(10)
(28)	Other Urinary Cancer	13.14(1)
(29)	Malignant Melanoma	0.00(0)
(30)	Other Skin Cancer	0.93(1)
(31)	Eye Cancer	0.00(0)
(32)	Cancer of Brain and Nervous System	0.93(6)
(33)	Thyroid Cancer	1.81(1)
(34)	Bone Cancer	1.63(2)
(35)	Soft and Connective Tissue Cancer	1.91(2)
(36)	Other Cancer	0.64(7)
(37)	Lympho- and Reticulosarcoma	1.08(5)
(38)	Hodgkin's Disease	0.76(2)
(39)	Leukemia	1.07(13)
(40)	Multiple Myeloma	0.45(2)
(41)	Other Cancer of Blood and Lymph	1.15(4)
(42)	Benign Cancer of Brain, and Nervous System	0.00(0)
(43)	Unspecified Neoplasm of Eye, Brain, and Nervous System	0.00(0)
(44)	Other Benign Neoplasm	2.16(3)
(45)	Diabetes Mellitus	1.03(20)
(46)	Pernicious Anemia	0.00(0)
(47)	Other Anemias	0.72(1)
(48)	Coagulative, Hemorrhagic Conditions	2.03(1)
(49)	Diseases of Blood Forming Organs	1.70(2)
(50)	Alcoholism	1.12(3)

Appendix A-5. Summary Observed to Expected Ratios for All Rural Workers (continued)

	Cause of Death	Observed to Expected Mortality Ratios
(51)	Mental Disorders	0.33(1)
(52)	Multiple Sclerosis	0.00(0)
(53)	Other Diseases of Nervous System and Sensory Organs	0.99(11)
(54)	Rheumatic Heart Disease	0.99(11)
(55)	Ischemic Heart Disease	0.97(460)
(56)	Chronic Endocardial Disease	1.61(8)
(57)	Other Myocardial Degeneration	0.10(1)**
(58)	Hypertensive Heart Disease	0.74(11)
(59)	Other Heart Disease	0.76(28)
(60)	Hypertension	0.83(4)
(61)	Cerebrovascular Disease	0.78(105)*
(62)	Diseases of Arteries and Veins	1.41(32)
(63)	Arteriosclerosis	0.71(13)
(64)	Acute Respiratory Infections	0.00(0)
(65)	Influenza	1.35(5)
(66)	Pneumonia	1.16(38)
(67)	Chronic Bronchitis	1.72(6)
(68)	Emphysema	0.98(14)
(69)	Asthma	1.03(4)
(70)	Pneumoconioses	1.06(21)
(71)	Diseases of Stomach and Duodenum	0.61(5)
(72)	Hernia and Obstructive Disease of Intestines	1.09(5)
(73)	Cirrhosis	0.78(11)
(74)	Other Diseases of Digestive System	1.16(20)
(75)	Acute Renal Failure	1.11(1)
(76)	Chronic Renal Failure	0.97(6)
(77)	Kidney Infection	0.00(0)
(78)	Urinary Calculi	0.00(0)
(79)	Hyperplasia of Prostate	0.30(1)
(80)	Other Male Genital Disease	0.00(0)
(83)	Other Genitourinary Disease	0.82(3)
(84)	Skin Infection	0.00(0)
(85)	Other Skin Disease	0.00(0)
(86)	Arthritis	1.40(2)
(87)	Osteomyelitis	0.00(0)
(88)	Other Musculoskeletal Disease	2.57(3)
(89)	Signs and Symptoms	1.55(10)
(90)	Tranportation Accidents	1.13(36)
(91)	Accidental Poisoning	0.00(0)
(92)	Accidental Falls	0.93(10)
(93)	Other Accidents	1.27(24)
(94)	Medical Complications	1.64(1)
(95)	Suicide	0.57(11)
(96)	Homicide	0.00(0)

\+ M.O.R.T.AL. Code (See Appendix A-3)
* $p < 0.05$
** $p < 0.01$

Appendix A-5. Summary Observed to Expected Ratios for Highway Maintenance Workers Only

	Cause of Death	Observed to Expected Mortality Ratios
(1)+	Respiratory Tuberculosis	0.43(1)
(2)	Other Tuberculosis	0.00(0)
(3)	Lip Cancer	0.00(0)
(4)	Tongue Cancer	1.22(1)
(5)	Other Cancers of Mouth	1.05(1)
(6)	Pharyngeal Cancer	0.66(1)
(7)	Esophageal Cancer	1.14(4)
(8)	Stomach Cancer	1.06(12)
(9)	Intestinal Cancer	1.16(18)
(10)	Rectal Cancer	0.56(3)
(11)	Cancer of Biliary Tract, Liver, and Gallbladder	1.75(5)
(12)	Liver Cancer	1.14(1)
(13)	Pancreatic Cancer	1.06(9)
(14)	Other Digestive Cancer	0.57(1)
(15)	Cancer of Larynx	0.65(1)
(16)	Cancer of Lung and Bronchus	0.85(29)
(17)	Other Respiratory Cancer	0.00(0)
(23)	Prostatic Cancer	1.20(21)
(24)	Testicular Cancer	2.75(1)
(25)	Other Male Genital Cancer	0.00(0)
(26)	Kidney Cancer	0.24(1)
(27)	Bladder Cancer	1.00(5)
(28)	Other Urinary Cancer	0.00(0)
(29)	Malignant Melanoma	0.00(0)
(30)	Other Skin Cancer	0.00(0)
(31)	Eye Cancer	0.00(0)
(32)	Cancer of Brain and Nervous System	0.52(2)
(33)	Thyroid Cancer	6.41(2)
(34)	Bone Cancer	1.51(1)
(35)	Soft and Connective Tissue Cancer	0.00(0)
(36)	Other Cancer	1.06(7)
(37)	Lympho- and Reticulosarcoma	1.11(3)
(38)	Hodgkin's Disease	0.69(1)
(39)	Leukemia	0.72(5)
(40)	Multiple Myeloma	0.00(0)
(41)	Other Cancer of Blood and Lymph	1.01(2)
(42)	Benign Cancer of Brain, and Nervous System	0.00(0)
(43)	Unspecified Neoplasm of Eye, Brain, and Nervous System	0.00(0)
(44)	Other Benign Neoplasm	1.22(1)
(45)	Diabetes Mellitus	1.18(13)
(46)	Pernicious Anemia	0.00(0)
(47)	Other Anemias	1.24(1)
(48)	Coagulative, Hemorrhagic Conditions	0.00(0)
(49)	Diseases of Blood Forming Organs	0.00(0)
(50)	Alcoholism	1.17(2)

Appendix A-5. Summary Observed to Expected Ratios for Highway Maintenance Workers Only (continued)

	Cause of Death	Observed to Expected Mortality Ratios
(51)	Mental Disorders	1.01(2)
(52)	Multiple Sclerosis	0.00(0)
(53)	Other Diseases of Nervous System and Sensory Organs	1.47(10)
(54)	Rheumatic Heart Disease	0.61(4)
(55)	Ischemic Heart Disease	1.00(278)
(56)	Chronic Endocardial Disease	2.19(6)
(57)	Other Myocardial Degeneration	0.39(2)
(58)	Hypertensive Heart Disease	0.78(7)
(59)	Other Heart Disease	0.96(19)
(60)	Hypertension	0.71(12)
(61)	Cerebrovascular Disease	0.90(67)
(62)	Diseases of Arteries and Veins	0.89(13)
(63)	Arteriosclerosis	1.08(11)
(64)	Acute Respiratory Infections	3.66(1)
(65)	Influenza	1.21(2)
(66)	Pneumonia	1.00(20)
(67)	Chronic Bronchitis	1.86(4)
(68)	Emphysema	0.55(5)
(69)	Asthma	0.52(1)
(70)	Pneumoconioses	1.13(14)
(71)	Diseases of Stomach and Duodenum	0.80(4)
(72)	Hernia and Obstructive Disease of Intestines	1.18(3)
(73)	Cirrhosis	0.90(9)
(74)	Other Diseases of Digestive System	1.19(12)
(75)	Acute Renal Failure	1.96(1)
(76)	Chronic Renal Failure	0.61(2)
(77)	Kidney Infection	0.67(1)
(78)	Urinary Calculi	0.00(0)
(79)	Hyperplasia of Prostate	0.00(0)
(80)	Other Male Genital Disease	0.00(0)
(83)	Other Genitourinary Disease	0.89(2)
(84)	Skin Infection	0.00(0)
(85)	Other Skin Disease	0.00(0)
(86)	Arthritis	1.33(1)
(87)	Osteomyelitis	0.00(0)
(88)	Other Musculoskeletal Disease	0.00(0)
(89)	Signs and Symptoms	1.27(7)
(90)	Tranportation Accidents	1.71(27)
(91)	Accidental Poisoning	0.67(1)
(92)	Accidental Falls	0.57(4)
(93)	Other Accidents	1.67(15)
(94)	Medical Complications	0.00(0)
(95)	Suicide	0.77(8)
(96)	Homicide	0.00(0)

\+ M.O.R.T.A.L. Code (See Appendix A-3)
* $p < 0.05$
** $p < 0.01$

Appendix A-5. Summary Observed to Expected Ratios for Urban Highway Maintenance Workers Only

	Cause of Death	Observed to Expected Mortality Ratios
(1)+	Respiratory Tuberculosis	0.00(0)
(2)	Other Tuberculosis	0.00(0)
(3)	Lip Cancer	0.00(0)
(4)	Tongue Cancer	0.00(0)
(5)	Other Cancers of Mouth	0.00(0)
(6)	Pharyngeal Cancer	0.00(0)
(7)	Esophageal Cancer	0.00(0)
(8)	Stomach Cancer	1.10(3)
(9)	Intestinal Cancer	1.52(7)
(10)	Rectal Cancer	0.66(1)
(11)	Cancer of Biliary Tract, Liver, and Gallbladder	0.00(0)
(12)	Liver Cancer	4.89(1)
(13)	Pancreatic Cancer	0.76(2)
(14)	Other Digestive Cancer	0.00(0)
(15)	Cancer of Larynx	0.00(0)
(16)	Cancer of Lung and Bronchus	0.80(10)
(17)	Other Respiratory Cancer	0.00(0)
(23)	Prostatic Cancer	1.58(7)
(24)	Testicular Cancer	0.00(0)
(25)	Other Male Genital Cancer	0.00(0)
(26)	Kidney Cancer	0.82(1)
(27)	Bladder Cancer	0.63(1)
(28)	Other Urinary Cancer	0.00(0)
(29)	Malignant Melanoma	0.00(0)
(30)	Other Skin Cancer	0.00(0)
(31)	Eye Cancer	0.00(0)
(32)	Cancer of Brain and Nervous System	0.00(0)
(33)	Thyroid Cancer	11.80(1)
(34)	Bone Cancer	0.00(0)
(35)	Soft and Connective Tissue Cancer	0.00(0)
(36)	Other Cancer	1.91(4)
(37)	Lympho- and Reticulosarcoma	2.42(2)
(38)	Hodgkin's Disease	0.00(0)
(39)	Leukemia	0.49(1)
(40)	Multiple Myeloma	0.00(0)
(41)	Other Cancer of Blood and Lymph	0.00(0)
(42)	Benign Cancer of Brain, and Nervous System	0.00(0)
(43)	Unspecified Neoplasm of Eye, Brain, and Nervous System	0.00(0)
(44)	Other Benign Neoplasm	0.00(0)
(45)	Diabetes Mellitus	1.65(5)
(46)	Pernicious Anemia	0.00(0)
(47)	Other Anemias	4.48(1)
(48)	Coagulative, Hemorrhagic Conditions	0.00(0)
(49)	Diseases of Blood Forming Organs	0.00(0)
(50)	Alcoholism	0.00(0)

Appendix A-5. Summary Observed to Expected Ratios for Urban Highway Maintenance Workers Only (continued)

	Cause of Death	Observed to Expected Mortality Ratios
(51)	Mental Disorders	1.49(1)
(52)	Multiple Sclerosis	0.00(0)
(53)	Other Diseases of Nervous System and Sensory Organs	0.89(2)
(54)	Rheumatic Heart Disease	1.51(3)
(55)	Ischemic Heart Disease	1.08(36)
(56)	Chronic Endocardial Disease	1.47(1)
(57)	Other Myocardial Degeneration	1.07(1)
(58)	Hypertensive Heart Disease	0.43(1)
(59)	Other Heart Disease	0.82(4)
(60)	Hypertension	2.63(2)
(61)	Cerebrovascular Disease	0.91(16)
(62)	Diseases of Arteries and Veins	0.41(2)
(63)	Arteriosclerosis	0.97(2)
(64)	Acute Respiratory Infections	12.44(1)
(65)	Influenza	0.00(0)
(66)	Pneumonia	0.18(1)
(67)	Chronic Bronchitis	0.00(0)
(68)	Emphysema	0.99(3)
(69)	Asthma	0.00(0)
(70)	Pneumoconioses	1.24(5)
(71)	Diseases of Stomach and Duodenum	0.67(1)
(72)	Hernia and Obstructive Disease of Intestines	0.00(0)
(73)	Cirrhosis	1.23(5)
(74)	Other Diseases of Digestive System	1.04(3)
(75)	Acute Renal Failure	0.00(0)
(76)	Chronic Renal Failure	1.24(1)
(77)	Kidney Infection	2.53(1)
(78)	Urinary Calculi	0.00(0)
(79)	Hyperplasia of Prostate	0.00(0)
(80)	Other Male Genital Disease	0.00(0)
(83)	Other Genitourinary Disease	0.00(0)
(84)	Skin Infection	0.00(0)
(85)	Other Skin Disease	0.00(0)
(86)	Arthritis	0.00(0)
(87)	Osteomyelitis	0.00(0)
(88)	Other Musculoskeletal Disease	0.00(0)
(89)	Signs and Symptoms	0.37(1)
(90)	Tranportation Accidents	3.30(13)**
(91)	Accidental Poisoning	1.74(1)
(92)	Accidental Falls	0.45(1)
(93)	Other Accidents	1.94(4)
(94)	Medical Complications	0.00(0)
(95)	Suicide	1.18(4)
(96)	Homicide	0.00(0)

\+ M.O.R.T.A.L. Code (See Appendix A-3)
* $p < 0.05$
** $p < 0.01$

Appendix A-5. Summary Observed to Expected Ratios for Rural Highway Maintenance Workers Only

	Cause of Death	Observed to Expected Mortality Ratios
(1)+	Respiratory Tuberculosis	0.72(1)
(2)	Other Tuberculosis	0.00(0)
(3)	Lip Cancer	0.00(0)
(4)	Tongue Cancer	2.23(1)
(5)	Other Cancers of Mouth	1.86(1)
(6)	Pharyngeal Cancer	1.20(1)
(7)	Esophageal Cancer	1.88(4)
(8)	Stomach Cancer	1.04(9)
(9)	Intestinal Cancer	1.04(11)
(10)	Rectal Cancer	0.53(2)
(11)	Cancer of Biliary Tract, Liver, and Gallbladder	2.59(5)
(12)	Liver Cancer	0.00(0)
(13)	Pancreatic Cancer	1.23(7)
(14)	Other Digestive Cancer	2.13(1)
(15)	Cancer of Larynx	1.16(1)
(16)	Cancer of Lung and Bronchus	0.93(19)
(17)	Other Respiratory Cancer	0.00(0)
(23)	Prostatic Cancer	1.07(14)
(24)	Testicular Cancer	3.84(1)
(25)	Other Male Genital Cancer	0.00(0)
(26)	Kidney Cancer	0.00(0)
(27)	Bladder Cancer	1.18(4)
(28)	Other Urinary Cancer	0.00(0)
(29)	Malignant Melanoma	0.00(0)
(30)	Other Skin Cancer	0.00(0)
(31)	Eye Cancer	0.00(0)
(32)	Cancer of Brain and Nervous System	0.81(2)
(33)	Thyroid Cancer	4.51(1)
(34)	Bone Cancer	2.03(1)
(35)	Soft and Connective Tissue Cancer	0.00(0)
(36)	Other Cancer	0.68(3)
(37)	Lympho- and Reticulosarcoma	0.54(1)
(38)	Hodgkin's Disease	0.99(1)
(39)	Leukemia	0.81(4)
(40)	Multiple Myeloma	0.00(0)
(41)	Other Cancer of Blood and Lymph	1.45(2)
(42)	Benign Cancer of Brain, and Nervous System	0.00(0)
(43)	Unspecified Neoplasm of Eye, Brain, and Nervous System	0.00(0)
(44)	Other Benign Neoplasm	1.76(1)
(45)	Diabetes Mellitus	1.01(8)
(46)	Pernicious Anemia	0.00(0)
(47)	Other Anemias	0.00(0)
(48)	Coagulative, Hemorrhagic Conditions	0.00(0)
(49)	Diseases of Blood Forming Organs	0.00(0)
(50)	Alcoholism	1.97(2)

Appendix A-5. Summary Observed to Expected Ratios for Rural Highway Maintenance Workers Only (continued)

	Cause of Death	Observed to Expected Mortality Ratios
(51)	Mental Disorders	0.82(1)
(52)	Multiple Sclerosis	0.00(0)
(53)	Other Diseases of Nervous System and Sensory Organs	1.80(8)
(54)	Rheumatic Heart Disease	0.23(1)
(55)	Ischemic Heart Disease	0.98(192)
(56)	Chronic Endocardial Disease	2.43(5)
(57)	Other Myocardial Degeneration	0.23(1)
(58)	Hypertensive Heart Disease	0.94(6)
(59)	Other Heart Disease	1.00(15)
(60)	Hypertension	0.00(0)
(61)	Cerebrovascular Disease	0.89(51)
(62)	Diseases of Arteries and Veins	1.19(11)
(63)	Arteriosclerosis	1.10(9)
(64)	Acute Respiratory Infections	0.00(0)
(65)	Influenza	1.27(2)
(66)	Pneumonia	1.37(19)
(67)	Chronic Bronchitis	2.78(4)
(68)	Emphysema	0.34(2)
(69)	Asthma	0.63(1)
(70)	Pneumoconioses	1.11(9)
(71)	Diseases of Stomach and Duodenum	0.91(3)
(72)	Hernia and Obstructive Disease of Intestines	1.56(3)
(73)	Cirrhosis	0.74(4)
(74)	Other Diseases of Digestive System	1.28(9)
(75)	Acute Renal Failure	2.73(1)
(76)	Chronic Renal Failure	0.40(1)
(77)	Kidney Infection	0.00(0)
(78)	Urinary Calculi	0.00(0)
(79)	Hyperplasia of Prostate	0.00(0)
(80)	Other Male Genital Disease	0.00(0)
(83)	Other Genitourinary Disease	1.31(2)
(84)	Skin Infection	0.00(0)
(85)	Other Skin Disease	0.00(0)
(86)	Arthritis	1.69(1)
(87)	Osteomyelitis	0.00(0)
(88)	Other Musculoskeletal Disease	0.00(0)
(89)	Signs and Symptoms	2.28(6)
(90)	Tranportation Accidents	1.18(14)
(91)	Accidental Poisoning	0.00(0)
(92)	Accidental Falls	0.67(3)
(93)	Other Accidents	1.54(11)
(94)	Medical Complications	0.00(0)
(95)	Suicide	0.56(4)
(96)	Homicide	0.00(0)

\+ M.O.R.T.A.L. Code (See Appendix A-3)
* $p < 0.05$
** $p < 0.01$

Appendix A-6. Benzene and Leukemia

The role of benzene in leukemia has been the subject of extensive and continuing study. Askoy (1974) in Turkey found a significantly increased incidence of leukemia among shoeworkers, an industry which used benzene as a solvent for adhesives. Between 1967-1975, 34 out of 39 cases of leukemia among workers chronically exposed to benzene were shoeworkers. These 34 individuals were among a group of 28,500 shoeworkers in Turkey with chronic exposure to benzene. In most cases, the industry had poor working conditions. Environmental monitoring in selected work areas found that benzene concentrations during adhesive use reached 210-650 parts per million (ppm). The appearance of leukemia corresponded to the introduction of benzene as a solvent between 1955-1960. The incidence of leukemia peaked in 1973 (seven cases). Subsequently, the number of cases declined until none were reported in 1976. This again corresponded with benzene use, which in 1969 was gradually stopped and replaced by gasoline. The leukemia incidence in the industry was 13/100,000 which was a statistically significant increase over the 6/100,000 incidence in the general population. Acute leukemias, especially acute myelogenous leukemia, were the most common forms of leukemia, and this observation was in agreement with the findings of other investigators. Fifty cases of leukemia in unexposed individuals exhibited a distribution quite different from that among the benzene exposed workers, particularly for chronic myelogenous leukemia (CML) and chronic lymphocytic leukemia (CLL). The average duration of exposure for the shoemakers that developed leukemia was less than 15 years (Askoy, 1976).

Vigliani (1964) reported the observation of epidemics of benzene poisoning in Milan and Pavia. In Milan, 66 cases of chronic benzene poisoning were observed between 1942-1975. Shoeworkers were the largest

single occupational group represented among the cases, with many other industries also included. Of the 66 cases, 11 had AML or its variants. The benzene levels measured in two of these plants were between 200-400 ppm, with peaks up to 1500 ppm. Again, the incidence of chronic leukemia was considerably lower than that of the general population. Vigliani estimated that the risk of acute leukemia was increased at least 20 times for these workers.

There are a number of other reports relating occupational exposure to benzene with the development of leukemia. McMichael (1975) followed an earlier cohort study with a case-control study investigating the association between leukemia and occupation with solvent exposure (including benzene) in the rubber industry. This follow-up study identified a significant association between lymphocytic leukemia and occupations with solvent exposure. A seven-fold increased risk of death from lymphocytic leukemia was observed for workers with high levels of exposure to certain solvents. This differs from the above reports by Askoy and Vigliani of the association between nonlymphocytic leukemia and high benzene exposure.

An increased risk of leukemia for workers exposed to benzene in the pliofilm industry was reported by Infante (1977). In a retrospective cohort study (the method used in the highway workers study) of all white male pliofilm workers with direct exposure to benzene between January 1940 and December 1949. Of 140 observed deaths, 7 were due to leukemia. The leukemia types were consistent with the results of Askoy and Vigliani. Infante calculated a ten-fold risk, over the United States white male population, for pliofilm workers dying from non lymphocytic leukemia.

A retrospective study found an interaction between occupational benzene exposure and radiation. Adult cases of leukemia among survivors of

(Ishimoru, 1971) the atom bomb blasts in Hiroshima and Nagasaki were matched with controls on the basis of age, sex, residence, and distance from the blast. The risk of leukemia was 2.5 times higher for those with potential occupational exposure to benzene or x-rays. The risk was significantly higher for those who had been employed in such situations for five or more years. The risks were similar in the two cities and higher for acute leukemia (2.9) than for chronic leukemia (1.8).

The above associations between occupational benzene exposure and leukemia are not absolute. In a study of leukemia mortality rates for 36,000 employees of 8 European affiliates of Exxon Petroleum Corporation, Thorpe (1974) detected no significantly increased SMR for leukemias. Of 18 cases of leukemia, only 8 were believed to have had benzene exposure. Thorpe pointed out that making a sharp distinction between "exposed" and "unexposed" was difficult. The study has also been criticized on methodological bases.

Death certificate studies have not consistently found increased leukemia mortality associated with employment in occupations with exposure to hydrocarbons and other petroleum products. However, one case-control study of 50 patients with nonlymphocytic leukemia, found significantly more cases than controls (including controls with other leukemias) employed as truck drivers, filling station attendants, etc. (Brandt, 1978). Other reports have suggested similar associations.

A number of cohort mortality studies and case control studies have been conducted within the rubber industry. The rubber industry at one time was a major user of benzene. Recent cohorts are more likely to have been exposed to solvents other than benzene, although benzene exposure still occurs. British studies reported increases in total leukemia mortality, with one study reporting a seven-fold increase in one tire plant

(Checkoway, 1984). U.S. studies have reported fairly consistent increases in all leukemias. While most studies have not indicated the specific types of leukemia, several reports suggested an increased risk for lymphocytic rather than nonlymphocytic leukemias. In the studies reporting increased risk of CLL, benzene exposures were generally low and three other solvents were suspect: hexane, carbon tetrachloride, and carbon disulfide.

The leukemogenic potential of benzene is not well understood. It is believed that inhalation is the major route for benzene toxicity, although skin absorption is possible. Benzene is lipid soluble and, after inhalation, benzene accumulates in tissues proportional to their fat content (Dean, 1978). Benzene is known to be toxic to the bone marrow after prolonged exposure.

Another effect appears to be random chromosomal aberrations in marrow and peripheral blood lymphocytes. In a study of bone marrow chromosomes in 56 patients with nonlymphocytic leukemia, Mitelman (1978) detected aberrations in 82.6% of those occupationally exposed to petroleum products (23 patients), compared with 24.2% of those not exposed. Another possible mechanism for induction of leukemia by benzene is lymphocyte damage resulting in an immune impairment, thus allowing malignant cells to proliferate.