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MORTALITY PATTERNS OF A GROUP OF RETIRED ASBESTOS WORKERS

By

Pierre Decouflé

B.S., St. Peter's College, 1964

M.S., Rutgers University, 1966

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I. INTRODUCTION

A. Background of the Problem

Numerous reports by many investigators from various countries have established the fact that an occupational inhalation of dust of different chemical and physical types of asbestos results in the development of asbestosis of the lungs which may be designated as an occupational pneumoconiosis.

In 1906, Montague Murray reported the case of an asbestos worker who had died in England in 1900 of "typical fibroid phthsis".[1] Sporadic such cases continued to be recorded and, finally, in 1928 Seiler reported on a case which seemed definitely to establish the relationship between the inhalation of asbestos dust and disabling and fatal pulmonary fibrosis.[2] The report by Merewether and Price (1930) remains the authoritative account of the disease whereby its occupational origin was proved and, accordingly, asbestosis was recognized as a compensatible disease under the Workmen's Compensation (Silicosis and Asbestosis) Act of 1930 in England.[3]

This particular disease results in a slowly progressive pulmonary fibrosis of the diffuse, interstitial variety which is irreversible. The length of time usually required to instigate these lesions varies, with individual response also depending on the intensity of exposure during this time.

Since 1935 an increasing amount of epidemiological, clinical, and pathological evidence also incriminates this health hazard as one of the environmental sources of lung cancer. In 1935 Lynch and Smith reported a case of lung cancer in a man with asbestosis.[4] The association of what were then both relatively rare diseases prompted the suggestion that there might be an etiologic relationship between them.

This possibility was strengthened by additional reports from Great Britain.[5] Between the years 1924 and 1963 a total of 392 deaths of males with asbestosis recorded on the death certificate were reported to the Medical Branch of the Chief Inspector of Factories. Of these deaths, 121 or 30.9 per cent were found to have lung cancer also recorded on the death certificate. By contrast, in 1962, which year represented the highest lung cancer mortality yet published for Great Britain, only 7.5 per cent of all deaths in males 20 years of age or older were due to lung cancer.

Asbestos-induced lung cancer is characterized by a latent period during which there are no clinical signs of the disease. It seems that at least 15 years from onset of exposure are usually required before this disease is manifested.

As asbestos dust levels in asbestos products manufacturing plants decrease over time to levels which are insufficient to cause clinical asbestosis it is still to be investigated whether there might be an excess risk of lung cancer in the absence of asbestosis.

The possibility of a causal relationship between asbestos exposure and neoplasms of the mesothelial surfaces of the pleural and peritoneal cavities was strongly suggested by a report from South Africa in 1960 by Wagner and his associates.[6] These tumors now follow asbestosis and lung cancer as an important cause of death among asbestos workers. As with lung cancer, there is no regular correlation between the severity of asbestosis and the occurrence of mesotheliomas, and many instances occur in subjects in whom there is little or no evidence of asbestosis. The latent period of these tumors is usually over thirty years from onset of exposure.

B. Review of Selected Epidemiological Studies of Asbestos Workers

In England, Doll conducted a study of 113 men employed in an asbestos textile factory where chrysotile asbestos was used almost exclusively.[7] The follow-up of each man began when he had completed 20 years of employment in areas where he was liable to be exposed to asbestos dust. Under this design, men first became eligible for follow-up in 1922 and all observation was terminated in 1953. Mortality among the subjects was analyzed between the ages 30 and 79.

It was found that a total of 39 deaths occurred in this group whereas only 15.4 were expected on the basis of the male population of England and Wales. The number of deaths from lung cancer was 11 observed versus 0.8 expected - a ratio of 14 to 1. All of these cases of lung cancer were associated with the presence of asbestosis. A crude dose-response relationship was then investigated by subdividing the sample into two groups according to length of employment (1 to 10 years, over 10 years) before January 1, 1933 - the date when regulations for the control of asbestos dust in factories became effective. Before this date, dust exposures were relatively higher than in subsequent years. It was found that as the length of employment before January 1, 1933 increased the ratio of the number of observed deaths from lung cancer to the expected number of lung cancer deaths (assuming that the risk was constant for varying lengths of employment before 1933) increased indicating that the incidence of lung cancer increased with increasing length of service before 1933.

Knox _et al_. have extended the study by Doll to include those men who were first employed with the same asbestos company _after_ 1933 and who had at least 10 years of exposure in areas where they were liable to be exposed to asbestos dust.[8] The period of observation was also increased to the middle of 1966.

As previously reported, the men who had 20 or more years of employment in dusty areas and who worked for some time before 1933 experienced a significant excess mortality from all causes. There were 71 observed deaths in all whereas only 33.3 were expected. In addition, a significant excess in mortality from lung cancer was found with 17 observed deaths from this cause against only 2.8 expected.

Again a dose-response relationship was examined, this time subdividing all men with at least 20 years of exposure in dusty areas into three subgroups characterized by their length of employment before 1933 (none, 1 to 10 years, over 10 years). After standardizing for length of observation and age a statistically significant reduction in mortality from lung cancer was found with reduction in length of exposure before 1933. This is in agreement with Doll's original conclusions and confirms that there was a significant decrease in the occupational hazard since 1932.

When the group of men who had 10-19 years of exposure in dust areas but were first employed after 1933 was analyzed it was found that there were 6 observed deaths due to lung cancer while 6.4 were expected. However, the authors are reluctant to interpret this apparent deficit as a real lowering of the lung cancer risk for this group of asbestos workers because of some possible artifacts in the data.

Mancuso conducted a follow-up study of 1,266 white male employees of an asbestos products manufacturing plant who were working there in 1938 or 1939.[9] The period of observation lasted until mid-1960. During this time there was a total of 166 deaths between the ages 25 and 64 of which 22 were due to asbestosis. Expected deaths for various causes were based on the average annual death rates for the state of Ohio which were computed from information reported on death certificates during the period 1950-1960 and population statistics from the U.S. decennial censuses.

Only 130.4 deaths from all causes were expected whereas 166 were observed. Fifteen deaths due to lung cancer were observed while only 5.4 were expected. In addition, an excess for cancer of the digestive organs and peritoneum was noted with 15 observed deaths versus 7 expected. Mancuso points out that these findings may be considered conservative for several reasons. One was the marked dilution factor of using a total plant population rather than the more limited population at specific occupational risk. Information on duration of employment was not available for the entire cohort. Furthermore, slightly over two-thirds of the members of the cohort were in the age group 15 to 34 in 1938 and the war and related events affected the pattern of continuity and duration of employment of these cohort members. The author also points out that an additional case of lung cancer was derived from microscopic review.

With respect to the association between asbestosis and lung cancer in this study it was found that of the 15 deaths due to lung cancer, 6 also had asbestosis present.

Selikoff _et al_. studied a group of 632 male insulation workers who had only intermittent exposure to materials containing limited amounts (often 2% to 20%) of asbestos under working conditions varying from very dusty, as in extracting old insulation in closed quarters, to those with little dust exposure as in building construction in open air.[10] This group consisted of all individuals who were members of two locals of a labor union as of January 1, 1942. However, a man entered the observation period only after completing at least 20 years of exposure to asbestos dust. This condition is similar to the one which Doll had previously imposed on his subjects and stems from the recognition that neoplasia associated with asbestos exposure seldom occurs less than 20 years from first exposure to the dust (latent period).

For this study all observation ceased on December 31, 1962 (giving a maximum of 21 years of follow-up) and mortality was analyzed for all ages over 35. It was found that over the entire period of observation 255 deaths from all causes occurred whereas only 203.5 were expected based on the white male population of the United States. Of these deaths 45 were due to cancer of the lung while only 6.6 were expected, yielding a near seven-fold increase in the risk of this disease among such insulation workers. The authors give no indication of the presence or absence of asbestosis in any of the 45 observed lung cancer deaths. Of added interest is the disparity between observed and expected deaths from cancers of the stomach, colon, and rectum combined, noted in this study. There were 29 observed deaths due to these causes whereas only 9.4 were expected, a three-fold excess risk.

Enterline studied a cohort of white males who worked in certain asbestos products plants in the United States at some time during the period 1948-51.[11] For use as a control a cohort of white males who worked in certain cotton textile plants in the United States was defined in the same way. Men in these latter plants were exposed to a dusty working environment also, albeit, one which had not been associated with the occurrence of neoplasia. All of the subjects were followed up to June 30, 1963 and mortality between ages 15 and 64 was analyzed. The men in the asbestos cohort were divided into three groups according to the type of asbestos products that were manufactured by the plant in which they worked in 1948-51. The three product lines were asbestos building products, asbestos friction materials, and asbestos textile products. It was stated that dust exposures were probably less in building products plants than in friction materials and both of these considerably less dusty than asbestos textile plants.

Information on the death certificate regarding asbestosis present as either the underlying cause of death or a contributory cause indicated that this disease appeared on death certificates most frequently for workers in asbestos textile products plants which seemed to confirm previous impressions regarding general levels of asbestos-dust exposure in the three asbestos products industries studied.

Standardized Mortality Ratios of observed to expected numbers of deaths were computed for various causes of death where the expected numbers of deaths were based on the age-cause-specific mortality rates in the white male population of the United States. The men employed in the cotton textiles plants experienced no significant excess mortality from any cause but did exhibit a remarkable deficit in deaths due to cancer of the respiratory system (SMR=31.1) which was unexplainable.

Of the three groups of asbestos workers only those in asbestos textiles plants showed excess mortality from all causes (SMR=120.6). Slight excesses for cancer of the respiratory system were seen in workers from asbestos building products plants (SMR=130.4) and in workers from asbestos friction materials plants (SMR=123.7). However, excess mortality due to this cause was more substantial in the workers from asbestos textiles plants (SMR=228.6). In the case of asbestos friction materials and asbestos textiles products workers the excess in deaths from diseases of the respiratory system was entirely due to deaths from asbestosis. In the asbestos textile products industry cancer of the digestive system appeared to be high (SMR=146.3).

Jacob and Anspach analyzed the mortality experience among workers in the Dresden asbestos industry from 1952 to 1964.[12] The asbestos exposure for these subjects occurred in occupations in the mixing, weaving, and grinding departments of a brake lining factory, in the production and processing of asbestos textiles and asbestos cement products. In these operations all types of asbestos were used. The group studied consisted of 1,521 men and 1,124 women.

It was found that lung cancer and neoplasms of the pleura were significantly increased among asbestos workers in the Dresden area when compared with the general population of that area of corresponding age and sex. Among the men in the study 23 deaths due to lung cancer were observed while only 11.1 were expected. In women there were 13 observed deaths from cancers of the lung and pleura whereas only 0.8 were expected.

Of the 1,521 men 426 were found to have asbestosis and of these 17 died of lung cancer. Only 3.1 would have been expected to die in this subgroup from this cause. Comparison of this ratio (17:3.1) with the corresponding ratio for all the men (23:11.1) seems to indicate that the risk of dying from lung cancer among Dresden asbestos workers is higher for those already suffering with asbestosis. Similar results were seen for the women. Unfortunately, no information on the age distribution of either the asbestosis cases or the rest of the subjects is given. Such data might aid in further interpreting these findings. For example, if the asbestosis cases were, on the average, much older than the non-cases this might imply a longer duration of asbestos exposure and hence make the asbestosis cases a higher risk group, per se.

In England, Newhouse studied 4,695 males who were employed with a particular asbestos products factory for at least 30 days anytime after April 1, 1933.[13] The follow-up of these subjects lasted to 1964 giving a maximum of 31 years of observation. The chief products of this factory were asbestos textiles and all types of insulation materials. Crocidolite, amosite, and chrysotile asbestos were all used in the manufacturing of the various products. Each man was categorized by the length of time spent actually working in the factory (under 2 years and over 2 years) and by the exposure grading of the dustiest job he had held (low, moderate and severe). Expected deaths for all causes were obtained from the mortality experience of England and Wales. The Case-Pearson tables of age-specific death rates for cancers of various sites and for respiratory diseases were used to obtain expected deaths for these specific causes.

The results of the study showed that an excess of observed over expected deaths did not occur until at least 16 years had elapsed after first exposure and then only in workers who had held jobs with the highest dust exposure rating. After this interval of time there was a statistically significant excess in deaths from cancer of the lung and pleura and from other cancers, both in men with less than 2 years of exposure and in men with more than 2 years of exposure. This seems to imply that men with brief but intense asbestos dust exposure, if followed for a long enough time period (at least 16 to 20 years) will exhibit excess mortality from lung cancer. For the category of respiratory diseases which includes asbestosis there was a significant excess in mortality only for the group of men who were exposed longer than 2 years and had worked in a job with a "severe" exposure rating. This finding would seem to emphasize the importance of a long, continuing exposure period with episodes of intense dust concentration for the production of asbestosis.

II. SCOPE OF THE STUDY

A. Objectives

There are several objectives in the present study. The most general one is to determine whether men who retire from one particular asbestos products manufacturing company after having worked in its asbestos products plants experience different patterns of mortality than the U. S. white male population of the same age at the same point in time. Because of previous findings in asbestos workers, some of which have been summarized above, particular attention will be paid to mortality from lung cancer, cancer of the digestive organs and peritoneum, and diseases of the respiratory system (which include asbestosis) observed in these retirees.

Other more specific objectives involve examining the effects of various characteristics of the pre-retirement work experience of these men on their subsequent mortality. Such variables include the usual occupation of the man during his employment in the asbestos products plants, the type of asbestos products with which he was primarily involved, and the amount of asbestos dust exposure he acquired before retirement.

The analysis of mortality by usual occupation will essentially contrast those retirees who worked primarily in "production" jobs with those retirees who worked primarily in "maintenance" and "service" positions. To date, no other study has separated these two types of exposures ("steady" versus "intermittent") for the purpose of a comparative mortality analysis.

The possibility of dividing the retirees into various subgroups according to the type of asbestos products with which they were primarily involved would enable any differential mortality which may be associated with this variable to show up. Only Enterline was able to separate a cohort of asbestos workers into subgroups which reflected to some degree the kind of asbestos products with which his subjects were working. The other studies quoted above either were not able to subdivide their cohort (Mancuso, Newhouse, Jacob and Anspach) or were dealing with homogeneous workers (Doll, Knox et al. - asbestos, textiles and Selikoff et al. - asbestos insulation products).

A quantitative measure reflecting the amount of asbestos dust exposure acquired by each man will be developed and used as an independent variable in the analysis of mortality from the specific causes listed above. This will lead to an attempt to define a dose-response relationship between amount of asbestos dust exposure and mortality from lung cancer. Crude estimates of dose were used by Doll and Knox et al. (years of employment before 1933), Enterline (the various asbestos products industries), and Newhouse (exposure rating of the dustiest job held during the follow-up period) to establish some kind of dose-response relationship between amount of exposure and lung cancer mortality. It is hoped that a more precise estimate of dose can be defined for the subjects in the present study.

Within the analysis of amount of asbestos dust exposure and mortality from lung cancer the effect of the age of the retiree at first employment with the asbestos products company will be investigated. Specifically, mortality from lung cancer will be studied within a "low-dose" group of retirees for both men who began work with the asbestos company at a relatively young age and for men who began work at a relatively old age to see if any differential in lung cancer mortality exists. Similarly, within a "high-dose" group of retirees the same calculations will be carried out. These detailed analyses will essentially contrast high doses spread out over a long period of time with high doses acquired in a short period of time. A similar contrast for low doses of asbestos dust exposure is implied. Here it should be kept in mind that short periods of employment and occupational exposure only occur during the older working ages of men and never during their younger working ages.

B. Limitations

An analysis of the mortality among retirees such as is presented here should be put into perspective, i.e. it must be realized that this group is only one part of the population of all men who were ever employed in the asbestos products plants of this particular company.

As a matter of fact, it is a very biased sample from this population since it consists only of men who remained employed and lived long enough to retire from the company. Furthermore, it excludes that group of men who were employed with the asbestos company at some time in their life but for one reason or another did not remain employed long enough to retire from the company although they did reach retirement age elsewhere (whether employed at that time or not).

Although it is true that retirees are a survivor group in a well-defined sense, it is not completely realistic to therefore assume that they can provide no information on asbestos-induced disease, especially lung cancer. Since 1945 lung cancer death rates in the U.S. have reached a peak <u>after</u> 65 years of age. This together with the long latent period associated with "asbestos-lung cancer" seems to indicate that a study such as the present one might prove to be indeed fruitful, although not necessarily yielding a true measure of risk.

If the population at risk for this investigation is taken as all men who have worked in asbestos products plants in the United States and eventually retired from the company to which the plants belong the present group of subjects is not a random sample from this population simply because it consists of the retirees from only <u>one</u> asbestos products manufacturing company. The asbestos products plants in this particular company may possess certain characteristics which are in marked contrast to the plants of other companies. For instance, they may be situated in different geographical areas of the country, contain disparate amounts of ventilation and dust suppression equipment, and even be constructed in quite diverse ways. Manufacturing processes and the types of asbestos used in the plants under study may also differ remarkably from other asbestos products manufacturing plants in the United States.

On the other hand, results from the present study warrant the attention of the entire asbestos industry as indications of what might be expected on a broader scale among all of its retirees.

Unfortunately, in this study a large enough group of retirees from the same asbestos company who acquired no asbestos dust exposure during their working lifetime was not available to serve as a control group for comparison purposes. Such a cohort would be very desirable as a control because each member would have been actually at work right up to retirement age as was the asbestos-exposed group.

Instead, recourse was made to the United States white male population of the same age at the same point in time to serve as a control group. There is a basic drawback to using national data such as this for comparison with the retirees under study. The fact that the men in this investigation reached retirement age while actively at work with the asbestos company implies that they were relatively healthy at the time they left the company. However, all white males in the United States reaching a comparable age include many who have been chronically ill up to that time and are subject to a high probability of dying shortly after reaching this age. Consequently, during the first few years after retirement, at least, it might be expected that the retirees should experience a more favorable mortality pattern than the population of white males simply because they were healthier to begin with.

An additional objection to comparing mortality of men who worked in asbestos products plants with general population mortality is that general population rates are not available for a number of characteristics which are known to contribute to differential mortality. Haenszel has noted, for example, that cancer incidence for a number of sites is quite different for native and foreign-born groups.[14] Another variable known to affect overall mortality as well as mortality from certain specific causes is socio-economic level. The group of retired asbestos workers being studied here is made up primarily of "blue collar" workers while in the U.S. white male population this occupational class constitutes less than half of all employed persons.

III. DATA

A. General Description of Data

In 1941 the asbestos products manufacturing company instituted a retirement plan which provided for compulsory cessation of employment with the company thereafter for every employee reaching age 65. This is termed a "normal" retirement. The retirement plan included a provision that those who were 65 or older in 1941 could work for an additional 24 months before accepting their retirement. Because of this and the necessity of retaining some older men during World War II there were men retiring during the period 1941 to 1945 who were older than 65 years of age.

The retirement plan also provided for two types of retirement at ages <u>under</u> 65. One was the "disability" retirement which allowed a worker with sufficient employment service to leave the company when he had developed an injury or disease severe enough to prevent him from continuing in his job. Such a person was entitled to financial benefits from the company to help compensate for his disability.

The other type of retirement at ages under 65 was termed an "early" retirement. Under this plan a worker could elect to leave the company for any personal reason and receive financial benefits in proportion to what he had already contributed himself to the retirement plan. It was also necessary in this case to have had a sufficient number of years of employment with the company before being able to exercise this privilege.

During the course of time since these provisions were first implemented many workers who technically qualified for a "disability" retirement were allowed to leave the company with an "early" retirement if it meant added financial benefits for them. Hence, the term "early retirees" can also refer to those separating from the company at ages under 65 with physical and mental disabilities.

It was decided to limit the study to those individuals retiring between July 1, 1941 and December 31, 1966 who had worked in any of eleven of the company's asbestos products plants <u>immediately</u> prior to retirement. This definition excludes some persons who had had work experience in these plants but who subsequently moved into sales, clerical, or administration positions with the company at other locations.

Altogether 1,735 such retirees were identified by the asbestos products company. Table 1 gives the distribution of these individuals by sex and type of retirement.

The relatively small number of female retirees made it impractical to study them as a separate cohort. In addition, including them with the male retirees would introduce a degree of heterogeneity which was considered unreasonable. For these reasons the female retirees have been excluded from the present study.

The 1,149 males listed as normal retirees comprise the main part of the group chosen for the present study. Included in this category are 107 men who were actually older than 65 at retirement. The latter individuals were almost always those men who were already 65 at the

Table 1

Distribution of 1,735 Persons Retiring from an Asbestos Products Company between July 1, 1941 and December 31, 1966 by Sex and Type of Retirement After Having Worked in Any of 11 of the Company's Asbestos Products Plants Immediately Prior to Retirement

Type of Retirement	Both Sexes	Male	Female
All Types	1,735	1,624	111
Normal	1,205	1,149	56
Early	182	157	25
Survived to Age 65 (as of 12-31-66)	104	88	16
Disability	348	318	30
Survived to Age 65 (as of 12-31-66)	72	63	9

time of the initiation of the retirement plan and left the company under the provision described above.

It was decided to augment the main study group of 1,149 subjects with those early and disability retirees who reached age 65 by December 31, 1966. There were two major reasons for this decision. One was the enlargement, somewhat, of the viewpoint of the study to the examination of mortality patterns at age 65 and over for men who had worked in the asbestos products plants of this company regardless of whether or not they had been continuously employed there until age 65. The 151 early and disability retirees included in the study are a small fraction of the men who permanently left employment in the asbestos products plants of the company before reaching age 65 and who survived to this age.

The second reason for inclusion of this group was to make the entire study cohort more comparable to the U. S. white male population which is to serve as a control group. In general, it is to be expected that men retiring at age 65 are healthier, as a group, than the national population of men of the same age since the latter group contains many individuals who have been chronically ill up to that time. However, many of the early and all of the disability retirees who survive to age 65 are chronically ill at that point and so dilute the general healthiness of the normal retirees resulting in a cohort which is more comparable to the U. S. white male population of the same age.

Exactly 1,300 male retirees comprise the final study group. Their mortality was examined through December 31, 1967 - the closing date of the study. This enabled each retiree to be followed for at least one year.

Of the eleven plants in which the retirees worked the largest are in the Northeastern and North Central sections of the U.S. with other smaller plants located in the South and Far West. One small plant is in the Province of Ontario, Canada from which 11 men qualified to enter the study. Most of these plants were engaged in the production of several types of asbestos products at the same time.

The output of these plants included: asbestos textiles, asbestos packings and friction materials, asbestos insulation products, and asbestos building products. This latter category includes: asbestos paper, asbestos shingles, asbestos floor tile, asbestos paints and putties, asbestos wall board, and transite pipe. One small plant and certain departments of some of the larger plants manufactured asphalt roofing materials, some of which contained no asbestos. The subjects of this study, then, represent the full spectrum of asbestos dust exposures and are, indeed, a heterogeneous sample with respect to this characteristic.

Information on each retiree needed to carry out the present study was provided by the asbestos products manufacturing company. Transcription of basic data from company employment and medical records onto a survey form (see Figure 1, Appendix A) especially designed for the purpose was done by staff employees of the company at the various plants. The major items among the data on each retiree included birth date and birthplace, race, type of retirement, presence or absence of pneumoconiosis at first employment with the company and at retirement, vital status as of January 1, 1968, and a complete work history from time of first employment with the company until retirement.

For those retirees who died on or before December 31, 1967 a copy of the death certificate was requested from the health department of the state in which the death took place. From these death certificates the underlying cause of death was determined and coded according to the Seventh Revision of the International Classification of Diseases[15] by a nosologist trained at the National Vital Statistics Division of the U.S. Public Health Service. In addition, other selected conditions entered on the death certificates were coded. For example, if lung cancer and asbestosis were both listed on the death certificate and the underlying cause of death was coded as lung cancer, it was routine to code the asbestosis separately as a contributory cause of death.

For each job that a man held during his entire employment with the asbestos products manufacturing company, the following items were coded: beginning and ending dates, department in which the job was performed, the exact title of the job, an estimate of the overall airborne dust concentration in the immediate vicinity of the job, and the type of asbestos contained in the products that were manufactured by that department.

In arriving at the estimated exposure rating for each job, the company used its current Environmental Hygiene Survey results as the basis for considering past exposures. These survey reports were initiated around 1955, and for the period of time preceding, earlier conditions were discussed with long service employees. Changes in conditions were related to process changes, machine installations, ventilation control expenditures, and a judgment determination was made. From these judgments a Potential Exposure Schedule was developed for the job classifications within each department. These schedules were drawn up separately for each of the asbestos product plants covered in this study.

The format of such an exposure schedule is essentially a cross-classification between the various jobs within the asbestos products plants and calendar year with respect to an estimated dust exposure rating. It was decided to use five broad categories to describe the average dust concentration in the immediate vicinity of any one job. The definitions of these five classes in terms of the average dust particle count in millions of particles per cubic foot (mppcf) are:

LEVEL I	:	Less than 5 mppcf
LEVEL II	:	5-10 mppcf
LEVEL III	:	10-30 mppcf
LEVEL IV	:	30-50 mppcf
LEVEL V	:	over 50 mppcf

The upper limit used to define LEVEL I is the same as the Threshold Limit Value (TLV) for asbestos dust established by the American Conference of Governmental Industrial Hygienists following a 1937 study of asbestos textile workers in a single plant by the United States Public Health Service.[16] This TLV has been based on results taken from an environment which was virtually 100 per cent asbestos dust. Strictly speaking, this is not directly applicable to environments which may be composed of much less than 100 per cent asbestos dust as was the surroundings in which most of the retirees under study worked.

A hypothetical example of a Potential Exposure Schedule is illustrated in Figure 1 for one department of one asbestos products manufacturing plant.

Although containing fictitious data, Figure 1 illustrates some typical patterns such as a general trend in most jobs for the intensity of dust exposure to decrease over time. Sometimes a decrease might be rather gradual as in JOB A while other jobs may exhibit a sharp decrease as in JOB D. Also it happens that some jobs may not yet have reached the lowest level of exposure as in JOBS B and C.

Another characteristic of the working environment of the subjects under study was the distinction between "steady" and "intermittent" dust exposures. All retirees who were primarily engaged in jobs which were directly related to the production of the various asbestos products were considered to have had a "steady" dust

	TIME PERIOD			
Job	Prior to 1940	1940-1950	1951-1960	After 1960
A	LEVEL III	LEVEL II	LEVEL I	LEVEL I
B	LEVEL II	LEVEL II	LEVEL II	LEVEL II
C	LEVEL IV	LEVEL III	1955 LEVEL III ¦ LEVEL II	LEVEL II
D	LEVEL V	LEVEL IV	LEVEL II	LEVEL I

Figure 1. Exposure Levels to Airborne Dust Containing Various Amounts of Asbestos by Job and Time Period in One Department of One Asbestos Products Plant (Fictitious)

exposure. On the other hand, retirees who worked chiefly in jobs which were not directly related to the daily production operation were assigned to an "intermittent" category of asbestos dust exposure. This latter group of men consists chiefly of maintenance workers such as electricians, millwrights, machinists, etc. and service personnel such as shipping and receiving laborers, truck drivers, etc. Retirees who had worked primarily in office and supervisory positions at the various plants were all considered to have "intermittent" exposures to asbestos dust of a Level I intensity.

There were three types of asbestos used in the manufacturing processes at the eleven plants in this study. By far, the most extensively used was chrysotile which was, in fact, an ingredient of every asbestos product made by this company except for certain industrial insulation products manufactured prior to 1964. It constituted between 5 per cent and virtually 100 per cent of the finished products.

Amosite asbestos was used mainly in the industrial insulations division of the company where it constituted from 5 to 40 per cent of the finished products.

Finally, crocidolite or blue asbestos was used primarily in transite pipe products where it constituted 3 per cent of the finished items. There was also small amounts of crocidolite asbestos used in the packings departments of two plants.

Most industrial insulation products contained both amosite and chrysotile asbestos in combination with cristobalite silica. Together these two types of asbestos constituted between 10 and 15 per cent of most insulation products.

Transite pipe products contained both crocidolite asbestos and chrysotile asbestos in combination with quartz silica. The total asbestos content of this product line was 18 per cent. Most of the other asbestos building products contained between 15 and 40 per cent chrysotile asbestos together with quartz silica.

Asbestos friction materials contained mainly chrysotile asbestos mixed with rubber and assorted resins. The asbestos content of these products ranged from 36 to 85 per cent.

Some of the asbestos plants in the study manufactured packings, textile, paper, and pipe covering products which contained at least 90 per cent chrysotile asbestos.

B. Preliminary Examination of Data

Before becoming involved in detailed analyses of the mortality patterns of the retirees, it is informative to examine the composition of this group with respect to certain pertinent variables.

Table 2 gives the distribution of the retirees by type and year of retirement. Normal retirements among asbestos workers reached a high of 271 during the period 1953-57. The rather low number of normal retirees in the most recent time interval is partly due to the

Table 2

Distribution of Study Population by Type of Retirement and Year of Retirement

Year of Retirement	Type of Retirement							
	All Types		Normal		">65"		Disability & Early	
	No.	%	No.	%	No.	%	No.	%
1941-66	1,300	100.0	1,042	100.0	107	100.0	151	100.0
1941-47	225	17.3	123	11.8	96	89.8	6	4.0
1948-52	208	16.0	195	18.7	4	3.7	9	6.0
1953-57	298	22.9	271	26.0	4	3.7	23	15.2
1958-62	332	25.6	250	24.0	2	1.9	80	52.9
1963-66	237	18.2	203	19.5	1	0.9	33	21.9
Mean Age at Retirement	65.0		65.0		69.0		61.8	

fact that the cut-off date for entering retirees in the study was December 31, 1966 so that this particular period is about a year shorter than the preceding ones.

Those men who were at least 66 years of age at retirement have been separated from the other normal retirees and designated by the symbol ">65". The preponderance of these retirees in the earliest time period is due mostly to the initiation of the retirement plan in 1941. As mentioned above men who were already 65 years of age or older in 1941 were allowed to continue working for up to two additional years from that time.

Most of the early and disability retirees who survived to age 65 retired during the 1958-62 period. One reason for the seemingly low number of these individuals in the last time period is that although there may have been many more early and disability retirees during that period, only a small proportion had reached their 65th birthday before the closing of the study on December 31, 1967.

On the average, the early and disability retirees included in this study were about 3 years younger than the normal retirees at separation from the company whereas the men retiring at ages older than 65 were about 4 years older than the normal retirees. However, for the entire study group the average age at retirement was 65 years.

Table 3 gives the distribution of the retirees by type of retirement and vital status at the close of observation. Overall, slightly more than half of the subjects had died on or before December 31, 1967.

Table 3

Distribution of Study Population by Type of Retirement and Vital Status on January 1, 1968

Status on 1-1-68	Type of Retirement							
	All Types		Normal		">65"		Disability & Early	
	No.	%	No.	%	No.	%	No.	%
Total	1,300	100.0	1,042	100.0	107	100.0	151	100.0
Alive	636	48.9	535	51.3	9	8.4	92	60.9
Dead	664	51.1	507	48.7	98	91.6	59	39.1

However, the proportion of deceased varied by type of retirement. A little less than half of all normal retirees had died during the follow-up period. Understandably, most of the retirees who were older than 65 at the time they left the company expired before the closing date since almost all of them entered at the very beginning of the observation period (Table 2). The lowest proportion of retirees who were deceased as of January 1, 1968 occurred among the early and disability retirees who survived to age 65. Approximately 40 per cent of these individuals had expired.

There were 1,281 retirees with complete work histories. These are shown in Table 4 by age at first employment with the asbestos company and year of first employment with the asbestos company.

The distribution of the 1,281 retirees by age at first employment is symmetric about the age group 35-44 years with mean age at first employment about 40 years. It can be seen that as time went on the distribution of the retirees by age at first employment shifted from the younger ages to increasingly older ages. In fact, from the time period prior to 1920 to the most recent time period (1940-59) the average age at first employment increased by approximately 20 years.

This phenomenon is easily explained if one keeps in mind that all of these individuals eventually did retire from the company after first being employed there. Anyone entering employment prior to 1920 and qualifying for retirement sometime after 1940 would in most cases have had to be relatively young when first hired. Men first employed

Table 4

Distribution of Retirees with Complete Work Histories
By Age at First Employment and Year of First Employment
With the Asbestos Company

Age at First Employment	Year of First Employment									
	All Years		Prior to 1920		1920-29		1930-39		1940-59	
	No.	%	No.	%	No.	%	No.	%	No.	%
15-64	1,281*	100.0	192	100.0	465	100.0	318	100.0	306	100.0
15-24	95	7.4	66	34.4	29	6.2	0	0.0	0	0.0
25-34	335	26.2	85	44.3	207	44.5	43	13.5	0	0.0
35-44	417	32.6	34	17.7	148	31.8	175	55.1	60	19.6
45-54	345	26.9	7	3.6	70	15.1	85	26.7	183	59.8
55-64	89	6.9	0	0.0	11	2.4	15	4.7	63	20.6
Mean Age at First Employment	39.8		29.1		36.2		42.2		49.7	

*Excludes 19 retirees for whom no work history was available.

during that period in an older age group would have reached retirement age prior to 1940 when there was no retirement plan in effect. Similarly, those men first hired in the most recent time period (1940-59) would not become eligible for retirement during the study period if they were relatively young at the time since they would not reach retirement age until after 1967.

A rough estimate of the average number of years worked with the company by the retirees in this study can be derived by consideration of the two overall mean values given in Tables 2 and 4. From Table 2 the mean age at retirement is 65 years while from Table 4 the mean age at first employment with the asbestos company is about 40 years. Subtracting these two figures would roughly estimate the average length of service as 25 years.

Table 5 gives the distribution of retirees with complete work histories by usual occupation with the asbestos company prior to retirement and age at first employment with the asbestos company. A little over two-thirds of the retirees were categorized as primarily having worked in jobs which were directly related to the daily production operations. About one-fourth of the retirees had been chiefly engaged in maintenance and service positions. The remaining individuals were mostly office and supervisory personnel with a few miscellaneous jobs also included in this sub-division.

Retirees who were primarily involved in production jobs were, on the average, older than either of the other two groups of retirees

Table 5

Distribution of Retirees with Complete Work Histories
By Age at First Employment with the Asbestos Company
And Usual Occupation Prior to Retirement

Age at First Employment	Usual Occupation							
	All Jobs		Production		Maintenance -Service		Office & Other	
	No.	%	No.	%	No.	%	No.	%
15-64	1,281*	100.0	800	100.0	343	100.0	138	100.0
15-24	95	7.4	52	6.5	23	6.7	20	14.5
25-34	335	26.2	191	23.9	103	30.0	41	29.7
35-44	417	32.6	272	34.0	112	32.7	33	23.9
45-54	345	26.9	224	28.0	86	25.1	35	25.4
55-64	89	6.9	61	7.6	19	5.5	9	6.5
Mean Age at First Employment	39.8		40.5		39.2		37.8	

*Excludes 19 retirees for whom no work history was available.

at first employment with the asbestos company. Those men who had worked in office and supervisory positions were, on the average, the youngest group with respect to age at first employment - being 3 years younger than those from production jobs. These differences appear to be slight especially between retirees from production jobs and those from maintenance and service positions.

The rather large number of men from maintenance and service jobs enabled this group to be studied apart from other asbestos plant workers.

In Table 4 it was seen that the average age at first employment for the retiree population was approximately 40 years. If it is assumed that these subjects were eligible to begin their working lifetime between ages 15 and 20 then many of the men under study had been employed in diverse occupations for 20 to 25 years before they began work with the present asbestos company. Potentially hazardous exposures may have occurred in some of these "previous" jobs which could have an effect on the mortality patterns observed in this study.

In an attempt to identify some of these prior health hazards the asbestos company was asked to provide information on any kind of dust exposure retirees might have had before being employed there. Although definite answers to this question were not always available it was found that 128 retirees had worked in coal mines, 24 had worked in jobs involving possible silica dust exposure, and 7 had previous asbestos dust exposure. With a little less than half of the subjects having definite answers to this item the above figures underestimate the actual numbers.

In addition, the presence or absence of any type of pneumoconiosis at first employment with the asbestos company as well as at retirement was noted for each man. Unfortunately, complete information on these items was not available for all retirees. Table 6 gives the distribution of the retirees by pneumoconiosis status at first employment and pneumoconiosis status at retirement. Because of the disease process involved here a man having pneumoconiosis at first employment was assumed to have it at retirement when the latter information was unknown to the asbestos company.

The number of men having pneumoconiosis at either point in time is underestimated not only due to the large number of subjects for whom no information was available but also because only rather severe cases of it were transcribed from the medical records of the company. However, this table gives a rough idea of the health of the retirees with respect to a relevant occupational disease which is not necessarily fatal.

Table 7 gives the distribution of the retirees under study by place of birth and vital status at the close of the study. Information on birthplace was more frequently known for the deceased retirees since the death certificate almost always contained this piece of data. Overall between 45.2 and 51.4 per cent of the subjects were foreign-born

Table 6

Distribution of Study Population by Pneumoconiosis Status
At First Employment with the Asbestos Company
And Pneumoconiosis Status at Retirement

Pneumoconiosis Status at Retirement	Pneumoconiosis Status at First Employment							
	Total		Present		Absent		Unknown	
	No.	%	No.	%	No.	%	No.	%
Total	1300	100.0	87	6.7	671	51.6	542	41.7
Present	230	100.0	87	37.8	12	5.2	131	57.0
Absent	657	100.0	0	0.0	651	99.1	6	0.9
Unknown	413	100.0	0	0.0	8	1.9	405	98.1

Table 7

Distribution of Study Population by Place of Birth
And Vital Status as of 1-1-68

Status on 1-1-68	Place of Birth							
	Total		United States		Other		Unknown	
	No.	%	No.	%	No.	%	No.	%
Total	1300	100.0	632	48.6	587	45.2	81	6.2
Alive	636	100.0	327	51.4	230	36.2	79	12.4
Dead	664	100.0	305	45.9	357	53.8	2	0.3

depending on whether the 81 dubious cases are all assigned to one category or another. If these are omitted altogether, then 48.2 per cent of the 632 + 587 retirees were foreign-born.

The 587 retirees known to have been foreign-born came from three main geographic areas: Canada (66), Western Europe (228), and Eastern Europe (280).

IV. METHOD OF ANALYSIS

To make efficient use of all of the data contained in each retiree's work history it was decided to divide the fifty-year age span (ages 15-64) during which each individual in the study could have worked into five ten-year intervals: 15-24, 25-34, 35-44, 45-54, 55-64. For each of these ten-year intervals two exposure scores were calculated: an unadjusted score and an adjusted score.

In arriving at these scores it was first necessary to assign a numerical value to each of the five asbestos dust exposure categories. An arbitrary weight of 1 was given to all Level I asbestos dust exposures (<5 mppcf). The weights for Levels II-IV were then derived by comparing the midpoint of the dust count range defining each category with the midpoint of Level I which is 2.5 mppcf. The midpoint of Level II (5-10 mppcf) is 7.5 mppcf which is three times the midpoint of Level I. Hence, a weight of 3 was assigned to asbestos dust exposures in the Level II range. The midpoint of Level III (10-30 mppcf) is 20 mppcf which is eight times the midpoint of Level I. This would mean that Level III asbestos dust exposures receive a weight of 8. The midpoint of Level IV (30-50 mppcf) is 40 mppcf which is sixteen times the midpoint of Level I. The weight for asbestos dust exposures in Level IV is 16. The open-ended interval of dust counts defining Level V (>50 mppcf) was arbitrarily assigned a weight of 25. Probably no important bias is introduced with this last numerical weighting since only a very small proportion of the jobs held by the retirees under study qualified for an exposure rating of 50 mppcf or greater.

Underlying this whole scheme of assigning numerical weights to the various asbestos dust exposure categories is the assumption that, on the average, the dust count level for all jobs in a given exposure category is close to the midpoint of that category. For example, in giving a weight of 8 to an exposure between 10 and 30 mppcf because the midpoint 20 mppcf is eight times 2.5 mppcf (the midpoint of Level I) it is assumed that dust counts for all jobs in this range average around 20 mppcf.

In a given ten-year age interval a retiree could have worked in one or more departments of a plant (e.g. rigid shingles, friction materials, transite pipe, etc.). For each of these departments an unadjusted exposure score was calculated by determining the length of time (rounded to the nearest year) during which he worked at each of the five levels of asbestos dust exposure. Let these times be denoted by t_1, t_2, t_3, t_4, t_5 and let t_0 be the time spent in a non exposed job. If the numerical weights 1, 3, 8, 16, 25 for the five exposure levels be designated by w_1, w_2, w_3, w_4, w_5 and $w_0=0$ be the weight for a non exposed job the unadjusted exposure score for the i^{th} department is calculated as:

$$S_i = \sum_{j=0}^{5} w_j t_{ij}$$

A comprehensive unadjusted exposure score for a given ten-year age interval is then obtained by summing the departmental scores over all departments, i.e.

$$S = \sum_{i=1}^{n} S_i = \sum_{i=1}^{n} \sum_{j=0}^{5} w_j t_{ij}$$

where $t_{ij} = 0, 1, \ldots, 10 (i=1,2,\ldots,n; j=0,1,\ldots,5)$

and

$$\sum_{i=1}^{n} \sum_{j=0}^{5} t_{ij} = 10 .$$

Such scores were calculated separately for each of the five 10-year age intervals and then these were summed to yield a total unadjusted exposure score which reflected the amount of asbestos dust exposure a man accumulated during his entire employment with the asbestos company.

No exposure score was assigned to those retirees who worked primarily in office jobs. These subjects were all assumed to have an intermittent dust exposure of _at most_ a Level I intensity for the entire length of time they were employed with the asbestos company.

This technique of computing exposure scores is an attempt to measure both length of exposure and intensity of exposure simultaneously. However, in this method the assumption is implicitly made that a short, intense exposure is equivalent to a long, light exposure. For example, if one retiree had worked in a Level II environment for eight years he would have accumulated an unadjusted score of 24 (8 x 3). Another retiree worked for only three years in a Level III environment would also have accumulated an unadjusted score of 24 (3 x 8). This assumption may or may not be realistic in studying the relationship between asbestos dust and disease.

In an attempt to further refine the estimate of dose an adjusted exposure score was also calculated. This was done only for those retirees who had worked primarily in production jobs since a knowledge of the specific department in which the man worked day to day was needed. Such a score was intended to quantify an individual's pure asbestos dust exposure as opposed to his asbestos-containing-dust exposure. This kind of an analysis would, hopefully, distinguish between two equal dust doses as defined by the unadjusted score but which were related to quite different percentages of pure asbestos.

The adjusted exposure score is a modification of the unadjusted score. Here, information on the percentage of asbestos in the final product manufactured in each department of each plant is taken into account. The calculation of an adjusted score assumes that the percentage of asbestos in the final product is directly related to the percentage of asbestos in the total airborne dust within a department. In other words, if the product manufactured in a particular department contains 90 per cent asbestos the airborne dust in all parts of this department is assumed to contain a relatively high percentage of pure asbestos dust. Similarly, if the product manufactured in another department contains only 10 per cent asbestos the total airborne dust in all parts of this department is assumed to contain a relatively low percentage of pure asbestos dust.

Although the actual percentage of pure asbestos in the total airborne dust in a department most likely varies with the different operations in that department, it is assumed here that all jobs within the same department are exposed to the same percentage of pure asbestos dust, viz. that of the product manufactured there. No attempt was made in this study to distinguish among the various phases of the production operation within each department, e.g. raw material preparation, actual manufacturing, and finishing end. In all likelihood, the concentration of pure asbestos dust was greatest in the vicinity of the raw materials preparation section and least in the finishing end section of a department. Nevertheless, it was felt that the computation of such an adjusted score would be a step in the right direction.

If in a given ten-year age interval an individual remained in one department, his adjusted score (S_A) is gotten by multiplying his unadjusted score for that interval by the percentage (p) of asbestos in the product manufactured there, i.e.

$$S_A = pS \; .$$

However, if in a particular ten-year age interval a person worked in two or more different departments, that part of the unadjusted score (S_i) calculated for each of those departments is first multiplied by the appropriate percentage (p_i); these adjusted sub-scores are then added together to yield the adjusted exposure score (S_A) for that age period, i.e.

$$S_A = \sum_{i=1}^{n} p_i S_i$$

where n is the number of different departments in which the individual worked during that ten-year age interval.

The adjusted scores for each ten-year age period are summed to obtain the total adjusted exposure score for each retiree.

Two equal adjusted exposure scores may arise from completely different circumstances. For example, suppose one retiree has worked for 20 years in the same department in a Level I exposure job. If the products manufactured in that department contained 80 per cent asbestos his adjusted exposure score is calculated as:

$$S_A = .80\ (20 \times 1) = 16.$$

On the other hand if another retiree has worked for 10 years in one department in a Level III exposure job where the products contain 20 per cent asbestos his adjusted exposure score is calculated as:

$$S_A = .20\ (10 \times 8) = 16.$$

Because of this numerical equality the implicit assumption is that these two work experiences are equivalent.

As a further illustration of the effect of these two exposure scores as estimates of dose the following example is given: Suppose that two individuals (A and B) have worked in an asbestos products plant for 16 years and 2 years respectively. A has worked continually at a Level I dust exposure where the products contain 25 per cent asbestos. B has worked continually in a Level III dust exposure where the products contain 75 per cent asbestos. Figure 2 summarizes three estimates of dose for these two individuals.

If length of exposure is used as the measure of dose then A's exposure has been 8 times as great as B's exposure. However, if the overall intensity is also taken into consideration the dose becomes the same for both individuals. Finally, if the percentage of asbestos is

Dose / Person	Length of Exposure Only	Unadjusted Exposure Score	Adjusted Exposure Score
A	16 years	16 x 1 = 16	.25 x 16 = 4
B	2 years	2 x 8 = 16	.75 x 16 = 12
Ratio of Doses (A/B)	8 : 1	1 : 1	1 : 3

Figure 2. Three Estimates of the Amount of Asbestos Dust Exposure Accumulated by Two Individuals in an Asbestos Products Plant

used in the estimate of dose the situation is changed once more with B's asbestos exposure now 3 times as great as that for A.

In a study which used only length of exposure as an estimate of dose, worker A would most likely be assigned to a higher dose category than worker B. Under the definition of dose in terms of length and intensity of exposure worker A and worker B would probably both be assigned to the same category of dose. Introducing the percentage of asbestos relevant to the two working environments leads to still a different assignment of dose. Now worker A would likely be put into a lower dose category than worker B.

Working environments which are homogeneous with respect to the percentage of asbestos in the manufactured products such as asbestos textile plants do not require the use of adjusted exposure scores to estimate dose. If it could also be established that all workers were subject to the same intensity of exposure there is no need of even an unadjusted score. Length of employment in the plant would probably suffice as an estimate of dose. However, with the multiplicity of asbestos products and exposure intensities to which the retirees in the present study were subjected the need for more complex estimates of dose are required. These may still be imperfect in developing dose response relationships but are better than length of employment.

The initial use of the unadjusted exposure scores was in facilitating the subdividing of all retirees who worked primarily in production jobs by the type of asbestos products with which they were chiefly involved prior to retirement. The categories of asbestos products chosen for this study together with their distinguishing characteristics are given in Table 8.

Whenever a retiree had worked in two or more departments characterized by different types of asbestos products, the unadjusted exposure score acquired in each of these environments was computed and the man was assigned to that category in which he had compiled the highest unadjusted score. In the case of ties, the length of time spent in each division was used as the deciding factor.

Some retirees had worked primarily in departments which produced asphalt roofing materials. In these sections there was virtually no asbestos dust exposure and consequently these individuals have been omitted from the more detailed analyses. A few of the men in this group had had brief episodes of asbestos exposure in other departments but the time was very short in comparison with that spent in the roofing sections. The chief exposures in asphalt roofing departments are dusts of talc, mica, and silica in varying amounts as well as asphalt fumes. No exposure scores were calculated for this group of retirees.

In evaluating the mortality patterns of the retirees, the principal measure used is the Standardized Mortality Ratio (SMR).

The SMR is the ratio of observed (O) to expected (E) deaths (multiplied by 100), i.e.

$$\text{SMR} = \frac{O}{E} \times 100 .$$

Table 8

Categories of Asbestos Products and Their Distinguishing Characteristics as Manufactured in the Asbestos Products Plants Under Study

Product	Type of Asbestos	Percentage Asbestos	Other Ingredients
Asbestos Insulations	Amosite & Chrysotile	10 to 15	Cristobalite Silica
Asbestos Cement Products	Chrysotile	25 to 40	Quartz Silica
Transite Pipe	Chrysotile Crocidolite	15 3	Quartz Silica
Asbestos Packings	Chrysotile	90 to 100	None
Asbestos Friction Materials	Chrysotile	40 to 80	Rubber & Resins
Asbestos Floor Tile	Chrysotile	15 to 30	Resins
Asbestos Paper and Pipe Covering (low pressure - air cell)	Chrysotile	90	Filler
Asbestos Textiles	Chrysotile	100	None
&			
Asbestos Fire Felt	Amosite Chrysotile	40 60	None

The observed deaths are the actual deaths which occurred among the retirees under study between July 1, 1941 and December 31, 1967. The expected deaths are those which would be anticipated if the retirees were subject to the schedule of age-cause specific death rates for the white male population of the United States during the same period of observation.

The procedure for the computation of expected deaths began with compiling person-years of observation (PYR) by attained age and by calendar period in a five by five table as shown in Figure 3. Here, person-years are terminated in the middle of the month of death.

Mortality rates among U.S. white males by cause and by age group for the years 1945, 1950, 1955, 1960, and 1965 were used as estimates of the corresponding average annual mortality rates during each of the five calendar periods shown in Figure 3. The expected deaths (E_A) from cause A was then computed by multiplying each of the 25 person-years values from the table in Figure 3 by the corresponding mortality rate (${}_A R_{ij}$) among U.S. white males and then summing these products, i.e.

$$E_A = \sum_{i=1}^{5} \sum_{j=1}^{5} {}_A R_{ij} \ (PYR)_{ij} \quad .$$

The mortality rates needed to compute expected deaths had to be calculated directly from the number of deaths which occurred among white males in each of the 5 age groups during each of the 5 calendar years. Such figures are published by the National Center for Health Statistics.[17-21] Enumeration of the corresponding U.S. white male

AGE	CALENDAR PERIOD				
	1941-47	1948-52	1953-57	1958-62	1963-67
65-69	PYR(1,1)	PYR(1,2)	PYR(1,3)	PYR(1,4)	PYR(1,5)
70-74	PYR(2,1)	PYR(2,2)	PYR(2,3)	PYR(2,4)	PYR(2,5)
75-79	PYR(3,1)	PYR(3,2)	PYR(3,3)	PYR(3,4)	PYR(3,5)
80-84	PYR(4,1)	PYR(4,2)	PYR(4,3)	PYR(4,4)	PYR(4,5)
85 & over	PYR(5,1)	PYR(5,2)	PYR(5,3)	PYR(5,4)	PYR(5,5)

Figure 3. Schematic Representation of How Person-Years Were Compiled for the Retiree Population.

population in each of these age-calendar year categories was from census figures for 1950 and 1960 while intercensal estimates were used for 1945, 1955, and 1965.[22, 23]

The cause-specific mortality rates for 1945 which were used as estimates of the average annual cause-specific mortality rates during the period 1941-47 are based on deaths which have been coded according to the Fifth Revision of the ICD. However, the causes of death among the retirees under study who expired during 1941-47 have been coded according to the Seventh Revision of the ICD. This introduces a slight bias into the results for certain causes of death because the manner of selecting the underlying cause of death changed from the Fifth Revision to the Seventh Revision. The causes most affected in this study are vascular lesions affecting the central nervous system (330-334), all forms of heart disease (400-443), in particular, coronary heart disease (420), and diseases of the respiratory system (470-527). However, coding of cancer deaths (140-205) was only slightly affected by the change in revisions. Furthermore, the scope of the study is such that only 4 per cent of the observed deaths and only 6 per cent of the person-years occurred in the period 1941-47 and so minimal effects are felt on the overall mortality from specific causes.

Although race was to be coded as part of the relevant information for each retiree, complete data on this item was available only for those retirees who had died during the period of observation. This was because only the death certificate contained the information. Tabulation of the deceased retirees by race showed that of the 664 retirees who had expired prior to January 1, 1968 only 27 or about 4 per cent were non-white. It was thus decided that use of rates for white males in the U.S. would be acceptable and not lead to any serious biases in the results. Details on the causes of death of these 27 non-white retirees are contained in Table 1, Appendix A.

An SMR based on a small number of observed deaths is subject to large variability and should be interpreted with caution. The usual method of judging this variability is to relate the observed number of deaths to a known probability distribution. The follow-up of each retiree can be considered as a "trial" and on each of these "trials" there are only two outcomes: the man dies before the close of observation or he does not. Clearly, the outcome on any one "trial" is independent of the outcome on any other "trial". If the simplifying assumption is made that each retiree has the same probability of dying (before the close of observation) then the observed number of deaths can be considered as a binomial variable. Reference to the binomial distribution will then yield "exact" confidence intervals and/or significance factors for judging whether or not the discrepancy between observed and expected deaths might have arisen by chance.

When the probability of dying is small (say, less than 10 per cent) the Poisson distribution is a good approximation to the binomial. Bailar and Ederer[24] have tabulated significance factors for an SMR both at the 5 per cent and 1 per cent levels where the observed number of deaths is assumed to be a Poisson variable. Based on these tables, SMR's significantly different from 100 at the 5 per cent level have been so designated in the text tables.

In the present study group all of whose members enter observation around age 65 total mortality rates are relatively high, in particular those at ages 75 and over. While the Poisson approximation may not be as appropriate in such a situation its use leads to only conservative inferences. In approximating a binomial variable the Poisson estimate actually results in fewer cases of a statistically significant result than would occur if the exact procedure was routinely used.

The SMR has certain distinct qualities which make it a useful and illustrative measure of mortality. In using it to analyze the mortality experience of a group of individuals (cases), the following question is implicitly asked: Have the cases experienced the same mortality pattern as the control group chosen for comparison? In most situations it is important to be able to recognize significant departures of the cases from the controls with respect to deaths from all causes and/or certain specific causes. The SMR will readily depict such deviations and their significance can be judged as described above.

It often happens that several distinct groups of cases are being studied simultaneously and comparison of each of these groups with the same control group can be done using SMR's. The resulting SMR's will then show which of the several groups of cases experienced significant departures from the control group vis à vis overall mortality or cause-specific mortality. However, this latter situation can pose a methodological problem. If, in addition to simply distinguishing those groups of cases which experienced an excess or deficit in mortality, it is intended to precisely rank the several groups of cases by the magnitude of their SMR's, the effort can be questionable. For example, if three groups of cases show SMR's for a particular disease of 120, 180, and 360 when compared to a suitable control group the ratios 180/120 and 360/180 taken at face value imply that the risk of dying from this disease for the second group of cases is $1\frac{1}{2}$ times that of the first while the risk for the third group of cases is 2 times that of the second. However, as Silcock points out these inferences can be misleading since, for example, the age distributions of the three groups of cases are not controlled in the calculations.[25] For the purpose of such a precise ranking as described here, he proposes the use of a ratio (or ratios) of adjusted mortality rates as a valid comparative measure. These rates can be adjusted for whatever variables the investigator deems pertinent such as age, race, sex, etc.

In the present study it will be necessary to analyze the mortality experience of several retiree subgroups simultaneously; in fact, this will frequently be the case. On the one hand, it is necessary to find those subgroups which exhibit excess mortality from specific causes and those which do not. SMR's provide a perfectly valid scheme for doing this. However, in an analysis of several retiree subgroups it may happen that two or more show excesses in mortality from a specific cause. In this case it would be desirable to rank the "excess" subgroups without drawing any wrong conclusions. This is possible if the subgroups involved do not differ greatly with respect to variables (e.g. age) other than the one under study.

Virtually all the retirees enter the follow-up period at age 65 so the initial age structures of any two retiree categories are similar. However, since entrance to the observation period continues up to one year before the close of the study, the average length of follow-up available to various retiree categories may differ according to the retirement year distributions of their members. For example, if all members of retiree category A retired between 1945 and 1950 while all members of retiree category B retired between 1960 and 1965, the men in A would have at least 10 more years of follow-up available to them than the men in B. This would mean that the A retirees could age from 65 to at least 80 during the follow-up period whereas the B retirees could only age from 65 to 70. During these added 10 years of observation the retirees in category A are exposed to the risk of dying from diseases whose incidence increases with age such as the class of cardio-vascular-renal diseases as well as diseases with long latent periods, e.g. lung cancer.

With respect to death from lung cancer, it is known that for the period 1945-1965 mortality rates among U.S. white males for this cause have reached a peak between ages 65 and 74 and show a gradual decrease after age 74.[17-23] However, every member of the study group has already survived to age 65 and this might delay their peak years for lung cancer mortality to possibly the 75-84 age period. If this is so, then it would be misleading to use SMR's in comparing two retiree categories, one of which was followed between ages 65 and 74 while the other was followed between ages 65 and 84. In the latter retiree category, death rates for lung cancer might be increasing with age while the corresponding rates for U.S. white males would be decreasing, thus producing an excess in observed over expected deaths which would not be comparable to the results for the first retiree category.

Whenever two or more retiree categories are compared in the analyses to follow the median year of retirement for each one is shown. This can serve as a guide in interpreting the results. Widely differing medians would imply that the retirement year structures of the categories being compared differ greatly and hence the SMR's must be interpreted with some caution. In most cases median years of retirement are not much different and the SMR's can be judged accordingly.

V. RESULTS

A. General Mortality Pattern of Retirees

Excluded from all of the following mortality analyses are six normal retirees known to have died before the closing date of the study but for whom the cause of death was not available. Two of these men died outside the U. S. and it was not feasible to obtain copies of their death certificates. Although the other four deaths occurred within the U.S., the particular state in which the death took place was not known. Pertinent data from the work histories of these men is contained in Table 2, Appendix A.

Table 1, Appendix B, gives total deaths and person-years distributed by age and calendar period for the remaining 1,294 retirees. In Table 2 of Appendix B the same information is presented by age and year of retirement. A list of all deaths occurring among the retirees by detailed cause is given in Table 3, Appendix B.

Table 9 shows the collective mortality experience of the 1,294 retirees by cause and age. During the age interval 65-69 (which would correspond to the period shortly after retirement) the retirees experienced deficits in mortality from "all other cancer", cerebral vascular lesions, coronary heart disease, and "all other causes". This is not surprising in view of the fact that these men had been actively employed just prior to this time period. However, these deficits were offset by

Table 9

Observed and Expected Deaths Through December 31, 1967, by Cause and Age, Showing Standardized Mortality Ratios (SMR's) for 1,294 Males Who Worked in 11 Asbestos Products Plants and Retired During 1941 - 1966 (Excluding 6 with Unknown Cause of Death)

Cause of Death and International List Number	65 - 69			70 - 74			75 and over			All Ages		
	Obs.	Exp.	SMR	Obs.	Exp.	SMR	Obs.	Exp.	SMR	Obs.	Exp.	SMR
All Causes	219	201.4	108.8	218	178.5	122.1*	221	198.9	111.1	658	578.8	113.7*
All Cancer (140 - 205)	47	38.2	123.0	52	31.2	166.7*	44	26.6	165.2*	143	96.1	148.9*
Digestive System (150 - 159)	15	14.6	103.0	23	12.3	187.0*	15	10.7	139.9	53	37.6	141.0*
Lung, Bronchus, Trachea & Pleura (162 - 163)	20	9.1	219.9*	13	6.1	213.3*	13	3.3	397.6*	46	18.5	249.2*
All Other Cancer	12	14.6	82.4	16	12.8	125.0	16	12.6	126.6	44	40.0	110.0
Cerebral Vascular Lesions (330 - 334)	17	18.6	91.3	22	20.6	106.7	21	29.4	71.4	60	68.6	87.4
All Heart Disease (400 - 443)	94	94.6	99.4	87	83.2	104.5	112	92.8	120.7	293	270.7	108.3
Coronary Heart Disease (420)	70	74.7	93.7	68	64.9	104.7	87	69.4	125.4*	225	209.1	107.6
All Other Heart Disease	24	19.8	120.9	19	18.3	103.7	25	23.4	106.7	68	61.6	110.4
Diseases of the Respiratory System (470 - 527)	22	10.1	217.4*	16	9.5	168.0	14	11.6	120.5	52	31.3	166.3*
Pneumoconiosis & Pulmonary Fibrosis (523, 525)	12	-	-	9	-	-	6	-	-	27	-	-
All Other Causes	39	39.8	97.9	41	33.9	120.9	30	38.5	78.0	110	112.2	98.0

*SMR Significantly Different from 100 at 5% Level.

rather large excesses in deaths from lung cancer and disease of the respiratory system. The excess (22-10.1) in deaths from this latter disease category was entirely due to the 12 deaths from pneumoconiosis and pulmonary fibrosis. This large excess in deaths, so soon after retirement, can be understood more readily if it is kept in mind that the men who died of these causes had to already have had pneumoconiosis or pulmonary fibrosis at retirement.

As the retirees aged they gradually lost some of their initial advantages and less instances of a deficit in mortality occur. For example, their mortality from all heart disease reached a 20 per cent excess at ages over 75 after a slight deficit between ages 65 and 69. Deaths from all cancer also increased among the retirees due mainly to a sharp rise in lung cancer mortality after age 75.

In contrast to these instances of increasing mortality from several causes among the retirees with age is the picture for diseases of the respiratory system. Deaths from these diseases decreased with age reaching a point at ages 75 and over where it was only 20 per cent above that of U.S. white males.

Overall, the retirees experienced significant excess mortality from cancer of the digestive system, cancer of the lung, and diseases of the respiratory system. With respect to this latter category of diseases, the observed excess (52-31.3) was entirely due to deaths from pneumoconiosis and pulmonary fibrosis.

At this point it is important to point out that of the 87 retirees in Table 6 who were reported as having pneumoconiosis at first employment with the asbestos company, four died of pneumoconiosis or pulmonary fibrosis and three died of lung cancer. It is possible that occupational exposures not accounted for in the present study might have been the underlying reasons for these deaths. On the other hand, exposure to asbestos dust as defined in this report could have been the necessary complicating factor which resulted in these deaths. At any rate, it would be incorrect to attribute these seven deaths as solely due to occupational exposures at the present asbestos company.

B. Mortality in Terms of Usual Occupation

There were nineteen retirees for whom no work history was available so that these men could not be classified by usual occupation. For one of them the cause of death was not known and he has already been eliminated from all analyses. The remaining 18 retirees are excluded both from the study of mortality in terms of usual occupation and the set of subsequent analyses. All of these individuals had died before the closing date of the study. Details on their causes of death and other personal data are included in Table 3, Appendix A.

There remain 1,276 retirees for whom an analysis by usual occupation is possible. Of this number 797 worked primarily in production jobs, 341 in maintenance-service jobs, and 138 in office and miscellaneous positions. Table 10 shows the mortality experience of each of these occupational groups for somewhat broader cause of death categories than in the previous table. The median year of retirement for retirees in each of these groups indicates that production and maintenance-service retirees are quite comparable in terms of mortality.

Both production and maintenance-service retirees exhibited excess mortality from all causes which was about 13 per cent above the U.S. experience. On the other hand, office retirees experienced approximately the same overall mortality pattern as U.S. white males. The most striking feature of this analysis is the sharp contrast between production retirees and maintenance-service retirees with respect to deaths from lung cancer and diseases of the respiratory system. While both groups experienced significantly high risks from lung cancer, the risk for maintenance-service retirees was much greater than that for production retirees.

The reverse was true for diseases of the respiratory system where production retirees experienced a two-fold excess in deaths from these causes while maintenance-service retirees enjoyed a slight deficit. Again the excess in deaths from respiratory diseases for production retirees was entirely due to deaths from pneumoconiosis and pulmonary fibrosis. A comparison of the results for this disease category in Table 9 with those for the same category in Table 10 for

Table 10

Observed and Expected Deaths Through December 31, 1967, by Cause and Usual Occupation, Showing Standardized Mortality Ratios (SMR's) for 1,276 Males Who Worked in 11 Asbestos Products Plants And Retired During 1941 - 1966 (Excluding 18 with Unknown Usual Occupation)

Cause of Death and International List Number	Production			Maintenance-Service			Office & Other		
	Obs.	Exp.	SMR	Obs.	Exp.	SMR	Obs.	Exp.	SMR
All Causes	410	364.5	112.5*	170	149.5	113.7	60	59.5	100.9
All Cancer (140 - 205)	78	60.3	129.3*	47	25.1	186.9*	15	9.8	153.6
Digestive System (150 - 159)	29	23.7	122.6	16	9.8	163.8	7	3.8	185.4
Lung, Bronchus, Trachea & Pleura (162 - 163)	20	11.5	173.9*	22	5.0	444.0*	4	1.9	209.3
All Other Cancer	29	25.2	115.2	9	10.4	86.3	4	4.1	98.1
Diseases of the Respiratory System (470 - 527)	41	19.6	209.1*	8	8.1	98.5	3	3.3	90.6
Pneumoconiosis & Pulmonary Fibrosis (523, 525)	23	-	-	3	-	-	1	-	-
All Other Causes	291	284.6	102.3	115	116.3	98.9	42	46.4	90.5
Median Year of Retirement	1956			1957			1959		

*SMR Significantly Different From 100 at 5% Level.

production retirees indicates that the original excess in mortality from respiratory diseases observed for all retirees is confined to those men who worked primarily in production jobs.

C. Mortality in Terms of Total Unadjusted Exposure Score

Analyzing mortality patterns of the retirees in terms of total unadjusted exposure score began with grouping the subjects into meaningful categories of exposure score. From Tables 2 and 4 it is estimated that, on the average, retirees had worked about 25 years with the asbestos products company prior to their retirement. This figure was considered as a hypothetical working lifetime of asbestos dust exposure for each retiree. Together with the three numerical values (1, 3, 8) used to weight asbestos dust exposure Levels I to III, it was used to define four categories to total unadjusted exposure score.

A man who worked each of 25 years at a Level I asbestos dust exposure would accumulate an unadjusted exposure score of 25 (25 x 1). This was designated as the working lifetime upper limit for exposure scores in the lowest category. Under this definition a person might have worked for only 3 years, each of which was at a Level III asbestos dust exposure, and consequently accumulate an unadjusted exposure score of 24 (3 x 8). This would qualify him to enter the lowest category of exposure score. On the other hand, another individual might have worked each of 40 years at a Level I asbestos dust exposure resulting in an unadjusted exposure score of 40 (40 x 1). Such a person would be assigned to a higher category of exposure score.

If each of the 25 years was spent at a Level II asbestos dust exposure the resulting unadjusted exposure score would be 75 (25 x 3). This was designated as the working lifetime upper limit for exposure scores in the next highest category of total unadjusted exposure score. The above example of a man who accumulated an exposure score of 40 over 40 years would fall into this category as well as an individual who worked each of 10 years at a Level II asbestos dust exposure.

A total unadjusted exposure score of 200 (25 x 8) would be accumulated when the entire 25 years were spent at a Level III asbestos dust exposure. This was designated as the working lifetime upper limit for exposure scores in the next highest category of total unadjusted exposure score. A person who spent his entire working lifetime (50 years) at a Level II asbestos dust exposure would accumulate an exposure score of 150 (50 x 3) and qualify to enter this category. At the same time another individual who worked for 10 years at a Level III asbestos dust exposure would accumulate an exposure score of 80 (10 x 8) and also qualify to enter this category.

The fourth and highest category of unadjusted exposure score consisted of all those retirees who had accumulated an exposure score of 200 or more. An unadjusted exposure score in this range could not be achieved unless some time had been spent at a Level III or higher asbestos dust exposure.

The four categories of total unadjusted exposure score used in the following mortality analyses are then: 0-24, 25-74, 75-199, 200 and over.

The 138 retirees who worked primarily in Office and miscellaneous positions technically qualified to be included in the lowest unadjusted exposure score category (0-24). However, they have been excluded from the results in this section since this particular group of subjects might well differ from production and maintenance-service retirees with respect to certain factors affecting mortality, e.g. socio-economic status, smoking habits, and place of birth. These subjects have already been reported on as a group in Table 10 so that the completeness of the study is not affected. Moreover, by adding the observed and expected numbers of deaths by cause for the Office retirees to those for production and maintenance-service retirees in the lowest exposure score category, SMR's can easily be derived for the lowest score category inclusive of Office retirees.

Also excluded from the results in this section are 78 retirees whose work experience with the asbestos company was mainly in the asphalt roofing departments of the various plants. The environment of these areas has been described above and it was felt that these subjects were not appropriate for this phase of the study.

There remain 1,060 retirees who worked primarily in either production jobs or maintenance-service jobs for whom an analysis by total unadjusted exposure score is presented in this section. Table 11

Table 11

Distribution of 1,060 Retirees Who Worked
Primarily in Production or Maintenance-Service Jobs
By Age at First Employment with the Asbestos Company
And Total Unadjusted Exposure Score
(Excludes 78 Who Worked in Asphalt Roofing Departments)

Age at First Employment	Total Unadjusted Exposure Score									
	All Scores		0 - 24		25 - 74		75 - 199		200 & over	
	No.	%	No.	%	No.	%	No.	%	No.	%
15 - 64	1060	100.0	249	100.0	320	100.0	348	100.0	143	100.0
15 - 24	71	6.7	9	3.6	23	7.2	14	4.0	25	17.5
25 - 34	261	24.6	22	8.8	79	24.7	97	27.9	63	44.0
35 - 44	363	34.2	81	32.6	102	31.9	134	38.5	46	32.2
45 - 54	290	27.4	91	36.5	90	28.1	100	28.7	9	6.3
55 - 64	75	7.1	46	18.5	26	8.1	3	0.9	0	0.0
Mean Age at First Employment	40.3		45.7		40.5		39.5		32.7	

shows the distribution of these retirees by age at first employment with the asbestos company and total unadjusted exposure score. It can be seen that there is a negative association between these two variables. Men entering employment with the asbestos company at the younger ages and who remain there until retirement have a much greater chance of accumulating large exposure scores than men entering employment at the older ages. Conversely, those retirees who accumulated relatively high exposure scores are most likely the ones who began employment with the asbestos company during the younger ages while those retirees who accumulated relatively low exposure scores are most likely the ones who began employment during the older ages.

The percentage distribution in Table 11 has been presented so as to most readily illustrate the second phenomenon. For example, of the 143 retirees in Table 11 who accumulated an exposure score of 200 or more approximately 62 per cent began their employment with the asbestos company between the ages 15 and 34. On the other hand, of the 249 retirees who accumulated an exposure score of 24 or less, 55 per cent began their employment with the asbestos company between the ages 45 and 64.

The reason for displaying the percentage distributions in Table 11 by age at first employment with the asbestos company within each of the four exposure score categories rather than vice-versa is that exposure score category is the variable under study in the present section. Age at first employment with the asbestos company is not the variable of primary interest here, but can be of help in interpreting a comparative mortality analysis of unadjusted exposure score.

Table 12 shows the distribution by category of unadjusted exposure score for the 1,060 retirees under examination in this section, production retirees alone, and maintenance-service retirees alone. It can be seen that the biggest disparity between production and maintenance-service retirees with respect to exposure score occurred in the 25-74 category where there were about 14 per cent more production retirees than maintenance-service retirees. Overall, there were about 8 per cent more maintenance-service retirees in the higher categories of unadjusted exposure score (75 and over) than production retirees.

Tables 13-15 show observed and expected deaths by category of unadjusted exposure score for 1,060 production and maintenance-service retirees combined, 721 production retirees, and 339 maintenance-service retirees respectively. Table 12 can be used as a reference to establish the number of retirees at risk in each of the various categories. In many instances the number of observed deaths are small and consequently the ratios must be interpreted with some caution. As in previous tables, SMR's significantly different from 100 have been so designated, but what is of primary interest here is the trend of SMR's rather than their absolute values.

In Table 13 for production and maintenance-service retirees combined the median years of retirement in each of the exposure score

Table 12

Distribution of 1,060 Retirees Who Worked Primarily in
Production or Maintenance-Service Jobs By
Usual Occupation and Total Unadjusted Exposure Score
(Excludes 78 Who Worked in Asphalt Roofing Departments)

Total Unadjusted Exposure Score	Total		Production		Maintenance - Service	
	Number	%	Number	%	Number	%
All Scores	1,060	100.0	721	100.0	339	100.0
0 - 24	249	23.5	156	21.6	93.	27.4
25 - 74	320	30.2	249	34.5	71	20.9
75 - 199	348	32.8	222	30.9	126	37.2
200 and over	143	13.5	94	13.0	49	14.5

Table 13

Observed and Expected Deaths Through December 31, 1967, by Cause and Total Unadjusted Exposure Score, Showing Standardized Mortality Ratios (SMR's) for 1,060 Males Who Worked Primarily in Production or Maintenance-Service Jobs in 11 Asbestos Products Plants and Retired During 1941 - 1966 (Excludes 78 Who Worked in Asphalt Roofing Departments)

Cause of Death and International List Number	0 - 24			25 - 74			75 - 199			200 & over		
	Obs.	Exp.	SMR	Obs.	Exp.	SMR	Obs.	Exp.	SMR	Obs.	Exp.	SMR
All Causes	126	133.6	94.3	150	144.8	103.6	171	139.0	123.0*	86	57.2	150.2*
All Cancer (140 - 205)	26	21.5	120.9	28	23.9	117.3	44	23.7	185.4*	21	9.9	211.9*
Digestive System (150 - 159)	9	8.6	104.3	12	9.3	129.6	14	9.1	153.3	7	3.8	182.0
Lung, Bronchus, Trachea & Pleura (162 - 163)	9	3.8	238.0*	8	4.7	172.0	13	4.8	268.2*	10	2.0	500.0*
All Other Cancer	8	9.1	87.9	8	10.0	80.3	17	9.8	174.3*	4	4.1	98.4
Diseases of the Respiratory System (470 - 527)	8	7.0	114.2	9	8.0	112.9	12	7.6	157.6	14	3.1	459.0*
Pneumoconiosis & Pulmonary Fibrosis (523, 525)	3	-	-	3	-	-	6	-	-	11	-	-
All Other Causes	92	105.0	87.6	113	113.0	100.0	115	107.7	106.8	51	44.3	115.2
Median Year of Retirement	1955			1957			1957			1955		

*SMR Significantly Different from 100 at 5% Level.

categories are not much different and comparisons among these categories should not lead to any serious bias. For all causes SMR's tended to rise from a slight deficit in the lowest category of unadjusted exposure score to a 50 per cent excess in the highest score category. Among these retirees mortality from all cancer also increased. The rise in cancer of the digestive system was roughly consistent with the increase for all cancer. Deaths from lung cancer were higher than those expected in each exposure score category, reaching a five-fold excess in the highest score category. The somewhat large SMR for this cause among retirees accumulating an unadjusted exposure score below 25 is somewhat puzzling and is certainly out of line in an otherwise increasing trend in mortality. SMR's for the category "all other cancer" show no particular trend except that a consistent deficit in deaths from these causes is broken by the significant excess in the 75-199 score category. The pattern for diseases of the respiratory system shows a plateau for SMR's in the two lowest exposure score categories after which a sharp increase occurs with the observed mortality over four and one-half times the expected in the highest score category. Excess deaths from these causes in the two highest categories of exposure score were entirely due to pneumoconiosis and pulmonary fibrosis. After excluding cancer and respiratory diseases, SMR's for all other causes exhibited an increasing trend though not as sharp as the one noted for all causes.

From Table 10 it was seen that the risk of dying from respiratory diseases among the retirees was mostly confined to those who worked primarily in production jobs. In Table 14 these retirees are studied with respect to unadjusted exposure score. In this instance, a discrepancy of three to four years in the median years of retirement occurs. The middle two score categories would be quite comparable as would the lowest with the highest. However, overall comparisons among all four categories might seem inappropriate. In this respect it could be argued that the consistent upward trend in the four SMR's (all causes) may not be the true case. For example, the apparent high mortality from all causes in the "200 and over" score category (SMR=153.3) as compared to the relatively low SMR (105.2) in the "25-74" category of exposure score might be due to an artifact in the data. Specifically, the 1957 median retirement year for the latter group of retirees seems to indicate that, on the average, these men had not aged as much as the former group of retirees (median retirement year=1954). Hence, the observed difference in SMR's might well be due to an older group of subjects being compared to a younger group. Such an objection might be overruled, however, by observing that for the two pairs of exposure score categories that are comparable the trend in rising SMR's with increasing exposure score is clearly evident. In any case, it will be sufficient to discern those broad patterns of mortality which may emerge.

Table 14

Observed and Expected Deaths Through December 31, 1967, by Cause and Total Unadjusted Exposure Score, Showing Standardized Mortality Ratios (SMR's) for 721 Males Who Worked Primarily in Production Jobs In 11 Asbestos Products Plants and Retired During 1941 - 1966 (Excludes 76 Who Worked in Asphalt Roofing Departments)

Cause of Death and International List Number	0 - 24			25 - 74			75 - 199			200 & over		
	Obs.	Exp.	SMR	Obs.	Exp.	SMR	Obs.	Exp.	SMR	Obs.	Exp.	SMR
All Causes	80	87.8	91.1	119	113.1	105.2	107	86.1	124.2*	59	38.5	153.3*
All Cancer (140 - 205)	16	14.0	113.9	22	18.6	118.0	24	14.7	163.5*	11	6.6	167.0
Digestive System (150 - 159)	4	5.7	70.6	11	7.2	152.0	7	5.6	124.2	4	2.6	154.8
Lung, Bronchus, Trachea & Pleura (162 - 163)	5	2.4	208.1	4	3.6	109.9	6	3.0	199.3	3	1.3	232.9
All Other Cancer	7	6.0	117.2	7	7.8	90.1	11	6.0	182.5	4	2.7	147.3
Diseases of the Respiratory System (470 - 527)	6	4.6	131.3	9	6.2	144.5	7	4.7	148.0	13	2.0	646.8*
Pneumoconiosis & Pulmonary Fibrosis (523, 525)	2	-	-	3	-	-	5	-	-	10	-	-
All Other Causes	58	69.2	83.8	88	88.3	99.7	76	66.7	113.9	35	29.9	117.1
Median Year of Retirement	1953			1957			1957			1954		

*SMR Significantly Different from 100 at 5% Level.

Since these results deal with a smaller subset of the data observed deaths from some causes will be quite small and this could make trends difficult to establish. Increasing SMR's for all causes in production retirees closely matches that seen in the combined group of retirees. SMR's for all cancer in production retirees increase steadily as before but the trend previously noted for cancer of the digestive system is not as clear. The picture for lung cancer is again somewhat ambigious with the persistence of a large SMR in the lowest score category. Despite the small number of observed deaths SMR's in the two highest score categories suggest elevated mortality among production retirees from this cause. SMR's for diseases of the respiratory system increased quite sharply in the highest exposure score category revealing a six-fold increase in observed over expected deaths. This excess as well as the more moderate ones in the other three categories were entirely due to deaths from pneumoconiosis and pulmonary fibrosis.

In Table 10 it was seen that the risk of dying from lung cancer among the retirees was mostly confined to those who worked primarily in maintenance-service jobs. Table 15 shows the results in terms of total unadjusted exposure score for this group. Median years of retirement are not much different here and comparisons should be quite valid. For all causes SMR's again tended to rise with exposure score category - a consistency which is quite striking. With this smaller subset of the data observed deaths again are quite small for

Table 15

Observed and Expected Deaths Through December 31, 1967, by Cause and Total Unadjusted Exposure Score, Showing Standardized Mortality Ratios (SMR's) for 339 Males Who Worked Primarily in Maintenance-Service Jobs in 11 Asbestos Products Plants and Retired During 1941-1966 (Excludes 2 Who Worked in Asphalt Roofing Departments)

Cause of Death and International List Number	0 - 24			25 - 74			75 - 199			200 & over		
	Obs.	Exp.	SMR	Obs.	Exp.	SMR	Obs.	Exp.	SMR	Obs.	Exp.	SMR
All Causes	46	45.7	100.6	31	31.7	97.8	64	52.9	121.0	27	18.8	143.9
All Cancer (140 - 205)	10	7.5	134.0	6	5.2	114.9	20	9.1	220.8*	10	3.3	300.8*
Digestive System (150 - 159)	5	3.0	168.9	1	2.0	49.5	7	3.5	200.3	3	1.3	237.5
Lung, Bronchus, Trachea & Pleura (162 - 163)	4	1.4	290.3	4	1.0	396.0*	7	1.8	381.3*	7	0.7	983.1*
All Other Cancer	1	3.1	32.0	1	2.2	45.6	6	3.7	161.0	0	1.3	0.0
Diseases of the Respiratory System (470 - 527)	2	2.4	82.2	0	1.7	0.0	5	2.9	173.4	1	1.0	96.2
Pneumoconiosis & Pulmonary Fibrosis (523, 525)	1	-	-	0	-	-	1	-	-	1	-	-
All other causes	34	35.8	94.8	25	24.7	101.0	39	41.0	95.2	16	14.4	111.1
Median Year of Retirement	1956			1958			1957			1957		

*SMR Significantly Different from 100 at 5% Level.

the specific causes. However, quite a sharp increase in the SMR's for all cancer is clearly evident. This rapid rise is mostly due to lung cancer where SMR's for all categories of exposure score run quite high. In the highest category alone the observed mortality is almost ten times the expected. The persistence of such a high SMR in the lowest exposure score category for maintenance-service retirees would not seem to fit the general pattern. A weaker trend for cancer of the digestive system is noticeable although the observed numbers of deaths are small. It has already been seen that there is no excess risk in mortality from respiratory diseases among maintenance-service retirees. This disease category is included in the present analysis mainly for the sake of completeness although the numbers of observed deaths are quite small.

A comparison of the two highest categories of unadjusted exposure score in Tables 14 and 15 indicates that for all cancer, cancer of the digestive system, and cancer of the lung, maintenance-service retirees experienced greater excesses in mortality than did production retirees.

D. Mortality in Terms of Total Unadjusted Exposure Score and Age at First Employment

In Table 11 it was seen that most of the production and maintenance-service retirees who accumulated unadjusted exposure scores over 75 began work in the asbestos company during the younger ages. At the same time those who accumulated unadjusted exposure scores under 75 tended to have begun their employment with the company at the older ages. This means that in analyzing mortality patterns by total unadjusted exposure score such as was done in Tables 13-15 the variable of interest (score) is confounded with the variable "age at first employment". This confounding variable may be of interest in its own right. If "age at first employment" can be interpreted as "age at first exposure to asbestos dust" then this variable is directly proportional to "time since first exposure" for members of this study group since almost every retiree enters the observation period at the same age, viz. 65. It may be that the biologic reaction to asbestos dust differs with the time since first exposure or "incubation period". Thus, the response to total amount of dust shown in Tables 13-15 may be simply a reflection of this "latent period". Studying the variables "total unadjusted exposure score" and "age at first employment" simultaneously could, to a certain degree, separate the effect of dose from time since first exposure. The problem can then be considered from two points of view. Starting with two or more groups of retirees, each of which is relatively homogeneous with respect to "age at first employment" the effect of increasing dose can be examined. Conversely, for a given category of amount of exposure, the effect of time since first exposure can be studied.

Table 16 presents some results on this issue for the 1,060 retirees who worked primarily in production or maintenance-service

Table 16

LUNG CANCER

	15 - 39				40 - 64			
	Pop.	Obs.	Exp.	SMR	Pop.	Obs.	Exp.	SMR
0 - 24	50	2	0.7	292.4	199	7	3.1	226.0
25 - 74	155	5	2.0	244.0	165	3	2.6	115.3
75 - 199	179	4	2.4	167.0	169	9	2.5	367.0*
200 and over	118	9	1.7	532.5*	25	1	0.3	322.6

jobs in terms of mortality from lung cancer. Here, only two broad categories of "age at first employment" are used since the number of lung cancer deaths available for analysis is so limited. It can be seen that the excesses previously noted in the two lowest exposure score categories (Table 13) are chiefly confined to retirees who began their asbestos exposure at younger ages, suggesting that for low doses time since first exposure is an important variable. Furthermore, the excesses exhibited in retirees accumulating relatively high exposure scores (75 and over) are maintained for both those first exposed early and those first exposed late in their working lifetime. This may indicate that, at least in such a retired population, heavy amounts of asbestos exposure increase the risk of dying from lung cancer independently of time since first exposure.

In Table 16 one of the seven deaths in the "40-64, 0-24" age-score category was of a man who had pneumoconiosis at first employment with the asbestos company and another of these deaths was of a man who had had previous silica dust exposure. Such circumstances could lead to an overstatement of the risk of dying from lung cancer in this age-score category of retirees if these previous events were responsible for the two lung cancers in question.

Table 17 shows the mortality experience from respiratory diseases (470-527) for 721 retirees who worked primarily in production jobs by "age at first employment with the asbestos company" and "total unadjusted exposure score". It can be seen that the large excess in

Table 17

RESPIRATORY DISEASES

	15 - 39				40 - 64			
	Pop.	Obs.	Exp.	SMR	Pop.	Obs.	Exp.	SMR
0 - 24	25	1(0)	0.6	163.9	131	5(2)	4.0	126.3
25 - 74	116	3(1)	2.2	137.6	133	6(2)	4.1	148.1
75 - 199	118	5(4)	2.1	238.1	104	2(1)	2.6	76.0
200 and over	73	11(8)	1.5	733.3*	21	2(2)	0.5	392.2

deaths from these causes noted for the highest exposure score categories (Table 14) has been mainly confined to those production retirees who began employment with the company before the age of 40. One of the two deaths in the "40-64, 200 and over" age-score category was of a man who had pneumoconiosis at first employment with the asbestos company. Consequently, the results for this age-score category of retirees might be overstated.

Comparison of the results shown in Tables 16 and 17 would seem to indicate that the risk of dying from lung cancer smong the retirees is less dependent on any particular combination of total unadjusted exposure score and age at first employment with the asbestos company than is risk of dying from respiratory diseases. For the latter set of causes both a high score and a long-term exposure (reflected by a young age at first employment) are indicated as prerequisites for increased mortality among the retirees.

E. Mortality in Terms of Type of Asbestos Products

In analysis of mortality by "type of asbestos products" it was decided to exclude any retiree who worked primarily in maintenance-service or office jobs. The majority of retirees from these occupations simply could not be classified by "type of asbestos products" since department titles did not appear on their work histories. Moreover, it became apparent that most retirees from office and maintenance-service jobs for whom department titles were known had worked in the asbestos cement division of the company. This tendency might well have been true for all men in these types of jobs or may have been peculiar to those having department titles in their work histories. The latter possibility could introduce a bias in the present analysis by adding retirees to the asbestos cement group which would be disproportionate to this group's true representation in the present study population. This bias might well be serious because of the very high mortality from lung cancer seen previously in maintenance-service retirees (Table 10). Improper or incomplete allocation of these subjects to categories of "type of asbestos products" could distort comparative lung cancer mortality among these categories.

Of the 797 retirees who worked primarily in production jobs, 702 could be classified into one of the five categories of "type of asbestos products" shown in Table 8. The remaining 95 production retirees consisted of 76 who worked in asphalt roofing departments and 19 who worked in miscellaneous product lines.

Table 18 shows the distribution of the 702 retirees by type of asbestos products and total unadjusted exposure score. It should be remembered here that assignment of a man to one of the five asbestos product categories does not necessarily imply that his entire work experience with the asbestos company was confined to departments within that particular asbestos product division. In many cases retirees had worked in two or more of the five categories of asbestos

Table 18

Distribution of 702 Retirees Who Worked Primarily in Production Jobs By Type of Asbestos Products and Total Unadjusted Exposure Score (Excludes 76 Who Worked in Asphalt Roofing Departments and 19 Who Worked in Miscellaneous Product Lines)

Total Unadjusted Exposure Score	Total		Asbestos Insulation Products		Asbestos Cement Products		Asbestos Packings & Friction Materials		Asbestos Paper & Pipe Covering		Asbestos Textiles & Fire Felt	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
All Scores	702	100.0	137	100.0	264	100.0	130	100.0	98	100.0	73	100.0
0 - 24	139	19.8	16	11.7	43	16.3	41	31.5	38	38.8	1	1.4
25 - 74	247	35.2	59	43.1	88	33.3	54	41.6	35	35.7	11	15.1
75 - 199	222	31.6	41	29.9	104	39.4	32	24.6	17	17.3	28	38.4
200 and over	94	13.4	21	15.3	29	11.0	3	2.3	8	8.2	33	45.1

products. In these situations assignment to a particular category was based on the total unadjusted exposure score accumulated in each category: the one with the highest score being chosen.

It may be seen from this table that retirees from asbestos cement products predominate, being almost twice in numbers as the next largest group. The category with the smallest representation is textiles and fire felt. With regard to this last category, of the 73 retirees so classified 61 were actually from textiles and 12 from the fire felt section. Table 8 indicated that asbestos flooring was to be included with packings and friction materials. Only five retirees were found to have had the majority of their exposure in this department and they have been included with 125 retirees from packings and friction materials. However, because of the great preponderance of the latter retirees this category will be denoted simply by "asbestos packings and friction materials". In Table 18 retirees from insulations and cement products are seen to be roughly similar in their distribution by total unadjusted exposure score. So too are retirees from packings-friction materials and paper-pipe covering. Retirees from textiles and fire felt, however, are somewhat unique exhibiting a highly skewed distribution toward the higher exposure score. Overall, retirees in these five product categories can be broadly reduced to three levels according to unadjusted exposure score. The highest level would be occupied by men from textiles and fire felt followed by retirees from insulations and cement products. The lowest level would consist of those from packings, friction materials, paper and pipe covering.

Table 19 contains an analysis of the mortality experience of retirees in each of the five categories of asbestos products. Median years of retirement differ here up to three years so that strict comparisons may not be warranted. The numbers of observed deaths from specific causes are quite small in some cases and this also makes precise comparisons more difficult. However, certain features are quite striking. The results for retirees in two categories (insulations and packings-friction materials) are examples. The excess of better than 40 per cent in total deaths among insulation retirees is quite large and is due mainly to deaths from lung cancer, cancer of the digestive system, and diseases of the respiratory system. A significant deficit of 25 per cent in deaths from all causes was observed in retirees from packings and friction materials. The deficit for all cancer, although based on only five observed deaths, is even more pronounced. Somewhat surprising is the result for diseases of the respiratory system where in the absence of elevated mortality from this set of causes three out of the four deaths were due to pneumoconiosis or pulmonary fibrosis. This is for one of the less dusty categories of asbestos products.

The significant SMR for all cancer observed in retirees in the asbestos cement category is due not only to the excesses for lung

Table 19

Observed and Expected Deaths Through December 31, 1967 by Cause and Type of Asbestos Products, Showing Standardized Mortality Ratios (SMR's) for 702 Males Who Worked Primarily in Production Jobs in 11 Asbestos Products Plants and Retired During 1941 - 1966 (Excludes 19 Who Worked in Miscellaneous Product Lines)

Cause of Death and International List Number	Asbestos Insulation Products			Asbestos Cement Products			Asbestos Packings and Friction Materials		
	Obs.	Exp.	SMR	Obs.	Exp.	SMR	Obs.	Exp.	SMR
All Causes	85	60.0	141.7*	120	101.0	118.8	55	73.9	74.4*
All Cancer (140 - 205)	19	10.2	186.4*	32	17.1	187.4*	5	11.8	42.3*
Digestive System (150 - 159)	10	4.0	250.9*	10	6.6	151.5	1	4.6	21.6
Lung, Bronchus, Trachea & Pleura (162 - 163)	5	2.0	250.8	6	3.5	173.9	1	2.2	46.0
All Other Cancer	4	4.2	94.9	16	7.0	227.8*	3	5.0	59.9
Diseases of the Respiratory System (470 - 527)	11	3.2	345.7*	9	5.5	163.7	4	4.1	98.1
Pneumoconiosis & Pulmonary Fibrosis (523, 525)	5	-	-	6	-	-	3	-	-
All Other Causes	55	46.6	118.0	79	78.5	100.7	46	58.0	79.3
Median Year of Retirement	1955			1957			1957		

*SMR Significantly Different From 100 at 5% Level

Table 19 (continued)

Observed and Expected Deaths Through December 31, 1967 by Cause and Type of Asbestos Products, Showing Standardized Mortality Ratios (SMR's) for 702 Males Who Worked Primarily in Production Jobs in 11 Asbestos Products Plants and Retired During 1941 - 1966 (Excludes 19 Who Worked in Miscellaneous Product Lines)

Cause of Death and International List Number	Asbestos Paper and Pipe Covering			Asbestos Textiles and Fire Felt		
	Obs.	Exp.	SMR	Obs.	Exp.	SMR
All Causes	57	47.9	119.1	43	36.4	118.0
All Cancer (140 - 205)	9	7.8	115.2	8	5.9	134.7
Digestive System (150 - 159)	2	3.1	64.1	3	2.4	126.7
Lung, Bronchus, Trachea & Pleura (162 - 163)	4	1.4	285.1	2	1.1	186.0
All Other Cancer	3	3.3	91.2	3	2.5	120.2
Diseases of the Respiratory System (470 - 527)	5	2.5	198.9	6	1.9	312.3*
Pneumoconiosis & Pulmonary Fibrosis (523, 525)	2	-	-	4	-	-
All Other Causes	43	37.5	114.6	29	28.6	101.5
Median Year of Retirement	1954			1956		

*SMR Significantly Different From 100 at 5% Level

cancer and cancer of the digestive system but also to the two-fold excess in deaths from "all other cancers" which was significant by itself. This latter result which is apparently out of the ordinary considering the previous results for this disease category could be due to chance alone. The SMR for lung cancer in retirees in the paper and pipe covering category suggests a possible excess risk for this disease in an asbestos products division which reflects relatively low exposure scores. The most notable result for retirees in the textiles and fire felt category is the three-fold excess in deaths from respiratory diseases which was entirely due to four deaths from pneumoconiosis and pulmonary fibrosis. It is interesting to note that the greatest excesses in deaths from respiratory diseases (both around three-fold) occurred in retirees from asbestos product lines having the least amount of asbestos in the final products (insulations) and in retirees from those product lines having the greatest amount of asbestos in the final products (textiles and fire felt).

F. Mortality in Terms of Total Adjusted Exposure Score

Under the assumption that it is the asbestos fiber, per se, which is most important in the etiology of lung cancer and other diseases among asbestos workers it would be important to quantify the relationship, if one exists, between the amount of asbestos fibers a man has been exposed to and subsequent mortality. The unadjusted exposure score used in previous analyses was influenced to a degree by other dusts, chiefly silica, which existed simultaneously with asbestos in the working environment. Derivation of an adjusted exposure score has already been described. Unfortunately, these scores could be computed only for retirees who worked primarily in production jobs. The reason for this is the same as the one for classifying only production retirees by "type of asbestos products" discussed in the previous section.

Table 20 shows the relationship of adjusted exposure score to unadjusted exposure score in terms of a cross-classification of the 721 production retirees by these variables. The same groupings used previously for unadjusted scores are retained here for adjusted scores for two reasons. One is that there are no obvious standards for defining score-specific groupings in the present case and the other is simply for ease of comparison with the results for corresponding categories of unadjusted exposure score. The 156 retirees having a total unadjusted exposure score less than 25 remain, of course, in this same category of adjusted exposure score. For this category it would be very difficult to distinguish the effect of either score in terms of cause-specific mortality even if large numbers of deaths from these causes were available. For each of the three highest categories of total unadjusted exposure score, considerable numbers of retirees were displaced into lower categories of adjusted exposure score.

Table 20

Distribution of 721 Retirees Who Worked
Primarily in Production Jobs by Total
Unadjusted Exposure Score and
Total Adjusted Exposure Score

Total Unadjusted Exposure Score	Total Adjusted Exposure Score									
	All Scores		0 - 24		25 - 74		75 - 199		200 & over	
	No.	%	No.	%	No.	%	No.	%	No.	%
All Scores	721	100.0	335	100.0	252	100.0	96	100.0	38	100.0
0 - 24	156	21.6	156	46.6	0	0.0	0	0.0	0	0.0
25 - 74	249	34.5	144	43.0	105	41.7	0	0.0	0	0.0
75 - 199	222	30.9	35	10.4	116	46.0	71	74.0	0	0.0
200 & over	94	13.0	0	0.0	31	12.3	25	26.0	38	100.0

Adjusted exposure score is, by derivation, closely related to the type of asbestos products with which a retiree worked. Table 21 illustrates this fact for the 702 of 721 production retirees who could be classified by "type of asbestos products". It can be seen that the majority of retirees in the lowest category of total adjusted exposure score worked primarily in asbestos insulation and asbestos cement products. These two product lines have the lowest percentage of asbestos in the final product but are responsible for relatively high total dust exposures. Most of the remaining retirees in this lowest adjusted score category were probably also in the same unadjusted score category since the products they were chiefly involved with contained relatively high amounts of asbestos. At the other extreme the two highest categories of total adjusted exposure score contain mostly retirees who worked primarily in asbestos packings, friction materials, paper, pipe covering, textiles, or fire felt. It is these product lines which contain the greatest percentage of asbestos in the final products. However, with the exception of asbestos textiles and fire felt total dust exposures in these departments are generally relatively moderate to low. From this table it can be seen that studying the relationship between total adjusted exposure score and cause-specific mortality simultaneously involves the effect of the variable "type of asbestos products".

Table 22 presents the results for 721 production retirees in terms of mortality by category of adjusted exposure score. For all causes SMR's tended to increase with score. This was also the case

Table 21

Distribution of 702 Retirees Who Worked Primarily in Production Jobs by Type of Asbestos Products and Total Adjusted Exposure Score (Excludes 19 Who Worked in Miscellaneous Product Lines)

Type of Asbestos Products	Total Adjusted Exposure Score							
	0 - 24		25 - 74		75 - 199		200 & over	
	No.	%	No.	%	No.	%	No.	%
Total	316	100.0	252	100.0	96	100.0	38	100.0
Asbestos Insulation Products	88	27.8	43	17.1	6	6.3	0	0.0
Asbestos Cement Products	135	42.8	103	40.8	25	26.0	1	2.6
Asbestos Packings & Friction Materials	53	16.8	55	21.8	22	22.9	0	0.0
Asbestos Paper & Pipe Covering	39	12.3	38	15.1	16	16.7	5	13.2
Asbestos Textiles & Fire Felt	1	0.3	13	5.2	27	28.1	32	84.2

Table 22

Observed and Expected Deaths Through December 31, 1967, by Cause and Total Adjusted Exposure Score, Showing Standardized Mortality Ratios (SMR's) for 721 Males Who Worked Primarily in Production Jobs in 11 Asbestos Products Plants and Retired During 1941-1966

Cause of Death and International List Number	0 - 24			25 - 74			75 - 199			200 & over		
	Obs.	Exp.	SMR	Obs.	Exp.	SMR	Obs.	Exp.	SMR	Obs.	Exp.	SMR
All Causes	164	157.9	103.9	125	105.0	119.1	50	42.7	117.1	26	20.0	129.7
All Cancer (140 - 205)	37	26.0	142.4	23	17.5	131.1	7	7.1	98.2	6	3.3	182.3
Digestive System (150 - 159)	15	10.2	146.4	5	6.8	73.5	4	2.8	145.3	2	1.3	151.1
Lung, Bronchus, Trachea & Pleura (162 - 163)	9	4.9	184.8	5	3.5	143.8	2	1.4	141.5	2	0.6	343.6
All Other Cancer	13	10.9	119.5	13	7.3	179.0	1	3.0	33.8	2	1.4	144.4
Diseases of the Respiratory System (470 - 527)	12	8.4	142.5	12	5.7	209.7*	5	2.4	211.6	6	1.0	582.5*
Pneumoconiosis & Pulmonary Fibrosis (523, 525)	4	-	-	8	-	-	5	-	-	3	-	-
All Other Causes	115	123.4	93.2	90	81.7	110.1	38	33.2	114.5	14	15.7	89.1
Median Year of Retirement	1956			1957			1956			1954		

*SMR Significantly Different from 100 at 5% Level

for production retirees in Table 14. However, the gradient for adjusted score is much less sharp than it was for unadjusted score. The results for lung cancer are based on small numbers of observed deaths, particularly in the two highest categories of adjusted exposure score. The high SMR in the "200 and over" score category does stand out among the four results for this cause. If this value is of any reliability it would indicate that the risk of dying from lung cancer is confined to those men who have experienced high exposures where it was likely that most of the dust consisted of asbestos fibers. The upward trend of SMR's for diseases of the respiratory system is consistent with a similar trend noted in terms of unadjusted exposure score except that large excesses show up sooner. In Table 14 it was only in the highest category of unadjusted exposure score that a large excess in these deaths occurred. However, a significant excess is shown in the 25-74 adjusted score category and this is maintained and surpassed in the two higher adjusted score categories.

It is informative to understand some of the results for adjusted score in terms of its relationship to "type of asbestos products" mentioned previously. For example, the SMR for cancer of the digestive system in the 0-24 adjusted score category is much greater than the corresponding SMR for the same category of unadjusted exposure score. In the reallocation of production retirees by adjusted score it can be seen from Table 21 that a considerable number of those in the lowest category of adjusted score had worked primarily in asbestos insulations and cement products. In Table 19 retirees from these two product lines accounted for most of the eleven "additional" deaths from these cancers observed in the 0-24 adjusted score category over what was initially found in the same unadjusted score category (Table 14). As a result of this "transfer" of deaths the SMR for cancer of the digestive system in the 25-74 adjusted score category is much lower than the corresponding SMR in the same category of unadjusted score. The appearance of rather high SMR's for diseases of the respiratory system in the middle two categories of adjusted exposure score is a result of reallocation of the men from asbestos insulations and cement products who accumulated high unadjusted exposure scores to these two adjusted exposure score categories.

VI. DISCUSSION

Although data presented here is based solely on the experience of males aged 65 and over who were no longer employed in the asbestos products industry the results are quite consistent with previous findings for actively employed asbestos products workers with respect to elevated mortality from cancer of the digestive system, lung cancer, and respiratory diseases.

Some investigators in the field of occupational health have commented on the appropriateness of analyzing the mortality patterns of survivor groups in the study of industrial populations. One objection which is often raised is that of "selection". By this is meant that the group or cohort under study at a given point in time consists of only those individuals healthy enough to reach that point. What is suggested here is that the more susceptible (to the particular industry-related disease(s) under investigation) persons have previously withdrawn from eligibility for the cohort because of disability, death, and unspecific reasons. In this respect Lloyd has pointed out that if there is an underlying relationship between occupation and cause-specific mortality, the pattern of mortality for survivors may be biased by the occurrence of exposure-related mortality <u>prior</u> to observation.[26] This is probably true for a disease like asbestosis which in the past has caused deaths among asbestos workers more frequently at ages under 65.[5,12] In order to draw an inference as to the relative mortality risk for this disease it would be more appropriate to study exposed populations under the age of 65. Surprisingly though, an excess risk for the category of respiratory diseases which includes asbestosis was detected in retirees and was entirely due to pneumoconiosis and pulmonary fibrosis. Furthermore, most of these deaths occurred among retirees who had first been exposed to asbestos dust more than thirty years before retirement (Table 17). However, for a disease such as lung cancer which has characteristically exhibited a long latent period in asbestos workers, observation restricted to ages 65 and over might indeed prove more useful than not. Even in the restricted age span of 65 and over a certain order is evident in terms of deaths from respiratory diseases which include asbestosis and lung cancer. It may be seen from Table 9 that the greatest excess in deaths from the former set of causes (470-527) occurred between ages 65 and 69 while the greatest excess from lung cancer occurred at ages 75 and over.

In this vein it is illustrative, methodologically, to compare the retirees' cause-specific mortality experience with the results of Mancuso and Enterline for asbestos products workers under age 65.[10,11] The excess in deaths from lung cancer noted for retirees was on about the same order as that in Mancuso's subjects and in the asbestos textile workers studied by Enterline. On the other hand, retirees had a much greater risk than did either the workers in asbestos building products or asbestos friction materials in the latter study. The excess in deaths from cancer of the digestive system among retirees was much lower than that observed by Mancuso but was quite similar to Enterline's finding in asbestos textile workers. Again the risk of dying from these cancers was greater among retirees than for workers in either of the other two categories of asbestos products in the latter study. The consistency between results of the present study and the work of Mancuso and Enterline is an example in which a survivor group provided about the same insight into industry-related disease problems as did two groups of active workers.

Of course the magnitude of the increased risk from occupationally related disease (s) will vary from one investigation to another because of differences in one or more features of the studies. These include composition of the cohort with respect to age at start of observation and area of exposure within the industry, length of observation period, age span during which follow-up continues, and selection of a comparison group. In the several studies quoted in Section I the lung cancer mortality rates ranged from a low of 1.2 to a high of 13.8 times the expected. The risk among retirees is well below that observed in the English studies as well as the results of Selikoff _et al_. for insulation workers.[7-9]

The study by Selikoff _et al_. covered mortality experience at ages 35 and over including a significant amount of follow-up at ages over 65.[9] The findings of an excess almost seven times that expected for lung cancer and a three-fold risk for cancers of the stomach, colon, and rectum combined in these subjects are substantially greater than the corresponding results among retirees. It would be informative to know how the observed excesses for Selikoff's workers were distributed before and after age 65. This would make comparison with the present study more valid.

In Table 9 SMR's for lung cancer among all retirees tended to rise with age indicating that the risk of dying from this disease had increased accordingly. Table 23 shows mortality rates from lung cancer in all retirees and these confirm the impression first gained from SMR's. It can be seen that for each of the two time periods death rates did increase with age. The increase is slightly greater in the earlier period. This situation contrasts with that of all U.S. white males. Mortality rates from lung cancer in the latter population reach a peak between the ages 65-74 and subsequently decrease. Observations among retirees, then, suggest a kind of postponement or delay in this peak until the very advanced ages. Possible explanations for this phenomenon include the relative healthiness of the subjects at the start of observation and the manifestation of a latent period for the disease.

Another way of looking at the pattern of lung cancer mortality in the retirees is by grouping them by year of retirement. This would be similar to establishing generation cohorts since most of the individuals in each group would be 65 at about the same point in time.
Table 24 shows the death rates from lung cancer in this way for suitable groupings of retirement years. In this table the 151 disability and early retirees who survived to age 65 have been classified by the year in which

Table 23

Lung Cancer Deaths Through December 31, 1967 by Age
And Calendar Period, Showing Mortality Rates
Per 10,000 Person-Years for 1,294 Males Who Worked in
11 Asbestos Products Plants and Retired During 1941 - 1966

Calendar Period	Age		
	All Ages	65 - 74	75 and over
1941 - 67			
Deaths	46	33	13
Rate	46.6	41.3	69.2
1941 - 57			
Deaths	8	6	2
Rate	20.3	17.7	36.6
1958 - 67			
Deaths	38	27	11
Rate	64.1	58.7	82.5

Table 24

Lung Cancer Deaths Through December 31, 1967 by Age And Year of Retirement, Showing Mortality Rates Per 10,000 Person-Years for 1,294 Males Who Worked in 11 Asbestos Products Plants and Retired During 1941 - 1966

YEAR OF RETIREMENT	AGE		
	All Ages	65 - 74	75 and over
1941 - 66			
Deaths	46	33	13
Rate	46.6	41.3	69.2
1941 - 47			
Deaths	6	0	6
Rate	23.3	0.0	56.7
1948 - 52			
Deaths	10	6	4
Rate	48.5	38.7	78.0
1953 - 57			
Deaths	14	11	3
Rate	54.7	48.8	98.0
1958 - 62			
Deaths	9	9	0
Rate	48.5	48.6	0.0
1963 - 66			
Deaths	7	7	0
Rate	85.3	85.3	0.0

they attained that age, i.e. for this group, "year of retirement" means "year in which age 65 was reached". It may be seen that the earliest cohort (1941-47) had the lowest rate of lung cancer even though it was followed for the longest period of time. Contrastingly, the most recent cohort exhibited the highest rate despite the limited number of years available for observation. The middle three retirement cohorts showed very similar mortality rates from lung cancer which were midway between the rates in the extreme groups. From these data there seems to be no clear connection between the amount of time given for observation and the expected rate of lung cancer which occurs.

In Table 10 the mortality experience of the retirees was analyzed according to usual occupation. The three categories which are presented there convey to some extent three general areas of exposure. Production jobs imply a daily, steady exposure whereas maintenance-service jobs involve mainly intermittent exposures which could be very intense on many occasions. Office positions could be considered as no exposure jobs or at most minimal-intermittent. The overall excess in lung cancer deaths observed for the three occupations combined became unequally distributed according to specific occupation. Both the relatively low risk for production retirees and the high risk for maintenance-service retirees are somewhat surprising. It would seem that the SMR in production retirees (174) may not convey the real magnitude of the risk for these particular individuals. However, Enterline found even lower SMR's for lung cancer in workers aged 15-64 from asbestos building products and friction materials.[10]

The SMR of 444 in maintenance-service retirees is not really comparable to any published result since no author has looked at these particular occupations within the asbestos products industry. Those investigators who have used Social Security records to establish cohorts of asbestos workers certainly could not distinguish among specific jobs within the industry. In addition, it is not known whether an individual who works as a millwright or electrician for an asbestos products company is classified as an asbestos worker or separately as a maintenance man. The types of exposures to which these individuals have been subjected are not unlike the ones encountered by Selikoff's insulation workers. Some maintenance-service retirees worked as machinists with relatively low levels of asbestos dust exposure. Others worked as painters, millwrights, and electricians with intermittent but very intense dust exposures.

In studies of the relationship between asbestos dust and disease considerable attention has been directed to the association between asbestosis and lung cancer. Results for maintenance-service retirees may indirectly yield additional information on this question. It can be seen from Table 10 that simultaneously with the four-fold excess in lung cancer deaths this subgroup of retirees experienced no excess in deaths from respiratory diseases and only three deaths were due to pneumoconiosis and pulmonary fibrosis. These findings could be used to hypothesize that an excess risk of bronchial carcinoma is possible in the absence of asbestosis. Table 4, Appendix A gives the specific jobs held by the 22 maintenance-service retirees who died of lung cancer together with other pertinent data.

Some attention has been given to the belief that there exists a group of "susceptibles" in any industrial population who will respond or react to the occupational environment in terms of developing disease if given sufficient time. In terms of the present study it might be hypothesized that a subgroup of asbestos workers are prone to develop "asbestos-lung cancer" given the right conditions and enough time. Given the present set of results for production and maintenance-service retirees with respect to mortality from lung cancer, the following conjecture might be made. The working environment of "susceptibles" in production jobs is conducive to the development of lung cancer before age 65 leaving relatively few survivors eligible to die of lung cancer in later years. On the other hand, environmental conditions for "susceptibles" in maintenance-service jobs relieves them, somewhat, of this disease before the age of 65, consequently enabling the many survivors to succumb to lung cancer later in life.

At this point it might be well to consider the lung cancer experience of the retirees in the light of several factors which could have influenced it and which have not been taken into consideration as yet. One such factor is cigarette smoking which has been shown to be associated with a high incidence of lung cancer in many reports.

Selikoff in his original study indirectly showed that cigarette smoking alone did not account for the nearly seven-fold excess in lung cancer deaths.[9] In a later extension of that study he was able to ascertain the smoking habits of all members of the cohort and an excess of the same magnitude was maintained even when smoking habits were taken into consideration.[27] In the latter study no lung cancer deaths occurred among the non-cigarette smokers prompting the suggestion that cigarette smoking and asbestos dust might act synergisticly in the production of lung cancer.

Unfortunately, in the present study information on smoking habits was available from company records for only a small fraction of the retiree population. Because of this it was impossible to present results either specific for, or adjusted for this variable. However, it is still reasonable to ask whether the observed excess mortality from lung cancer in the retirees is due to differences in their smoking habits from those of U.S. white males. An indirect answer to this question can be provided by comparison of a subset of the present data with that reported on by Kahn for several classes of smokers.[28] Initiated by Dorn in 1954 this smoking study followed-up a group of U.S. veterans who were holders of U.S. Government Life Insurance. The cohort consisted of 293,658 individuals, almost all of whom were white males in white collar or skilled occupations. The group was subdivided by smoking category and observed between July, 1954 and December, 1962 during the age span 35 to 84.

For comparison with the present study it was decided to calculate lung cancer mortality rates based on person-years and observed lung cancer deaths occurring between ages 65 and 84 for several classes of smokers. In turn, the subset of data for retirees that was chosen to calculate death rates was person-years and lung cancer deaths occurring between ages 65 and 84 during the limited time period 1953 to 1962. This period closely approximates the time interval covered by Kahn's study but is longer by one and one-half years. Among the retirees 25 of the 46 total lung cancer deaths occurred in this time interval. Table 25 presents the resulting lung cancer mortality rates for three categories of retirees and four classes of smokers. It can be seen that for the retirees as a whole lung cancer rates appear to be between the limits set by smokers of 21-39 cigarettes per day and smokers of two or more packs per day. This would mean that if the observed excess in lung cancer deaths among retirees was due entirely to their differential smoking patterns it would be equivalent to all retirees smoking about 2 packs of cigarettes per day at retirement. Such a comparison would indicate that the overall lung cancer excess in retirees cannot be explained in terms of cigarette smoking alone. Lung cancer rates for production retirees seem to lie between the corresponding rates for smokers of 10-20 cigarettes per day and smokers of 21-39 cigarettes per day. If the excess in lung cancer deaths observed for this group of retirees were to be attributed solely to their unusual smoking habits it would be equivalent to all of these retirees smoking about a pack of

Table 25

Lung Cancer Deaths and Death Rates Per 10,000
Person-Years by Age for 4 Categories of Current Cigarette Smokers,
1954-1962 and 3 Groups of Retirees, 1953-1962

Current Cigarette Smokers	65 - 74	75 - 84
1 - 9/day		
Deaths	44	5
Rate	11.9	26.0
10 - 20/day		
Deaths	239	15
Rate	23.5	38.8
21 - 39/day		
Deaths	194	7
Rate	38.8	55.0
Over 39/day		
Deaths	50	3
Rate	55.9	129.3
All Retirees		
Deaths	19	6
Rate	48.9	70.8
Production Jobs		
Deaths	9	2
Rate	36.3	36.8
Maintenance-Service Jobs		
Deaths	10	3
Rate	95.5	145.8

cigarettes per day at retirement. It is conceivable that cigarette smoking habits among production retirees were responsible for at least some of their excess lung cancer deaths but definite conclusions are not entirely possible. The situation for maintenance-service retirees, however, is quite striking. Lung cancer rates among these men appear to exceed those of heavy cigarette smokers (over 39/day) and certainly permit the inference that patterns of cigarette smoking in this group of retirees do not explain their excessive risk of lung cancer.

Haenszel has reported on cancer mortality among foreign-born white males residing in 35 states for the year 1950.[14] Among other findings he has noted a significant excess (33%) in observed deaths from lung cancer for total foreign-born white males when compared to native-born white males in the same 35 states. In analyzing lung cancer mortality among foreign-born white males from each of 12 countries, he found excesses among the immigrant groups from eight of these countries and deficits among the other four. The rather large proportion of foreign-born among the retiree population has been shown in Table 7. It is possible that this demographic characteristic of the study group may have contributed to the significant excess in lung cancer deaths. Among all U.S. white males aged 65 and over in 1950, 23.7 per cent were foreign-born.[29] In 1960 the corresponding percentage was 21.2.[30] These figures are both less than half of the estimated proportion of foreign-born among the retirees. In this respect the comparison group used in the present study differs markedly from the retiree population. Of the 587 retirees known to have been foreign-born, 476 (81.1%) were from the 12 countries studied separately by Haenszel. Of these 476 individuals 375, or 63.9 per cent of all foreign-born retirees, were from the eight countries exhibiting excess lung cancer mortality and 101, or 17.2 per cent of all foreign-born retirees, were from the four countries showing deficits in lung cancer mortality. There was a disparity between production retirees and maintenance-service retirees in the proportion of foreign-born. Among the former group 54.2 per cent were immigrants while 40.0 per cent of the latter group were foreign-born. In an effort to ascertain the effect of this variable on the lung cancer findings presented here, an analysis of the 632 native-born retirees was carried out. SMR's for lung cancer were calculated for the entire U.S. born group as well as for production and maintenance-service retirees separately. It should be recalled that in such an analysis the other extreme with respect to birthplace is reached, i.e. about 20 to 25 per cent of the comparison group is foreign-born while no one in the study group is. The most unbiased results should lie somewhere between the original findings and the ones presented here. Table 26 shows the results for native-born retirees as compared to the original findings for all retirees. Overall, exactly half of the 46 lung cancer deaths occurred in native-born retirees, the proportion in production retirees being much lower than in maintenance-service retirees. It can be seen that for retirees from all occupations the original SMR value is more than maintained. However, SMR's specific for job show

Table 26

Population and Observed and Expected Deaths from
Lung Cancer by Usual Occupation, Showing
Standardized Mortality Ratios (SMR's)
For All Retirees and Native-Born Retirees

Usual Occupation	All Retirees				Native-Born Only			
	Pop.	Obs.	Exp.	SMR	Pop.	Obs.	Exp.	SMR
All Occupations	1294	46	18.5	249.2	632	23	8.2	278.8
Production Jobs Only	797	20	11.5	173.9	320	5	4.2	119.3
Maintenance-Service Jobs Only	341	22	5.0	444.0	192	14	2.5	555.8

quite divergent trends. The significant excess for all production retirees has now diminished substantially in the native-born subgroup. On the other hand, the SMR for native-born maintenance-service retirees is even greater than that for all such retirees. It is possible, then, that at least some of the excess in lung cancer deaths observed in production retirees might be due to a demographic factor, viz. birthplace. However, this same factor does not seem to explain the high risk among maintenance-service retirees.

Another factor which should be considered in the interpretation of SMR's for lung cancer is geographic variation in mortality from this cause within the U.S. Although all SMR's presented here are in reference to the entire U.S. white male population the asbestos products plants of interest were located in only six states. Therefore, most of the deaths occurred in these particular states. Gordon _et al._ have reported on lung cancer mortality among white males in each of the 48 states for the year 1950.[31] They published results in the form of ranking the 48 states by age-adjusted mortality rates. Two of the six states in question fall in the highest quintile and one of these is responsible for a large proportion of all deaths among the retirees. Three other states are in the second highest quintile while the remaining one ranks in the third highest quintile. Such a circumstance highlights another drawback to the use of national mortality data as a means of comparison. In the present study it would seem that lung cancer mortality rates for all U.S. white males are probably lower than the ideal control rates.

This would tend to overstate the lung cancer risk somewhat. Unfortunately, rates specific for certain combinations of demographic variables are not available on a state by state basis so that the more appropriate figures could not be used.

It has been noted in Table 9 that SMR's for all causes of death were consistently greater than 100 among retirees in general even in the years immediately following retirement. Such a detrimental mortality experience in a group of men who had been actively employed shortly before can be partially explained in terms of the socio-economic structure of the study group as compared to that of the U.S. population. The 138 retirees from office and miscellaneous positions comprise about 10 per cent of all retirees. Among males aged 60-64 (the age group immediately prior to the usual compulsory retirement age) employed in 1950 in the U.S., the percentage of white collar workers which is roughly comparable to this figure was 30 and in 1960 it was 34.[29, 30] It is well known that total mortality varies with occupational level, e.g. white collar workers have lower total death rates than do blue collar workers.[32] A priori then it might be expected that U.S. males with their three to one ratio of white collar workers would exhibit a more favorable mortality pattern than the retirees, even in the absence of any occupational hazard.

On this point it is of interest to note that in Table 10 retirees who worked primarily in office jobs (a "white collar" occupational group) did not experience a more favorable overall mortality than U.S.

white males despite their apparent advantage in terms of socio-economic status. Excess deaths from lung cancer and gastro-intestinal cancer balanced out the deficits in mortality from other causes. These specific excesses indicate that office retirees might have had significant amounts of asbestos exposure which affected their post-retirement mortality patterns.

It is practically impossible to precisely separate three competing forces which have influenced the overall mortality of the retirees. The first of these is their particular socio-economic structure which has just been discussed. The second is the relative healthiness of this group at time of retirement which was commented on in a previous section. Finally, there is the carry-over effect of the working environment which is really the one that is of primary interest. In attempting to isolate this latter factor total mortality may not be the best indicator because of the first two competing forces. Reliance on cause-specific mortality then becomes necessary.

A noticeable result in the present study is the rather consistent disease-specificity which emerges. By this is meant that increased mortality among the retirees seems to be confined to only those disease categories to which previous evidence has pointed, viz. lung cancer, respiratory diseases and, to a lesser extent, cancer of the digestive system. For example, in Table 9 which shows the mortality pattern of the entire study group by age and cause the deficits in deaths from such degenerative diseases as "all other cancer", cerebral vascular lesions, and heart disease in the 65-69 age group are quite remarkable. Although mortality from these causes did increase slightly among the retirees with age the overall results showed observed deaths quite close to what would be expected. In Table 10, where the retirees were classified by usual occupation, this same circumstance persists. Here separate categories for cerebral vascular lesions and heart disease are not shown but these two sets of diseases contribute heavily to the category "all other causes". In this latter category it can be seen that observed deaths were consistently quite close to those expected even reaching a 10 per cent deficit among office retirees. Results for "all other cancer" also followed this same pattern showing at most a 15 per cent excess in production retirees while exhibiting a 14 per cent deficit in maintenance-service retirees.

Berkson has commented on the seeming non-specificity in the association of cigarette smoking and disease.[33] He observes that in several of the prospective studies carried out on this problem there are excesses in deaths among smokers for many disease categories in addition to lung cancer. In view of this, he has suggested that the observed associations may simply be spurious and devoid of etiological meaning. On this point data presented here would appear to be free of such complicating features.

In Tables 13-15 where mortality by unadjusted exposure score was examined the results might have been affected by a particular kind of systematic error. It is possible that early periods of employment with the asbestos company were not recorded on the survey form for some retirees because of missing or incomplete employment records at the individual plants. This would be reflected in more men beginning their employment with the company at older ages than was actually the case. Such a situation would tend to understate asbestos exposure and consequently unadjusted exposure score. If lung cancer mortality does, in fact, increase with amount of asbestos exposure as determined by unadjusted score the pattern of SMR's for this disease over the four score categories would be affected by a misclassification of retirees.

For example, if the 0-24 score category contained a number of retirees for whom a true unadjusted score was much higher, the resulting SMR could be biased upward. That this might indeed be the case is given some plausability by the result in the lowest score category in Table 14 for respiratory diseases. There were 6 observed deaths from these causes, 2 of which were due to pneumoconiosis and pulmonary fibrosis. The latter two deaths, which accounted for the entire excess, occurring in retirees who seemingly had very low exposures are somewhat surprising. In the past these diseases have been associated with much greater amounts of asbestos exposure. Contrastingly, if a number of retirees were omitted from the highest score category due to understating of employment with the asbestos company the SMR might be biased downward.

In addition to the scores used in this report there were two other variables which could have been used to estimate dose, both being somewhat cruder. One is "age at first employment with the asbestos company". Since almost all of the retirees were removed from further exposure at age 65 this variable would at least determine the length of employment which in turn might be correlated with amount of exposure. Indeed, Table 11 indicated that "age at first employment" was closely associated with total unadjusted exposure score for production and maintenance-service retirees. The other variable is "year of retirement". The reasoning which would lead to use of this estimate of dose is that dust exposures were probably higher the further back in time a man worked. Those individuals retiring in 1941 might then have been exposed, on the average, to higher levels of asbestos dust than those retiring in the 1960's. Table 27 shows the distribution of the retirees by total unadjusted exposure score and year of retirement. It can be seen that for this particular group of men there was no association between these variables and hence use of "year of retirement" as an estimate of dose would not have been very fruitful.

Among the 558 deaths in the present study for which the death certificate was located three involved the term "mesothelioma" as the underlying cause. Two were mesotheliomas of the pleura. One of these was coded as malignant (163) probably because metastases to the lung and pericardium were indicated by the attending physician. The other was coded as benign (212) probably because the presence of metastases was not indicated anywhere on the certificate. The third

Table 27

Distribution of 1,060 Retirees Who Worked
Primarily in Production or Maintenance-Service Jobs
By Total Unadjusted Exposure Score and Year of Retirement

Total Unadjusted Exposure Score	Year of Retirement									
	1941-47		1948-52		1953-57		1958-62		1963-66	
	No.	%	No.	%	No.	%	No.	%	No.	%
All Scores	178	100.0	168	100.0	256	100.0	271	100.0	187	100.0
0 - 24	66	37.1	45	26.8	42	16.4	65	24.0	31	16.6
25 - 74	47	26.4	47	28.0	81	31.6	87	32.1	58	31.0
75 - 199	45	25.3	48	28.5	96	37.5	83	30.6	76	40.6
200 & over	20	11.2	28	16.7	37	14.5	36	13.3	22	11.8

such case was a mesothelioma of the peritoneal cavity. This was coded as malignant (158) probably because it was accompanied by the phrase "generalized carcinomatosis".

Table 28 contains some information on all deaths occurring among the initial group of 1,735 retirees identified by the asbestos company and referred to in Table 1. The symbol "<65" denotes deaths at ages under 65 while the symbol "65+" is meant to indicate deaths at ages 65 and over. The 8 deaths listed under the heading "mesothelioma" are all those for which this term appeared on the death certificate. In every case it was selected as the underlying cause of death. Interestingly enough, this condition was referred to by six different code numbers of the ICD list (7th Revision). These codes were: 158, 163, 197.9, 211, 212, and 227.

Table 28

Distribution of Deaths Occurring Between 1941 and 1967
Among 1,735 Persons Who Retired From an
Asbestos Products Manufacturing Company During 1941-1966,
By Sex, Type of Retirement, and Selected Causes

	Total Deaths	Lung Cancer	Pneumoconiosis and Pul. Fibrosis	Meso-thelioma
		Males		
Total	848	67	52	7
Normal	605	42	25	3
Disability and Early	243	25	27	4
<65	184	21	25	4
65+	59	4	2	0
		Females		
Total	30	2	4	1
Normal	18	1	1	0
Disability and Early	12	1	3	1
<65	8	1	1	0
65+	4	0	2	1

VII. SUMMARY

A follow-up study was conducted of 1,300 men who retired from a U.S. asbestos products company during 1941-1966. These individuals had been employed at several asbestos products plants just prior to retirement. They were observed to December 31, 1967. Detailed work histories were available for virtually all subjects which included estimates of the dust concentration at each job held. Scores were calculated which reflected the total amount of dust exposure a man accumulated up to retirement. From these it was possible to rank the subjects by the relative severity of their past occupational exposures. The mortality experience of the study group was compared to that of all U.S. white males of corresponding age during the same time period. Emphasis was placed on relating each of several variables from the work history to cause-specific mortality.

The major findings of the study were:

1. Overall, the retirees experienced significantly elevated mortality from lung cancer, cancer of digestive system, and respiratory diseases. The lung cancer risk was two and one-half times that predicted by the experience of U.S. white males. The entire excess in respiratory diseases was due to deaths from pneumoconiosis and pulmonary fibrosis.
2. The excess for lung cancer observed among all retirees

was unequally shared by the two major occupational subgroups. Men who had worked primarily in production jobs experienced a 75 per cent excess while a four-fold risk was seen in men who had worked primarily in maintenance-service jobs. The entire excess in deaths from respiratory diseases was confined to men who had worked primarily in production jobs.

3. The pattern of SMR's for lung cancer by category of unadjusted exposure score was somewhat equivocal. After showing a rather large excess of lung cancer deaths in the lowest score category, SMR's decreased and then increased monotonically, reaching a five-fold excess in the highest score category. Among retirees who worked primarily in production jobs SMR's for respiratory diseases increased sharply in the highest category of unadjusted exposure score.

4. When the variable "age at first employment with the asbestos company" was analyzed in conjunction with unadjusted exposure score it was observed that the previous excess in deaths from respiratory diseases among production retirees was maintained only in the "high score - young age" category. On the other hand, the excess in lung cancer deaths among retirees was somewhat independent of age-acore category.

Various factors were discussed which could have contributed to the unusual lung cancer experience seen in the retirees. Among these were differential smoking habits and birthplace. It was shown that the observed differences in lung cancer mortality could not be explained by differences in cigarette smoking patterns alone. Also, it was demonstrated that the large proportion of foreign-born among the retirees could not account for the observed excess in lung cancer deaths.

APPENDIX A

A. PERSONNEL RECORD

Name ____________________ Emp. No. ____________________ Location ____________________

(1-9) Soc. Sec. # ____________________ (10-11) Birth Date ____________________
(12-13) Birth: State or Country ____________________

(14) Sex: M ____1 F ____2 (15) Race: white ____1 Mex. ____2 Negro ____3
Other ______________ ____4 Unknown ____9

(16) Educational Level: 8 yr. or less ____1 9-12 yr. ____2 Over 12 yr. ____3 Unknown ____9

(17) Usual Occ.: Sales ____1 Office ____2 Prod. ____3 Other ____________ ____4 Unknown ____9

(18) Prior Dust Exp.: None ____0 Coal ____1 Silica ____2 Coal & Silica ____3
Other ________________ ____4 Unknown ____9

(19-20) Last residence (state only): ______________________________

(21) Rate of pay/yr. First Job ______________ (22) Rate of pay/yr. Retirement: ______________

Figure 1. Retiree Survey Form

B. MEDICAL RECORD

(23) Retirement type: Normal ____0 Disability ____1 Early ____2 Unknown ____9

(24) Employ. Health Status: No pneu. ____0 Pneu. ____1 Unknown ____9

(25-26) Retirement Health Status:

Occupational (25): Normal____0 Asbes.____1 Silic.____2 Mixed Pneu.____3 Other Pneu.____4

Occupational Injury____5 Other________________ ____6 Unknown____9

Non-Occ. (26): Normal____0 Cardiovas.____1 T. B.____2 Emphy.____3 CA-lung____4

Other CA____5 Arthritis____6 Other ____________ ____7 Unknown____9

(27) Smoking Habits: None____0 Cigarette____1 Pipe____2 Cigars____3 Unknown____9

(28) Status 12-31-67: 1. Alive____0

2. Deceased____1 ____________date ______________certificate*

*If not available, cause of death ______________________________________

Figure 1. Retiree Survey Form (continued)

C. WORK HISTORY SUMMARY

Location	Dates	Department	Job Title	Amt. of Exp.	Inter. or Steady	Type of Asb.	Other Exp.

Figure 1. Retiree Survey Form (continued)

Table 1

Causes of Death of 27 Non-White Males
Who Retired Between 1941-1966 and Died
On or Before December 31, 1967

Cause of Death and International List Number	Deaths
Respiratory Tuberculosis (001-008)	1
All Cancer (140-205)	4
Cancer of Lung, Bronchus, Trachea, Pleura (162-163)	1
Cancer of Breast (170)	1
Cancer of Prostate (177)	1
Cancer of Bladder and Other Urinary Organs (181)	1
Cerebral Vascular Lesions (330-334)	2
All Heart Disease (400-443)	11
Coronary Heart Disease (420)	7
Other Hypertensive Disease (444-447)	1
Nonsyphilitic Aneurysm of Aorta (451)	2
Influenza with Pneumonia (480)	1
Emphysema without Bronchitis (527.1)	2
Accidents (800-962)	2
Suicide (970-979)	1

Table 2

Occupational Data and Year of Death of 6 Males
Who Retired Between 1941-1966,
Died on or Before December 31, 1967
For Whom No Death Certificate Was Located

Usual Occupation	Type of Asbestos Products	Unadjusted Exposure Score	Year of Retirement	Year of Death
Maintenance-Service	Unknown	73	1950	1967
Production	Paper	171	1949	1956
Production	Cement	66	1949	1967
Unknown	Unknown	Unknown	1950	1951
Production	Insulations	66	1952	1960
Maintenance-Service	Unknown	20	1961	1966

Table 3

Available Data and Causes of Death of 18 Males
Who Retired During 1941-1966,
Died on or Before December 31, 1967
For Whom No Work History Was Available

Year of Retirement	Year of Death	Cause of Death And International List Number
1943	1946	Respiratory Tuberculosis (001)
1944	1947	Cancer of Stomach (151)
1946	1955	Cancer of Prostate (177)
1946	1958	Cancer of Prostate (177)
1949	1958	Cerebral Hemorrhage (331)
1942	1945	Cerebral Hemorrhage (331)
1945	1947	Cerebral Thrombosis (332)
1953	1956	Coronary Heart Disease (420)
1948	1954	Coronary Heart Disease (420)
1941	1946	Coronary Heart Disease (420)
1950	1965	Coronary Heart Disease (420)
1942	1946	Other Myocardial Degeneration (422)
1946	1948	Unspecified Disease of Heart (434)
1943	1945	Hypertensive Heart Disease (442)
1941	1950	Hypertensive Heart Disease (443)
1946	1949	Hyperplasia of Prostate (610)
1941	1949	Hyperplasia of Prostate (610)
1952	1952	Fracture of Skull (803)

Table 4

Occupational Data of 22 Males Who Worked
Primarily in Maintenance-Service Jobs,
Retired During 1941-1966 and Died from Lung Cancer
On or Before December 31, 1967

Job(s)	Total Unadjusted Exposure Score	Age at First Employment With the Asbestos Company
Oiler, Millwright	576	29
Electrician	267	31
Millwright	133	44
Machinist	3	45
Millwright	64	49
Machinist	22	43
Electrician	275	30
Machine Operator (Packings Department), Yard Clean-up Man	112	40
Truck Driver	30	34
Painter	169	42
Unloader (Insulations), Laborer (Cement), Carpenter	347	23
Fireman (Power House)	0	24
Electrician, Mechanic	114	45
Pipe Fitter	248	28
Machinist, Mechanic	65	34
Tinsmith	221	33
Foreman (Machine Shop)	22	43
Millwright	175	31
Construction Laborer	63	47
Laborer (Cement), Electrician	280	30
Machinist, Mechanic	109	47
Rigger, Painter	152	45

APPENDIX B

Table 1

Distribution of Total Deaths and Person-Years Through December 31, 1967 by Age and Calendar Period for 1,294 Males Who Worked in 11 Asbestos Products Plants And Retired During 1941-1966

Calendar Period	Age					
	All Ages	65 - 69	70 - 74	75 - 79	80 - 84	85 & over
1941 - 67						
Deaths	658	219	218	135	64	22
Person-Years	9866.94	4964.49	3022.66	1303.08	460.87	115.83
1941 - 47						
Deaths	26	12	9	4	1	0
Person-Years	603.29	359.37	165.21	70.92	7.79	0.00
1948 - 52						
Deaths	69	30	19	12	7	1
Person-Years	1305.21	794.46	363.37	103.25	42.67	1.46
1953 - 57						
Deaths	119	47	42	22	5	3
Person-Years	2027.12	1054.41	652.00	241.12	61.42	18.17
1958 - 62						
Deaths	203	65	57	53	19	9
Person-Years	2757.20	1364.08	813.96	414.21	130.33	34.62
1963 - 67						
Deaths	241	65	91	44	32	9
Person-Years	3174.12	1392.16	1028.12	473.58	218.67	61.58

Table 2

Distribution of Total Deaths and Person-Years Through December 31, 1967 by Age and Year of Retirement for 1,294 Males Who Worked in 11 Asbestos Products Plants And Retired During 1941-1966

Year of Retirement	Age					
	All Ages	65 - 69	70 - 74	75 - 79	80 - 84	85 & over
1941 - 66						
Deaths	658	219	218	135	64	22
Person-Years	9866.94	4964.49	3022.66	1303.08	460.87	115.83
1941 - 47						
Deaths	196	23	47	58	46	22
Person-Years	2570.79	706.00	806.75	603.12	339.08	115.83
1948 - 52						
Deaths	161	45	49	49	18	0
Person-Years	2061.87	868.71	680.62	390.83	121.71	0.00
1953 - 57						
Deaths	167	53	86	28	0	0
Person-Years	2558.12	1282.50	969.62	305.92	0.08	0.00
1958 - 62						
Deaths	92	56	36	0	0	0
Person-Years	1855.50	1287.62	564.67	3.21	0.00	0.00
1963 - 66						
Deaths	42	42	0	0	0	0
Person-Years	820.66	819.66	1.00	0.00	0.00	0.00

Table 3

Distribution of 664 Deaths by Detailed Causes Occurring Between
July 1, 1941 and December 31, 1967 Among 1300 Males
Who Worked in 11 Asbestos Products Plants and
Retired During 1941-1966

Cause of Death and International List Number	Deaths
All Causes	664
Respiratory Tuberculosis (001-008)	15
All Cancer (140-205)	143
Cancer of Buccal Cavity and Pharynx (140-148)	4
Cancer of Esophagus (150)	4
Cancer of Stomach (151)	23
Cancer of Intestines (152-153)	7
Cancer of Rectum (154)	7
Cancer of Liver (155-156)	3
Cancer of Pancreas (157)	6
Cancer of Peritoneum (158)	1
Cancer of Unspecified Digestive Organs (159)	2
Cancer of Larynx (161)	2
Cancer of Lung, Bronchus, Trachea & Pleura (162-163)	46
Cancer of Breast (170)	1
Cancer of Prostate (177)	11
Cancer of Kidney (180)	3
Cancer of Bladder & Other Urinary Organs (181)	2
Cancer of Eye (192)	2
Cancer of Brain (193)	1

Table 3

(continued)

Distribution of 664 Deaths by Detailed Causes Occurring Between July 1, 1941 and December 31, 1967 Among 1300 Males Who Worked in 11 Asbestos Products Plants and Retired During 1941-1966

Cause of Death and International List Number	Deaths
Cancer of Other Endocrine Glands (195)	1
Cancer of Other and Unspecified Sites (199)	9
Malignant Lymphoma (200, 201, 203)	4
Leukemia (204)	4
Benign Neoplasms & Neoplasms of Unspecified Nature (210-239)	1
Diabetes Mellitus (260)	10
Vascular Lesions Affecting Central Nervous System (330-334)	60
Diseases of the Circulatory System (400-468)	323
Chronic Rheumatic Heart Disease (410-416)	5
Arteriosclerotic (Coronary) Heart Disease (420)	225
Nonrheumatic Endocarditis & Other Myocardial Degeneration (421-422)	30
Other Diseases of Heart (430-434)	11
Hypertensive Heart Disease (440-443)	22
Other Hypertensive Disease (444-447)	6
General Arteriosclerosis (450)	13
Nonsyphilitic Aneurysm of Aorta (451)	6
Other Circulatory Disease (400-402, 452-468)	5
Diseases of the Respiratory System (470-527)	52
Influenza & Pneumonia (480-493)	13

Table 3

(continued)

Distribution of 664 Deaths by Detailed Causes Occurring Between July 1, 1941 and December 31, 1967 Among 1300 Males Who Worked in 11 Asbestos Products Plants and Retired During 1941-1966

Cause of Death and International List Number	Deaths
Bronchitis (500-502)	2
Silicosis (523.0)	1
Anthracosilicosis (523.1)	1
Asbestosis (523.2)	15
Pneumoconiosis (NOS) (523.3)	4
Other Chronic Interstitial Pneumonia (525)	6
Emphysema Without Bronchitis (527.1)	7
Other Respiratory Diseases (470-475, 510-522, 524, 526, 527.0, 527.2)	3
Ulcer of Stomach & Duodenum (540-541)	2
Cirrhosis of Liver (581)	11
Chronic Nephritis & Other Renal Sclerosis (592-594)	1
Accidents (800-962)	15
Suicide (970-979)	5
Unknown Cause	6
All Other Causes	20

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