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HISTORICAL RESEARCH REPORT

Research Report TM/81/10
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Coalminers' mortality in relation to radiological category, lung function and exposure to airborne dust. Final report on CEC Contract 7246-16/8/001

Miller BG, Jacobsen M, Steele RC

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Coalminers' mortality in relation to radiological category, lung function and exposure to airborne dust

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SUMMARY

This report describes mortality among 29 553 British coalminers. They represent 93.5% of 31 611 men who were surveyed radiologically at 24 coal mines in the period 1953 through 1958. Vital status for the remaining 6.5% (2 058 men) was not established.

Comparisons with age, regional and calendar-year-specific death rates for all men in the areas where the collieries were situated showed that the miners studied had lower mortality than British men generally. There is strong evidence from results for men who had worked in England and Wales that the relatively favourable mortality experience among these miners was less marked during the latter period of the follow-up. This is consistent with other prospective studies of groups composed of persons employed in industry, and it points to the operation of the so-called "healthy worker" effect in these data.

Death rates among the 5 253 men from the four Scottish collieries considered were also 16% lower on average than the published Scottish statistics but the follow-up rate for this group was lower (91.8%) than that achieved for the English and Welsh miners (93.8%), and there is evidence suggesting that the untraced Scottish miners included a disproportionately high number who have died. Detailed cause-specific analyses of the available material were therefore confined to results for 24 736 men who had been employed at the English and Welsh collieries and whose vital status 22 years after the start of the follow-up was established.

The main aim of the work was to consider risks of death attributed to various underlying causes, as recorded on death certificates, in relation to radiological signs of pneumoconiosis, measures of lung function, and exposure to respirable coalmine dust. Information regarding these factors was obtained from the records of the National Coal Board's Pneumoconiosis Field Research. The initial radiological surveys for that prospective study constitute the

start of the 22-year mortality follow-up reported here. Estimates of the miners' exposures to airborne dust before the start of the study were made using information on occupational histories, obtained at interviews with the men, and average concentrations of respirable dust in six broad categories of coalmining activities at the collieries concerned during the ten years after the initial medical surveys.

The statistical analyses of contrasts between sub-groups, defined according to different levels of the various factors of interest, were made by estimating age-specific survival probabilities using life-table methods. Standard errors of these statistics are provided in tabular presentations of results, and the statistical significance of some of the observed trends has been investigated using methods based on Cox's regression model for survival data.

Miners with progressive massive fibrosis at the start of the study, including those with earliest signs of this disease (category A in the International Labour Office's Classification system) had considerably higher mortality than their colleagues with no large shadows on their radiographs initially. Survival rates for those with category 1 simple pneumoconiosis were also low, for all ages greater than 24 years, in comparison with men whose radiographs had been classified as category 0 initially. There was no consistent trend for mortality to increase with increasing category of simple pneumoconiosis. Results pooled over all three categories (1, 2 and 3) for the age-group 25-34 indicated a mortality hazard for non-violent causes about 1.6 times as high as that for similarly aged men with no radiological signs of the disease at the start of the study ($P < 0.05$), but this effect was not observed in men over 35 years of age.

Mortality attributed to pneumoconiosis, to bronchitis and emphysema, and possibly also to other respiratory diseases, was more severe for miners who had relatively high exposures to respirable coalmine dust before the start of the follow-up. These findings are reflected in a tendency for mortality from all internal causes to increase with increasing ranges of estimated dust exposures.

Risk of death from cancers of the digestive system also tended to increase with increasing dust exposure, but there was a similar association between mortality due to these diseases and the presence of pneumoconiosis on the radiographs. It is not clear therefore whether the results implicate exposure to dust *per se*.

There is no suggestion of an association between lung cancer and exposure to coalmine dust, nor is there any sign that miners with coalworkers' pneumoconiosis are at greater risk than others of developing this disease - if anything, the contrary appears to be true. Analysis of data from a sub-group, for whom information on smoking habits was available confirmed the latter finding, and indicated that lung cancer mortality among the smokers in this sub-group was about five-and-a-half times higher than among non-smokers.

There was a clear and consistent pattern of higher mortality over 12 years for miners with relatively low levels of standardised timed Forced Expiratory Volumes (FEV_1). The increased risks for men with relatively low levels of lung function was evident in terms of deaths attributed to lung cancer, to bronchitis and emphysema (for those aged 55 to 64 at start of follow-up), to pneumoconiosis, to other respiratory diseases, and to ischaemic heart diseases.

A study of mortality in a sub-group in relation to the quartz content of the coalmine dust to which the men had been exposed showed conflicting patterns. No conclusions specific to the effect of quartz are possible from these results because the variations in the quartz levels were closely associated with different collieries and the geographical regions in which they were situated.

1. INTRODUCTION

If a man elects to enter an arduous occupation such as coalmining, if the pre-employment medical examination passes him as fit to work underground, and if he is able to continue to cope with the heavy physical demands of such a job for any length of time, then he is likely to have been more physically fit in the first place than another man chosen randomly from the general population. "Other things" (smoking, eating and drinking habits and social conditions) being equal, and provided that he is not killed accidentally at work or elsewhere, such a miner would be expected to live at least as long, and quite possibly longer, than other men, unless he develops a fatal disease peculiar to his occupation. Respiratory diseases resulting from inhalation of airborne coalmine dust are undoubtedly hazards for coal miners, and in particular, the massive fibrosis of the lung diagnosed radiologically by characteristic large shadows, is a progressive and disabling condition which may shorten life.

Nevertheless, ARLIDGE (1892) noted that in the latter half of the nineteenth century British coalminers appeared to have low mortality in general "although in the matter of diseases of the respiratory system their death rate is high". A few years earlier OGLE (1885) had discussed the occupational mortality statistics that had excited Arlidge's comment, and Ogle drew attention then to the importance of the selection effects mentioned above. These so-called "healthy worker effects" have been the subject of renewed interest in recent years because they may mask the effects of occupational health hazards in mortality studies of industrial groups.

JACOBSEN (1976) therefore argued that if it is desired to study the effects of the working environment on persons employed within a particular industry then it may be more helpful to concentrate on "internal" comparisons between sub-groups, rather than on contrasts with the general population or other external "control" groups. The aim should be to assess morbidity or mortality in relation to a standard of health that the men concerned might have expected to enjoy in the absence of the suspected occupational hazard.

This was the primary objective of the large-scale prospective study of British coalminers' health, known as the Pneumoconiosis Field Research, which began in 1953. The same reasoning constituted the rationale for a study of mortality among more than 17 000 of the 31 000 miners who were included in that project. All those with radiological signs of pneumoconiosis at the start of the research, and a 50% stratified random sample of the other men in that population, were considered. Mortality over 14 to 18 year periods was described for 96% of these miners, whose vital status had been determined as at 31 July 1972. The main results were as follows.

> Miners under the age of 35 and with simple pneumoconiosis at the start of the follow-up had lower survival rates than those without pneumoconiosis, but in general, over all age groups, coalworkers' simple pneumoconiosis was not associated with increased mortality. Men with categories B or C of complicated pneumoconiosis (Progressive Massive Fibrosis, PMF) at the outset had considerably higher death rates than miners without this disease, but those with early signs of PMF (category A) were not, apparently, at greater risk, except those aged 55 or more at the start of the study.
>
> The results confirmed that coal miners were not immune to the well established ill effects of smoking on health. The cigarette smokers studied experienced relatively high mortality attributed on death certificates to bronchitis and emphysema and to cardiovascular diseases, and they suffered a nearly eight-fold excess of lung cancer deaths compared with their non-smoking colleagues. But there was no evidence that either coal mining as such, or the presence of pneumoconiosis, or high dust exposures among men with no pneumoconiosis was associated with an increased risk of developing lung cancer. In fact, the lung cancer death rates among men with higher categories of simple pneumoconiosis or PMF were substantially lower than those found for men without pneumoconiosis.
>
> However, both the presence of simple pneumoconiosis, and high exposures to dust among miners with no pneumoconiosis initially, were associated with increased incidence of deaths from cancers of the digestive system.
>
> General mortality, due to all non-violent causes, was not clearly associated with increasing dust exposures. But among men with no pneumoconiosis initially there was a distinct and statistically significant positive gradient between increasing ranges of exposure to dust before the start of the follow-up and subsequent mortality attributed to bronchitis and emphysema (JACOBSEN, 1976)*.

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* This thesis includes a discussion of earlier studies. ROCKETTE (1977) has also published a valuable and extensive historical review of the literature on coalminers' mortality.

These findings have provoked comment in the journals. (LEADING ARTICLES, 1979, 1980; ROOKE _et al_, 1979; DAVIES, 1979; JACOBSEN, 1979a; JACOBSEN, 1980; MORGAN, 1980). More recent reports of other studies of British coalminers' mortality have corroborated only some of the results (COCHRANE _et al_, 1979; COCHRANE and MOORE, 1980).

We now describe results from an extension of the same research. All the miners seen at the initial radiological surveys of the Pneumoconiosis Field Research in the 1950s were included, and the period of follow-up has been increased to between 22 and 26 years. The main purpose of the new work has been to see whether the additional data are consistent with the earlier results summarised above.

2. METHODS

2.1 The study group

In 1953, the National Coal Board began a major epidemiological study of working coalminers, the Pneumoconiosis Field Research (PFR). JACOBSEN (1979b) presents a review of the methods and principal results of this work, which centred round periodic surveys at which working miners had a chest x-ray film taken and answered a questionnaire on respiratory symptoms and smoking habits.

Twenty-four collieries were surveyed for the first time during the period 1953 through 1958. A total of 31 674 persons were seen, and this represented more than 90% of the men working at these coal mines whose approximate geographic locations are shown in Figure 1.

The study of mortality being reported now refers to all those mineworkers, from the 24 collieries, who had chest radiographs taken at the first surveys during the years 1953 through 1958.

2.2 Data available

Each man included in the mortality follow-up was interviewed about his previous occupational history at the time that the initial chest radiograph was taken. At the second and subsequent surveys the medical examinations were extended to include spirometry (FEV_1 and FVC), with measurements of height and weight, and a questionnaire on respiratory symptoms and smoking habits was also applied by trained staff (ROGAN et al, 1961). The radiological classifications of films made at the first two surveys and used in this report are those described by FAY and ASHFORD (1960). These were independent assessments by at least two physicians within a relatively short time interval (not more than one year), using four categories of simple pneumoconiosis of the ILO (1953) classification. Large shadows (Progressive Massive Fibrosis) were categorised according to size as A, B or C. Where there was disagreement between the two readers' classifications, the film concerned was re-examined jointly by the physicians concerned and a "definitive" classification was made on the basis of their conference. Further details of radiological methods are summarised by JACOBSEN (1979c).

Data on each individual's exposure to dust after the first survey were collated from records of attendance at work and measurements of respirable dust concentrations in the working environment. Time worked in each area was multiplied by the concentration measured in that area and the products totalled to give a cumulative exposure expressed in units of ghm^{-3}. Time worked prior to the first survey was divided into six broad categories of coalmining activity, and these times multiplied by mean concentrations corresponding to these categories, as determined during approximately ten years following the first survey. Estimates of exposure accumulated before the first survey were thus produced (JACOBSEN et al, 1977).

Dust samples collected for the purpose of assessing concentrations between the first and third surveys were later analysed for their composition by an interference microscope technique (DODGSON, 1963; DODGSON et al, 1971). These analyses yielded the proportions of quartz and of kaolin plus mica present in the dusts. Since the third survey, compositional determinations have been made by direct ashing at 380°C and subsequent infra-red spectroscopy (DODGSON and WHITTAKER, 1973). These proportions were used together with the data on exposure to mixed respirable dust, to give cumulative exposures to mass concentrations of the corresponding non-coal components of the mixed dust, again in units of ghm^{-3}.

Since an individual's inclusion in the study group did not depend on his attendance or non-attendance at subsequent surveys, (and since if he died during the follow-up he could not have appeared at surveys taking place after his death) the amount of data available varied widely between members of the study group. Some contributed only one film, whereas for others medical information and x-ray films covering a period of 25 years were available. In particular, 14 of the collieries did not receive fourth and fifth surveys and no PFR data are available for the men at these collieries after the third surveys, which took place between 1963 and 1968. Analyses which attempt to relate mortality to data gathered in the course of the PFR are therefore restricted to appropriate subsets of the study group for whom the relevant material is available.

2.3 Follow-up methods

When it was decided, in 1970, to incorporate in the PFR a study of the subsequent mortality of the mineworkers surveyed, it was necessary to investigate possible ways of ascertaining the vital status of these men.

The follow-up tracing of men to determine vital status took place in two phases, of which the second constituted part of the current project. However, the analyses use data from both phases, and it is therefore necessary to record some details of each, and of the preliminary feasibility study which led to the choice of follow-up methods.

For the feasibility study, a 1% systematic sample of the cohort was taken. An attempt was made to trace these through records held by the National Coal Board. Within a few months it was apparent that even the most painstaking search could not resolve the vital status of a sufficiently large proportion of the study group. Discussions were therefore started with the offices of the Registrars General of England and Wales and of Scotland, and with the Department of Health and Social Security, in order to explore the possibility of using national records to trace the cohort members. There are three major files with information on vital status of individuals resident in Great Britain. The first two are the National Health Service Central Registers (NHSCR). That for England and Wales is controlled by the Office of Population Censuses and Surveys (OPCS, formerly the Office of the Registrar General). A separate NHSCR is maintained for residents in Scotland under the control of the Scottish General Register Office (SGRO). The unique identification for each record on the file is the NHS number accorded to each person registered with a doctor under the National Health Service.

The third source of information on vital status is the Records Branch of the Department of Health and Social Security (DHSS). The records there are confined to adults who are part of the National Insurance scheme, and the unique identification of each record in these files is the National Insurance (NI) number, not the NHS number. No thesaurus is currently available linking NHS and NI numbers.

Phase I of the follow-up consisted of the tracing of a sample of the original study group, defined as all those whose x-rays at the first survey showed any signs of pneumoconiosis, and an age- and colliery-stratified 50% sample of the remainder. The total size of this sample was 17 738 men.

The identification available for the whole study group consisted of surnames and dates of birth. Full forenames were known only for a small proportion, and initials, where available, were not necessarily complete. National Insurance numbers had been confirmed for most men (97%), but no NHS numbers were available.

Cards containing all available identifying data for 48 350 men were prepared for the Mortality Study and an Autopsy Study being initiated at the same time. Records Branch of the DHSS annotated these cards manually with corrections (spelling of names, dates of birth, etc.), with full forenames, and with classification into one of four categories; "dead", "alive", "vital status uncertain", and "not traced". The last two categories were distinct in that the first indicated a man had been positively identified, but it was not known whether he was alive or dead; the category "not traced" referred to men for whom the identifying information provided was insufficient for a positive identification to be made. Dates of death were provided by DHSS where available. The major part of these searches took place in July 1972, though some searches continued through subsequent months.

The information obtained from DHSS was edited manually and transferred to punch cards for amending and updating of research computer files. Intensive efforts were made to supplement, using NCB sources, the identification data for men untraced by DHSS.

The computer was used to produce cards, printed in a format convenient to OPCS and SGRO, with updated information about all the men in the mortality study sample who had not been declared "alive" by the DHSS. The OPCS and SGRO proceeded to confirm deaths in the NHSCR and/or in the annual Registers of Deaths. For men confirmed as deceased, arrangements were made for the provision of copies of death certificates or certified extracts from death registers. The Chief Medical Statistician of the OPCS provided codings of the underlying cause of death, according to the International Classification of Diseases (ICD).

Of the 17 738 men in the stratified sample, 3 883 were discovered to have died up to 31.7.72. Analyses of the causes of these deaths in relation to other data available on this sample and selected subsamples marked the culmination of Phase I of the tracing exercise, and formed the bulk of the work for a Ph.D. thesis by JACOBSEN (1976). The procedures used were estimated to have traced the vital status of about 97% of the sample.

In 1977, the study was extended to include all of the men examined during the first round of PFR surveys. Out of almost 32 000, nearly 4 000 had already been established as dead during the first phase. Arrangements were made with the OPCS and SGRO to have searches made in the NHSCR and Registers of Deaths for the remaining 28 000 cases. As before, cards were prepared containing all identifying data for each case, including last known address (in most cases supplied by DHSS in 1972).

OPCS and SGRO searched for these men by name in the NHSCR. Where cases could not be identified unambiguously, the card was returned to the Institute as untraced. Where possible, the identification data were supplemented and the card returned for a further attempt at tracing in the NHSCR.

Where a case was currently registered in the NHSCR, his record was "flagged", indicating that when death occurred, details were to be provided to the Institute. As in Phase I, for those who had died, the cause of death was coded according to the ICD, and the coded copy of the death certificate or extract from the Register was sent to the Institute with the case card. For those who had left the United Kingdom or who had joined the Armed Forces, the OPCS notified the Institute but continued to flag the record. In Scotland, such cases were not identified separately to the Institute.

A direct-access computer system was set up to replace the punch-card-based system previously used for file updating. The new system provided direct, simple and rapid interrogation and updating of individual case records, via Visual Display Unit terminals.

During 1980, when the tracing operations in the NHSCR had been substantially completed, it was noted that the proportion of untraced cases for Scotland was higher than for England and Wales. This was discussed with staff of the SGRO who explained that they did not have easy access to details of deaths occurring prior to about 1974. Such deaths could be found only by searching at Register House in Edinburgh and this could be done simply only for cases where a date of death was known. Dates of death were available from earlier searches made by the DHSS for about half of the untraced men. These were supplemented by further dates found with the assistance of the Compensation Branch of the National Union of Mineworkers.

Searches were then made at Register House by Institute staff, with assistance from the SGRO. Where death was established, the SGRO provided ICD codings.

A few cards (79 from Scotland and 448 from England and Wales) were, inadvertently, not sent for tracing with the others; all of these were men who had not been traced by the DHSS in Phase I. The English and Welsh cards were sent to the OPCS in 1980. The Scottish ones were held back, since the SGRO were making additional searches at that time for records of men previously not traced.

2.4 Coding causes of death

The basic mortality data are date of death and "underlying cause of death" as recorded on the death certificate; a man was considered known to be dead when both date and cause were available for him. For ten men, dates of death but no causes of death were available. These were treated as having uncertain vital status and were regarded as untraced.

The coding of the causes of death was performed by OPCS nosologists, using the usual conventions employed by the Registrars General, i.e. according to the International Classification of Diseases, Injuries and Causes of Death (ICD) produced by the World Health Organisation. Deaths recorded in the present study occurred during the period 1953-1980, during which time the ICD system underwent three revisions.

In phase I of the follow-up, the revision used for coding a death from England or Wales depended upon the year in which the death occurred. The codes for the causes and groups of causes of interest in this study had not altered with the introduction of the seventh revision (WHO, 1957) from those used in the sixth revision; for the purposes of this study they have been considered to be the same, and referred to as seventh revision throughout. However, the eighth revision (WHO, 1969) was more extensive and altered the codes for several relevant causes.

In order to avoid having to consider the ninth revision, coding for deaths in phase II of this study was specifically requested to be according to the eighth revision (although the ninth revision was used by the Registrars General in their routine work from 1979 onwards).

The Registrar General provided confirmation of deaths occurring in Scotland in the form of manuscript copies of death register entries during phase I. These were sent for coding to the OPCS nosologists who had coded the English and Welsh certificates. Since this work was carried out during 1973/74 it was convenient to use the eighth revision of the ICD throughout. This has continued to date, so all deaths occurring in Scotland have been coded according to the eighth revision.

It has been necessary to reconcile codings made under the seventh and eighth revisions of the ICD. Table 1 sets out the approximate correspondence between certain broad groups of causes thought to be of interest for this study, and defines these groups for the subsequent analyses. Also shown are the numbers of deaths classified as belonging to each cause-group, over the entire follow-up period, as known at 1/8/80.

In all revisions, ICD codes below 800 signify clinical conditions, diseases and illnesses, whereas codes 800-999 are for violent and accidental causes such as poisoning, suicide, murder, road accident, accident at work, etc. In all that follows, causes of death with codes less than 800, i.e. excluding violent, constitute the cause-group labelled "all internal causes".

2.5 Statistical methods

This section outlines the statistical concepts and considerations underlying the analyses performed for the present report. More detailed description of the theory and computational methods is presented separately in an Appendix.

2.5.1 Describing survival

The statistical distribution of survival (or failure) times for a set of individuals can be described in a variety of ways. In this report, we have concentrated on two of these, the survivor function and the hazard function.

The survivor function is a function of time, and its value at any point in time is the probability of surviving at least to that time. The hazard function is defined as the instantaneous failure rate at each point in time, given survival to that time.

Thus the hazard function describes the effect of the "force of mortality" at different times, while the survivor function summarises these effects up to each time.

The two functions provide different but equivalent representations of survival experience. They are related by a functional identity, and specification of one therefore completely specifies the other. It follows that analyses of survival data can be performed in terms of either, depending on the particular questions of interest and/or the relative simplicity of the mathematics.

In analysis of a particular data set, the focus may be on any (or some combination) of the following; a) estimation of the survivor/hazard function; b) comparison of either function between groups of individuals; c) relation of the forms or specific parameters of these functions to other variables measured or observed on the individuals (covariates).

In this report the majority of the results are presented as point estimates of the survivor functions of various subgroups of the study at set points in time.

2.5.2 Censoring

In a mortality study of this kind it is usually necessary to analyse available data before all subjects have died; some subjects may also be "lost to follow-up" during the study, so that their vital status is not known after a certain time. In either case, the only survival information available on these subjects is the last time at which they were known to be alive, and the actual times of death are not known. Such survival data are said to be censored. The statistical theory and the practical mechanics of the analysis of survival data are made rather more complex by the presence of censoring in the data.

2.5.3 Competing risks and independence

We wished to consider separately results for different specific causes of death, as well as for mortality in general. At any point in time, a member of the study group who is still alive may die of one of a number of competing risks. One way of dealing with this situation is to perform a separate analysis for each cause of interest, and this is accomplished by treating deaths throughout the study from other causes as censoring events. The statistical methods for censored data can then be applied.

It is customary to justify various theoretical results by assuming that the competing risks, and any actual censoring mechanism present, are all statistically independent of each other. However, because a single "underlying cause of death" only is being considered here, it is not possible to test the assumption from our data. (A limited exploration of how "multiple coding" of causes of death would affect results has been reported by JACOBSEN (1976) using data from the first part of this study.)

2.5.4 External comparisons and standardisation

In humans, the age-specific mortality rate, or hazard, for general mortality (and also for many specific causes) increases with age. When comparing the mortality of a study group with e.g. the entire population, it is necessary, if incorrect conclusions are not be be drawn, to allow for any differences in age distributions between the study and reference populations. Similar remarks apply to any factor for which both the distributions in the populations and the patterns of mortality differ, e.g. geographical location, sex, social status, etc.

There are several methods of adjusting for differences of this kind; the most widely used has been the technique known as "indirect standardisation". To standardise for age distribution differences, age-specific reference population death rates are applied to the study population in order to calculate the number of deaths that would be expected at each age if the standard rates had occurred. The ratio of the total observed deaths in the study population to the total expected is the Standardised Mortality Ratio (SMR): if study and reference populations have the same underlying pattern of mortality, thenthe expected value of the SMR is 100%.

Adjustment for age and geographical location by region has been used to produce SMRs for each of the collieries considered in this report, for comparison with mortality of British men in general.

2.5.5 Internal estimation

The SMR is a useful summary statistic, but it does not provide any information on the shape of the survivor or the hazard function over the period of the study, whether in the study group as a whole or in selected subgroups. Estimates of these functions can be used to suggest parametric representations, to warn against features in the data which would make the SMR a misleading (or over-simplified) summary, or to compare graphically the mortality experience of two or more groups at different points during the follow-up.

In the present study, we have estimated hazard and survivor functions by "life-table" methods commonly employed in demographic and actuarial work. The follow-up period is divided into discrete time-intervals and the numbers entering, leaving, dying and censored in each interval are used to provide estimates of successive points on the hazard function; results are cumulated over intervals to estimate the survivor function. These procedures require no assumptions about the shape of the functions. Comparisons between survivor functions may be made using non-parametric tests, but these are not easily extended to nested or crossed classifications by multiple factors.

2.5.6 Mathematical models for internal comparisons

Formal statistical analyses are facilitated by assuming and fitting mathematical models to the data. The general framework formulated by COX (1972) is flexible and embraces many special cases of interest. Under this family of models, the hazard for an individual is expressed as the product of two terms, the first common to all individuals in the study, and the second, analogous to a regression equation, to include terms specific to the individual. Standard maximum-likelihood methods are applicable if the underlying common term in the hazard is specified parametrically; however, Cox's work has shown that inferences on the second part of the hazard can be made without making such parametric assumptions.

For large data sets, analyses using Cox's model can be extremely costly in computation, since they involve iterative calculations at every time of death. In the present study, an approximation involving the grouping of time into intervals, as in the life-table methods above, has been used; this approximation considerably reduces the amount of computation, by summarising the individual data in a pre-analysis step; the formal analysis is then performed on the summary data.

3. RESULTS

3.1 Results of follow-up

3.1.1 Length of follow-up

A copy of the direct access database file containing the data on vital status of the study group members was made on 1/8/80. The information contained in the file on that date was thus "frozen" at that time, and it was this copy which was used for the analyses reported now.

In general, when a man dies after he has been "flagged" in the NHSCR, it takes some months for his death certificate to be obtained, coded as to cause, and sent to the Institute. The information on file at 1/8/80 does not, therefore, represent adequately the vital status of the study group on that date. An effective termination date for the study follow-up period must be set somewhat earlier.

The 24 collieries in this study all had their first surveys at different times, and the last took place around April 1958. A termination date of April 1980 would thus permit the miners at this colliery to be followed-up for 22 years, and those at other collieries for periods longer than this. Figure 2 shows the length of follow-up available for each colliery taking April 1980 as a termination date.

In some analyses it has been necessary to restrict the study group to survivor populations attending also the second or subsequent surveys. In such cases, the follow-up has been deemed to start at the later survey, and has therefore covered a shorter time span.

3.1.2 Vital status

During the data processing it was discovered that of the 31 676 computer records of 1st survey x-rays, two were blank duplicates, and a further 63 were not for coalminers working at the collieries, but for ancillary staff who happened to be present when the x-ray units were operating and who accepted the offer to have a chest x-ray taken. The true size of the study group under the definition already given was therefore 31 611 coalminers.

Table 2 describes the follow-up achieved up to the end of July 1980 in terms of the tracing status recorded at that time for each man in the database file. Note that while 250 men were reported as having "embarked", all of these were from English and Welsh pits and no one from the Scottish pits was so recorded. We understand that the Scottish part of the NHSCR has in the past not maintained records for men who have left the country. Such men will therefore be "untraced" and lost to follow-up.

The "untraced" men include those for whom positive identification was not made; some of these were completely untraced, while for others the information was insufficient for positive identification, e.g. where forenames were not known and two men in the NHSCR had similar surnames and dates of birth to those on the tracing card. For ten men, a date of death was supplied, but the cause of death was not known (probably because they died abroad).

It is probably appropriate to compare the Scottish "untraced" with the English and Welsh "untraced" and "embarked" pooled. These constitute 6.6% and 4.6% respectively of the totals in the study. This is considered to be a result of the greater difficulty of tracing men already deceased in the Scottish records and suggests an under-reporting of deaths from Scotland.

The additional efforts of the staff of the SGRO to trace these men through auxiliary record systems have produced, at the time of writing, the notification of an additional 83 deaths. These occurred in the main in the mid-1970's, and have the effect of reducing the Scottish untraced to 5.0% of the total, a figure nearer that for England and Wales. This information became available only after the start of the analyses reported now.

Of the 448 cases whose cards were sent late to OPCS, 40 had been returned by 1/8/80 as "insufficient information", and they are included in the untraced category in Table 2. Of the remaining 408 outstanding cards for England and Wales, at time of writing 133 deaths have been established, another 148 remain untraceable and 127 are still being processed by OPCS. The small numbers and the non-systematic selection of these cases suggest that any bias introduced by their omission is likely to be negligible.

Of the 29 553 men regarded as traced, over one-third had died by the end of a follow-up period which varied, by colliery, from 22 to over 26 years. Table 3 shows an analysis of these deaths by calendar year for each colliery.

3.2 Crude cause-specific mortality

Table 4 describes deaths from all internal causes occurring up to 22 years from the first survey, by colliery and by cause group. Deaths from the Scottish collieries are excluded, as are deaths from violent causes (ICD 800-999). Due to differing lengths of follow-up by colliery, this Table does not show all deaths recorded for the English and Welsh collieries, but the common length of follow-up constitutes a convenient basis for comparison.

There are 6 654 deaths in Table 4, from a risk-set comprising 24 736 men present at the first surveys at the English and Welsh collieries. Each cell of Table 4 shows the percentage contribution that number of deaths makes to the total number of deaths from internal causes within the colliery concerned.

Table 5 shows the same data by cause-group and age at first survey (not age at death), with percentages as above.

These Tables are presented primarily for information, and they show differences in the proportional patterns of mortality between age-groups and between collieries. Note however that other things being equal, a colliery which has increased mortality from one cause must necessarily show a corresponding decrease in the proportion of deaths from other causes, and *vice versa*. These Tables do not take any account of when the deaths occurred within the 22-year follow-up period.

The comparisons between collieries of cause-specific mortality presented in later sections were made by methods which take into account time of death and competing risks from several causes of death.

3.3 Comparisons with published mortality statistics

The mortality experience of the study group was compared with that of the general population using official mortality statistics published in the Annual Reports of the Registrars General. These were the numbers of male deaths and mid-year male home population in each calendar year 1953-78, stratified by 10-year age groups (under 25, 25-34, ... 55-64, 65+) and by region within Great Britain. Population death rates were calculated by dividing the number of deaths by the population size. (The regions used by the Registrars General altered in 1974, with the reorganisation of local government, but the locations of the collieries were known in relation to both sets of boundaries and the appropriate rates were used throughout.)

The Standardised Mortality Ratios in Table 6 are based on age and calendar year specific death rates for all men in the geographical regions where the collieries were situated.

Three values of the SMR are shown in each case. The first summarises the mortality within a period 1953-72. (The actual period of follow-up for each pit varies from 14 to 18 years, depending on when the first survey took place. The computer program was designed to make appropriate adjustment for different lengths of follow-up.) The second SMR is based on deaths occurring in the seven years 1973 through 1979. The final column of the Table shows the SMR for the maximum follow-up period possible, up to and including December 1979.

None of the SMR's in the last column of Table 6 exceeds 100%. Thus there is no evidence that death rates among the men studied were higher than published rates for British men generally.

All but one of the collieries in England and Wales show an increase in the SMR during the last seven years as compared with results referring to the earlier years. This is interpreted as evidence of the so-called "healthy worker" effect in the data.

At the start of the study, all the men studied were in full-time employment. By virtue both of selection for fitness to be employed in the first place, and of selective migration out of the industry among those who became less fit after recruitment, working miners at the time of the first survey were likely to be more fit, on average, than their contemporaries generally. As the follow-up proceeded, an increasing proportion of the numbers at risk left the industry. It is therefore to be expected that the inherent bias associated with comparing mortality in an employed population with the experience of all men (including the disabled and hospitalised) would diminish with time. The results from England and Wales are clearly consistent with this argument.

FOX and COLLIER (1976) discuss the effects, on comparisons of mortality, of selection for recruitment and continuing employment in an industry, and note that these effects were first described over 100 years ago by OGLE (1885). They conclude that these effects can severely prejudice the usefulness of the SMR for the study of mortality in industrial cohorts, and suggest that other mathematical models may be more useful.

The four Scottish collieries show a pattern the reverse of that for England and Wales. We interpret this as an artefact arising from the bias in the incomplete follow-up for Scottish collieries. Of the 83 deaths recently notified for Scottish men considered untraced when Table 6 was produced, all but three occurred between 1973 and 1979. Had this information been available in July 1980, the calculated SMR's for this period for the Scottish collieries J, O, P, S would have been somewhat higher. This is interpreted as additional evidence that the data on deaths from the Scottish pits were incomplete when the analyses were performed.

3.4 Internal comparisons

3.4.1 General

The main aim of this study is to investigate possible differences in mortality arising from differences in the auxiliary variables available (e.g., exposure to dust, radiological category). SMR's, based on published death rates, are not ideal for this purpose, partly because quantitative estimates of the contrasts of interest would be affected by the standard death rates used to calculate the SMR's (and these are of no intrinsic interest here), and also because the "healthy worker effect", noted above, may be expected to operate differently for different causes of death (e.g., chronic and acute conditions). The remainder of the work reported below is therefore based on so-called "internal comparisons" between sub-groups, with no reference to any external population.

3.4.2 Choice of time origin

In general, the sub-groups considered include miners from several collieries, and these come into view in the study at different time points. If comparisons are made in individual calendar years, then the length of the follow-up is different for the different collieries, and furthermore the selection effect occurs at a different time in each colliery. If the variable by which sub-groups are defined varies markedly between collieries, then the differential selection effect in each year is a potential source of bias in the comparisons.

For the internal comparisons described below we have therefore defined the time origin (i.e. the start of the follow-up period) as the time of the first survey at each colliery, regardless of calendar year. The follow-up period was then measured in time elapsed since first survey. (Where availability of data required that analyses could take place only among populations surviving to a subsequent survey, then the origin was redefined as the time of the survey concerned.) The first year of follow-up thus corresponds to different calendar years in different collieries, and this could be an alternative source of bias if secular trends are present in the underlying mortality patterns. Examination of the general population death rates for all causes indicated that secular mortality trends over the period 1953-79 were fairly gradual, and often masked by variation in the population. We therefore consider that the degree of possible bias associated with this choice of time origin is small, and probably negligible compared with the very real differential selection effects to be expected if calendar years had been used. We plan to investigate the validity of this subjective judgement in further studies, using Cox's regression model.

3.4.3 Omission of the Scottish collieries

Another, and potentially more serious, source of bias is the suspected deficiency of death records from the Scottish collieries. The different tracing procedures used in the two separate phases of the work implies that a larger proportion of Scottish deaths are suspected "missing" from the early 1970's. We decided therefore to omit the four Scottish collieries from the remainder of the analyses reported now. The results from the Scottish collieries will be studied further when there is evidence that the death notifications are more complete.

3.4.4 Presentation of results

The majority of the internal comparisons in this report have been made by estimating survival probabilities at fixed times by life-table methods, within subgroups of the study group. The stratification has been performed by age at the time origin and by the other factors of interest. For the cause-specific analyses, a separate computer run was made for each cause of interest, and deaths from other causes were treated as censored events. (Since those untraced were not included in the initial risk sets and the follow-up period chosen was shorter than that available for all collieries, death from "other causes" was, in fact, the only relevant censoring event.)

A uniform method of presentation has been adopted for results from the various analyses. In Tables 7 *et seq* the left side of each cell contains the size of the risk set at the time origin, and the number of deaths observed over the stated length of follow-up. On the right side of the cell are the estimated survival probabilities expressed as a percentage, with an approximate standard error, on the same scale, below it. These figures summarise the mortality experience from the cause of interest over the intervals which constitute the follow-up period.

In some cases (e.g. in Table 9.1) the risk-sets are empty at the start of follow-up, indicating that no information is available. Also, some of the risk-sets over 65 years of age are so small that all the men concerned died from causes other than the one being studied before the end of the follow-up period. No sensible estimate of survival can then be made. In both cases, a dash stands for information which is not available.

3.4.5 Interpretation of results

For the cause-specific analyses, the estimated survival may be interpreted as the hypothetical net probability of not dying from that cause if it were the only risk present, provided that the risks are independent. We have noted earlier that the assumption of independent risks cannot be tested from these data. This means that if two different causes of death show an association with the same factor, then there is no way of deciding whether the risks are themselves naturally associated. In what follows we shall often apply Occam's Razor and prefer the simplest explanation for such associations and we emphasise that clarification cannot be gained by more searching statistical analysis, but only by appeal to criteria other than our mortality data (e.g., medical considerations, common sense, results from other studies).

3.5 Mortality compared between collieries

3.5.1 Sample

The overall risk-set for these analyses was all traced men from the English and Welsh collieries, numbering 24 736.

3.5.2 Method

The data were analysed by the life-table method described in the Appendix. The time origin was defined as the time of the first survey, and the follow-up period was taken as 22 years. This corresponded to a termination date in

April 1980 for colliery N and variously earlier times for the other collieries. The men were stratified by colliery and by age at first survey.

The results, for selected cause groups, are presented in Tables 7.1-7.4 in the format described in 3.4.4. Examination of the overall risk-sets in these Tables shows that there were some differences in the age distributions between the collieries.

3.5.3 All internal causes (Table 7.1)

The survival figures within each age-group are similar for the different collieries. No colliery exhibits consistently high or low survival across age-groups. Although there are fewer collieries in some regions than in others, the observed ranges in the better-represented regions are not indicative of any particular regional trend. There appears to be no evidence that mortality experience from all internal causes differs consistently between the collieries or between regions.

It is possible that consistent differences in cause-specific mortality may be masked by conflicting patterns or by sampling variation overall. Accordingly, we examined cause-specific survival for some selected causes.

3.5.4 Lung cancer (Table 7.2)

In the main, the numbers of deaths in the age-groups below 35 at the first survey are too small to allow useful comparisons to be made. In the age-groups from 35 to 64, collieries D and A appear to have the worst survival rates. The South Wales collieries exhibit the highest survival. The general impression from the Table is consistent with the view that lung cancer mortality in Britain is highest in the north and lowest in the south.

Using only the Phase I sample, and a shorter follow-up period, JACOBSEN (1976) found lung cancer mortality to be highest in collieries D and A: the results of the present study confirm this finding.

3.5.5 Pneumoconiosis (Table 7.3)

The estimated survival figures for pneumoconiosis may be compared with the figures in Table 8, which shows the distribution amongst collieries of radiological classifications of the x-rays taken at the first survey.

It is clear that the collieries with the lowest pneumoconiosis survival rates are those with the highest prevalence of pneumoconiosis at the first survey. This is not presented as evidence that simple pneumoconiosis increases mortality hazard; the same collieries also have the highest prevalence rates of progressive massive fibrosis (PMF). However, it seems intuitively acceptable that the higher the prevalence of the disease, the more men will progress to the more serious form, which is often fatal.

The degree to which radiological category may be used as a prognostic indicator of mortality will be examined in a later section.

3.5.6 Bronchitis and emphysema (Table 7.4)

Similarities are apparent between the patterns of mortality in this Table and those for pneumoconiosis mortality in Table 7.3. There is a strong suggestion that the collieries with high pneumoconiosis mortality also have high bronchitis and emphysema mortality.

3.5.7 Comments

Mortality from pneumoconiosis and from bronchitis and emphysema have been found to be high in certain collieries, and it has been noted that these collieries are the ones with the highest prevalence rates for pneumoconiosis diagnosed radiologically. A possible interpretation of the observed increases in mortality for both causes simultaneously might be that the increases were due to higher dust concentrations or more dangerous kinds of dust at certain collieries. However, as noted above, the colliery-specific data in Table 7 do not allow us to discriminate between this hypothesis and any other involving underlying patterns of association between the hazards or difficulty in diagnosing cause of death. In subsequent sections relationships are examined between mortality and factors for which data are available.

3.6 Mortality compared by radiological status

3.6.1 Sample

By definition, every member of the study group had an x-ray film taken at the first survey. The overall risk-set for the analyses presented in this section consisted of all traced men from the English and Welsh collieries, and contained 24 736 men.

3.6.2 Method

The data were analysed by the life-table method described in the Appendix. The time origin was defined as the time of the first survey, and the follow-up period was taken as 22 years. The men were stratified by age and by the classification assigned to the first survey x-ray film; category 0 indicates the absence of significant radiological abnormality, categories 1-3 increasing levels of simple pneumoconiosis, and categories A, B, and C represent increasing severity of Progressive Massive Fibrosis (PMF).

The results for selected cause-groups are presented in Tables 9.1-9.6 in the format described in 3.4.4. The risk-sets in these Tables display a pattern of increasing proportions in the higher categories for the higher age-groups. This is consistent with the progressive nature of PMF, and of simple pneumoconiosis in continued employment in dusty conditions.

3.6.3 All internal causes (Table 9.1)

The survival estimates in this Table show that men with progressive massive fibrosis (PMF), including those with 'A' shadows, had markedly poorer survival rates than other miners. The contrast between men with simple pneumoconiosis and those whose radiographs were originally classified as category 0 is less clear-cut. The risk-sets for category 3 are small, and estimates of survival for this category are therefore relatively imprecise. In each age-group, the survival rates for category 1 (which constitutes the majority of the pneumoconiotics) are lower than for category 0, but the results for category 2 do not reinforce any suggestion of a trend. There is no consistent gradient in survival with increasing category of simple pneumoconiosis.

3.6.4 Lung cancer (Table 9.2)

There are relatively few deaths from lung cancer in the younger age-groups and this, coupled with the small risk-sets for the higher radiological categories, makes it difficult to draw any conclusions about relative risk amongst the younger men. In the age-groups above 45 years, where there are more deaths and where the proportions in the higher radiological categories are greater, there is no consistent evidence to suggest increasing or decreasing survival with increasing radiological category. However, these figures do not distinguish between smokers and non-smokers. Analyses in section 3.7 will expand this investigation to allow the distinction to be made.

3.6.5 Stomach cancer (Table 9.3)

Again, the sizes of the risk-sets for the higher pneumoconiosis categories prevent detailed conclusions being drawn. In the lower categories, men in the age-groups from 35 upwards in category 1 exhibit worse survival rates than their peers in category 0. Category 2 continues this apparent trend in the age-groups 35-44, 45-54 and 65+, while the reverse is true in the age-group 55-64, although given the size of the standard error it is apparent that this could be due to sampling variability. Consideration of whether this apparent effect is statistically significant is deferred to section 3.9, where exposure to respirable dust is considered as an additional variable.

3.6.6 Bronchitis and emphysema (Table 9.4)

There is no obvious pattern of increasing mortality from bronchitis and emphysema with increasing initial category, except in the age-group 35-44. However, it may be misleading to single out this age-group, since the combination of small risk-sets and low numbers of deaths in category 3 and for PMF means that the survival estimates for these categories are of relatively low precision, as shown by the size of the standard errors.

3.6.7 Pneumoconiosis (Table 9.5)

The overall impression in this Table is clear: pneumoconiosis mortality increases consistently with increasing initial category. This finding is fully in accordance with expectation given the increasing risk of developing PMF with increasing category of simple pneumoconiosis, and the known relatively high mortality for men with PMF.

It should be noted that the radiological category used here is that of the first survey x-ray film, and this does not necessarily accord with the radiological category immediately before death.

3.6.8 Other respiratory diseases (Table 9.6)

There is no evidence here to suggest a relationship between radiological category and mortality from respiratory diseases other than pneumoconiosis or bronchitis and emphysema.

3.6.9 Comments

The data have been analysed in terms of initial radiological category, and of course this does not necessarily represent the category attained before death. Among the men whose first survey radiographs were classified as category 1, whose mortality was more severe than that experienced by those with no radiological signs at start of follow-up, there will be some who progressed to higher categories of pneumoconiosis during the subsequent 22 years. Future work will examine mortality in relation to available data on radiological classifications over the period of follow-up. It seems clear, however, that the presence of PMF is associated with increased subsequent mortality.

3.7 Lung cancer mortality compared by radiological status and smoking habits

In an earlier section on the results of an analysis of lung cancer mortality in association with radiological category, no consistent relationship was observed between category and mortality. That analysis took no account of smoking. In this section we report the result of some additional analyses undertaken to investigate lung cancer mortality and radiological category after allowing for smoking effects.

3.7.1 Sample

Included in the analysis of lung cancer mortality and radiological category in Table 9.2 were 24 736 traced men from England and Wales who attended the first survey. Since the questionnaire on smoking habits etc. was not introduced to the PFR until the second survey, information on smoking habits was not available for the whole group, but only for those seen also at the second survey. In England and Wales, these numbered 16 954 of those traced, and this sample was used for the analysis.

3.7.2 Method

In order to make adjustment for smoking habits, and also so that formal significance tests could be made, the analysis was performed under the general framework of the log-linear model, using Holford's approximation to Cox's model, as detailed in the Appendix.

The sample was stratified into 10-year age-bands by age at the second survey, and into three categories of classification of the second survey x-ray films; category 0, categories 1, 2, 3 (simple pneumoconiosis) and categories A, B, C (PMF). Replies to the questionnaire on smoking were used to classify the men further as smokers, ex-smokers and non-smokers (defined as those who had never smoked as much as one cigarette per day for one year). No distinction was made between pipe, cigarette and cigar smokers for this analysis.

A computer program written at the Institute was used to accumulate the total time at risk (adjusted for censoring), and the number of lung cancer deaths, in each interval of one year from the second survey, for every combination of the cross-classifying factors age, smoking and radiological category. These summary values were then used as input to a GENSTAT program. Survival estimates at 17 years were produced as an intermediate result and are presented in Table 10 in the usual format.

3.7.3 Results (Table 10)

Table 10 shows estimates of survival from lung cancer at 17 years after the second survey, stratified by age, smoking habit and presence of pneumoconiosis or PMF. Of the whole sample 79% were classified as smokers. In this group, the survival estimates suggest a lung cancer hazard decreasing from men with category 0 films through the pneumoconiotics to the PMF cases. The numbers of deaths below age 35 being too small, the data for the age-groups 35-64 only were subjected to analysis under the formal statistical model. The analysis yielded proportional hazards for simple pneumoconiosis and PMF of 0.84 and 0.64 respectively, relative to those men with category 0 films. The formal test of the hypothesis that all three subgroups had the same hazard corresponded approximately to a 10% significance level; the evidence is thus not strong that these differences are due to other than chance.

In the non-smokers, the numbers of lung cancer deaths were too small for formal statistical comparison. Note however that no deaths at all were attributed to this cause among those with radiological signs of abnormality. Even allowing for the fact that these men may be dying of other diseases (such as pneumoconiosis), and that the initial risk-sets may be a poorer guide to the time at risk, we might have expected to see a few deaths in these groups if the hazards were the same as for the category 0 men. The pattern is consistent with that observed for the smokers but cannot be regarded as conclusive.

The ex-smokers were the smallest group, and no trends are apparent in their survival estimates.

Differences between the smoking categories are of interest in their own right. Over the whole Table, adjusted for age but ignoring radiological category, the analysis indicates that the differences between the smoking categories are highly significant. Parameter estimates from the analysis model gave the smokers a fitted hazard function 5.5 times that of non-smokers of the same age. The ex-smokers' hazard was 2.4 times that of the non-smokers.

3.7.4 Comments

The results for the smokers and non-smokers do not contradict the hypothesis that lung cancer mortality is reduced in those men with pneumoconiosis, but neither do they confirm the hypothesis with any certainty. If such an effect is real, it is not large, even by 17 years of follow-up. A longer period of follow-up may shed more light on the question, as might inclusion, in the analysis of the smokers, of information on the amount of tobacco consumed per individual.

What is clear is that pneumoconiosis affords no protection from lung cancer, since the difference between smokers and non-smokers in lung cancer mortality is evident in each of the categories of radiological classification in Table 10.

3.8 Mortality compared by exposure to mine dust

3.8.1 Sample

Estimates of individuals' exposure to respirable mine dust prior to the first survey had been calculated from industrial histories, as described by JACOBSEN et al (1977). Within England and Wales this information was available for 19 809 men. Of these, 259 had been classified as unreliable by the interviewer at the time of the survey. (This may have been because of language difficulties with miners of foreign origin, obvious memory gaps among older miners, or seriously inconsistent responses to the questions.) The remaining 19 550 men were taken as the overall risk-set for the comparison of mortality between groups exposed to different dust conditions.

3.8.2 Method

The risk-set was split (arbitrarily) into four roughly equal-sized groups corresponding to increasing ranges of estimated cumulative dust exposure up to the first survey: up to 30 ghm^{-3} (4792 men); over 30 and up to 90 ghm^{-3} (4882); over 90 and up to 180 ghm^{-3} (5007); and over 180 ghm^{-3} (4869). The highest observed value was 914 ghm^{-3}, and only 28 men had values greater than 600 ghm^{-3}.

The age-distributions within these four subgroups were naturally very different, with older men predominating in the higher exposures, and vice versa. The distribution of the risk-sets by age at first survey in Tables 11.1-11.9 shows clearly the association between age and accumulated exposure. There is still sufficient spread of exposures within each of the age-groups from 25 to 64 to enable comparisons to be made, given sufficient deaths.

Survival estimates at 22 years from the first survey were calculated using the life-table methods described in the Appendix.

3.8.3 All internal causes (Table 11.1)

The survival estimates show a clear pattern of increasing mortality with increasing exposure to dust, with minor exceptions. The age group 55-64 is the most conspicuous exception; although the highest and lowest survival come from the lowest and highest dust exposure groups, the pattern is not maintained in the two intermediate groups.

The estimates of exposure up to the first survey are based both on assumptions made regarding the dust conditions in the collieries before measurements were actually taken by PFR investigators, and on the individual miners' recollections of occupational history up to the first survey. Both of these possible sources of error may be expected to affect the estimates for older men more than for younger men. Further, the association between age and exposure means that the risk-sets for the lower exposures are small for the older men, implying poor precision of estimation anyway.

It seems likely that the extremes of the dust exposure ranges separate fairly well men who worked mostly in relatively dusty and non-dusty conditions, even in the older age-groups. Over the whole Table, the conclusion that increasing dust exposure is related to increasing mortality appears unequivocal. It is of interest to examine specific causes of death to investigate this effect further.

3.8.4 Lung cancer

There is no consistent trend in mortality from lung cancer with increasing exposure to dust.

3.8.5 Cancers of the stomach, digestive organs and peritoneum (Tables 11.3 and 11.4)

Neither of these Tables displays any consistent trend in mortality with increasing dust exposure. In view of the interest in the hypothesis of a relationship between these causes of death and pneumoconiosis, and of the relationship between exposure to respirable dust and pneumoconiosis, a more complex analysis of these factors is reported in section 3.9.

3.8.6 Other cancers (Table 11.5)

The estimates of survival across the dust exposure categories are very similar within each age-group from 25 to 64. There is no evidence that mortality from this cause-group is related to exposure to dust.

3.8.7 Bronchitis and emphysema (Table 11.6)

This Table shows a clear trend of increasing mortality attributed to this cause-group with increasing exposure to respirable dust, apparent in each of the age-groups between 25 and 64.

3.8.8 Pneumoconiosis (Table 11.7)

Despite the relatively small numbers of deaths, the trend of increasing mortality with increasing exposure to dust is readily apparent within an age-group.

3.8.9 Other respiratory diseases (Table 11.8)

While a trend is not readily apparent in this Table, there is a suggestion that the higher exposure groups have lowest survival. In particular, the age-groups from 35 to 64, in which most of the deaths occur, all have a lower survival in the highest exposure range than in the lowest.

3.8.10 Ischaemic heart disease (Table 11.9)

In this Table, no trend in survival is apparent with increasing dust exposure.

3.8.11 Comments

As discussed above, the exposures used here may not be entirely reliable. Furthermore, the association between age and exposure (reflected in the relatively smaller risk-sets in the bottom-left and top-right cells of Tables 11) complicates the problem of distinguishing between these two factors. Further analyses, based on Cox's full model, and incorporating exposures accumulated over the period of follow-up as a time-dependent covariate, are likely to provide better estimates of the effects of dust exposure and of their statistical significance.

However, it seems clear from this analysis that mortality attributed to pneumoconiosis, to bronchitis and emphysema, and possibly also to other respiratory disease, was more severe for miners who had experienced relatively high exposures to respirable coalmine dust before the start of the follow-up. These results are reflected in the clear trend for mortality from all internal causes to increase with increasing ranges of dust exposure.

3.9 Mortality from cancers of the digestive system compared by radiological status and exposure to mine dust

In this section, we examine further earlier suggestions of an association between the presence of radiological signs of pneumoconiosis and subsequent mortality from cancers of the digestive organs. Since the trends noted in Table 9.3 (for stomach cancer) may reflect direct effects of exposure to respirable dust, rather than the radiologically identified abnormalities in the lung, the following analysis incorporates both these variables simultaneously. The cause-group studied was all cancers of the stomach, digestive organs and peritoneum, i.e., groups 2 and 3 in Table 1, combined.

3.9.1 Sample

The sample available for this analysis was all those who had reliable dust exposure up to the first survey, i.e., the same overall risk-set as used for the analyses described in section 3.8. However, we felt that the numbers of PMF cases would be too small to permit useful analysis after sub-division by ranges of dust exposure, and they were therefore omitted. There remained 19 108 men for study.

3.9.2 Method

The men were classified by 10-year age groups at first survey, into four ranges of exposure to dust (using the same class boundaries as described in 3.8.2), and additionally as non-pneumoconiotic or pneumoconiotic depending on whether the classification of the first survey x-ray film was category 0 or not. A computer program written at the Institute was used to accumulate total time at risk and number of deaths from cause-groups 2 and 3 in each interval of one year from first survey for each combination of the (age x pneumoconiosis x dust exposure) cross-classification. The summary data were stored on a computer file and used as input to a GENSTAT program written to perform analyses of the log-linear models described in section A5 of the Appendix.

3.9.3 Results (Table 12)

This Table shows estimates of survival at 22 years from cancers of the stomach, digestive organs and peritoneum, stratified by age, exposure to dust prior to first survey, and presence or absence of simple pneumoconiosis. There is considerable dependence between these classifying factors; the higher dust exposures occur in the older men, and the prevalence of pneumoconiosis increases with exposure to dust.

The standard errors of the survival estimates are functions both of the initial risk-sets and of the of observed deaths, but, because of the imbalance in the risk-sets, patterns in the Table are not immediately obvious.

Formal statistical analyses were performed on the data summarised in a selected subset of the cells of Table 12. In order to work with reasonably-sized risk-sets, these analyses were confined to the age-groups 35-64. The cells used were those marked with an asterisk in Table 12.

The results from the analyses indicated that when the radiological categories were pooled there was a significant trend of increasing mortality with increasing exposure to dust. When the dust categories were pooled, then the simple pneumoconiotics had significantly greater mortality than those classified as category 0. When mortality was considered over all the cells, then neither dust exposure nor pneumoconiosis was associated significantly with increased mortality after adjustment for the other factor ($P > 0.1$ in both cases).

3.9.4 Comments

The analyses reported in this section have confirmed that there is an association between cancers of the digestive organs and either mine dust or the condition of pneumoconiosis or both. However, since these factors are themselves strongly associated, it is not possible here to discriminate between the alternative hypotheses, that dust can cause pneumoconiosis which can in turn cause the cancers, or that dust can cause both independently.

The dust exposures and the pneumoconiosis variables used here are those prior to and at the first survey respectively. Those dying of the causes of interest may well have accumulated more dust exposure and/or progressed up the scale of radiological categories before their deaths. Further analyses incorporating the dependence of these factors on time are necessary to try to separate the exposure and radiology effects on these causes of death.

3.10 Mortality compared by lung function

3.10.1 Sample

The earliest survey from which reliable lung function measurements are available for all collieries is the third PFR survey. These are the Forced Expired Volume in one second (FEV_1) and the Forced Vital Capacity (FVC).

Mortality in relation to lung function has been examined within the sub-group surviving and remaining in the collieries up to the third survey at least. This sub-group is considerably smaller than the whole study group, due to deaths, men leaving the industry, non-attendance at the survey, and the fact that most men aged over 55 at the first survey would have retired in the 10-11 years between the first and third surveys. (The surveys were designed to be of mineworkers in employment, although a few retired men living locally would often turn up to have an x-ray film taken.)

FEV_1 was measured for 11 869 men who attended at the third surveys. These were taken as the overall risk-set for the analyses reported here.

3.10.2 Method

The measurement FEV_1 is known, on average, to be positively related to body size, and to decline with age. A cross-classification of the sample by age and FEV_1 therefore displays the sort of dependence between the sizes of the risk-sets and the age-groups that was observed with dust exposure in section 3.8, as shown in Table 13. A convenient standardisation is available which removes a large part of this dependence.

Khosla (1971) showed that the index defined as

$$KI = \frac{FEV_1.(Age)^{\frac{1}{2}}}{Ht^2}$$

was nearly uncorrelated with age and height. We have adopted this as an (approximately) age- and height-standardised index of lung function.

The 11 869 members of the risk-set were split into four roughly equal groups on the basis of the calculated values of Khosla's Index (KI). Most of them fall into the range 0.1 to 1.0 when FEV_1 is expressed in millilitres, height in centimetres and age in years. Life-table analyses were then performed using these groupings and ten-year age-groups as at third survey. The time origin was defined as the date of the third survey for each colliery, and the follow-up was taken as 12 years from this point, i.e. to May 1980 for the colliery with the latest third survey.

The results are shown in Tables 14.1-14.6 for selected groups of causes of death. It is evident that while the sizes of the risk-sets are not in exactly equal proportion in each age-group, the degree of dependence is not great. With the exception of the over-65 age-group the risk-sets in each of the cells are adequate for the analyses.

3.10.3 <u>All internal causes</u> (Table 14.1)

There is a clear and consistent pattern of reduced survival with lower values of KI at all ages less than 65 years, implying an association between low levels of FEV_1 as measured at the start of follow-up for this sub-group (at the third surveys) and subsequent mortality. Cause-specific analyses follow.

3.10.4 <u>Lung cancer</u> (Table 14.2)

The numbers of deaths from lung cancers in 12 years amongst men under 45 at third survey are too small to permit useful comparisons. In the groups 45-54 and 55-64 there is a consistent trend of increased lung cancer mortality with decreased lung function.

3.10.5 <u>Bronchitis and emphysema</u> (Table 14.3)

There is clear indication in this Table of increased mortality from bronchitis and emphysema in men between 45 and 64 with reduced lung function.

3.10.6 <u>Pneumoconiosis</u> (Table 14.4)

Although the numbers of pneumoconiosis deaths are relatively small over the 12 years, there still appears to be an association between increased pneumoconiosis mortality and decreased lung function.

3.10.7 Other respiratory diseases (Table 14.5)

Again, despite the small numbers of deaths in total, it seems clear that decreased lung function is associated with decreased survival from this group of causes.

3.10.8 Ischaemic heart disease (Table 14.6)

Although the survival estimates in each age-group do not follow the order of the groupings by lung function, it is apparent that those with the lowest lung function in each age-group are those who experience the highest mortality from ischaemic heart disease.

3.10.9 Comments

It has been clearly shown that survival is lower for men whose lung function is reduced in comparison with their peer group. This is true at least of deaths due to lung cancer, bronchitis and emphysema, pneumoconiosis, other respiratory diseases and ischaemic heart disease. With the exception of pneumoconiosis, these are causes of death likely to show an increase in smokers, and standardised FEV_1 is well known to be lower for smokers. It is therefore important to note that non-smokers and smokers have not been distinguished in Tables 14.1-14.6, and that no adjustment has been made for smoking habit.

While this does not alter the fact that reduced lung function has been found to be a strong prognostic indicator of increased mortality hazard, it would be unwise to postulate causal pathways without separating the smokers from the non-smokers; further analyses with the addition of smoking habit as an explanatory factor are required to examine the aetiologies of these causes of death.

3.11 Mortality compared by exposure to mine dust and quartz

3.11.1 Sample

The most reliable data on exposures to quartz for miners included in this study are based on laboratory analyses of dust samples taken with the MRE Gravimetric sampler, that is, after the third of the radiological surveys at each colliery. Estimates of earlier exposures to quartz dust, including exposures before the research began, appeal to approximations from infra-red analyses of bulked aliquots of dust from stored Thermal Precipitator slides (DODGSON et al, 1977), and they imply also that the concentration and composition of the dust to which the miners were exposed before the first surveys was similar to that measured in the first ten years of the study. For this analysis of the possible effect of quartz in mixed dust with respect to mortality we thought it desirable to exclude men whose exposures to quartz were derived solely from the earlier, less secure data. We therefore confined attention to men from the nine English and Welsh collieries where dust measurements continued after the third surveys.

The exposures available for each man were examined for continuity. It was assumed that a man's last recorded exposure corresponded to the period in which he was last exposed to mine dust, up to around the end of 1978. A man was omitted if any exposure for an earlier period was missing or unreliable. The number of men in the overall risk-set was 9 504.

3.11.2 Method

Men were stratified into 10-year age-groups as at the first survey. Cumulative totals of each man's recorded exposures to mixed dust and to quartz were calculated. The total quartz exposure was expressed as a percentage of the mixed dust exposure, and the men were divided into three roughly equal groups according to the value of % quartz.

It was decided to model the dust exposure variable as increasing with exposed time. Since no information was available on the rates of accumulation of exposures during the inter-survey periods, cumulative exposures at different time points were estimated by linear interpolation between the survey dates (or up to the date of death, if a man died in an inter-survey period for which an exposure was recorded for him). Taking the first survey as the time origin, each man was classified into a range of cumulative dust exposure separately in each yearly interval in which he was alive. The follow-up period was taken as 22 years.

The numbers of deaths from selected causes, and the total times at risk, were accumulated into the cells of a table cross-classified by interval, age, cumulative dust exposure and % quartz. This Table was used as input to a GENSTAT program to perform analyses under Holford's approximation to Cox's proportional hazards model. Summary Tables of estimated survivor function were produced as described in section A6 of the Appendix.

It should be noted that in Tables 15.1 to 15.5, the initial risk-sets are categorised by the cumulative dust exposures at the time of the first survey. Since exposures were recalculated in each interval, a man may have contributed time at risk in later intervals to higher exposure categories than that in which he entered the follow-up period. The relationships between the quantities presented within each cell of these Tables are therefore somewhat different from those in other Tables of estimated survival in earlier sections of this report.

3.11.3 All internal causes (Table 15.1)

For this smaller risk-set no association is apparent between survival and cumulative dust exposure (cf Table 11.1), and there is no consistent trend of survival with increasing % quartz. Formal analysis of the data summarised in this Table for the age-groups 35-64 confirmed the absence of any significant dust effect, but suggested that differences between the % quartz categories were significant at better than the 2.5% level. Examination of the fitted parameters of the model suggested best survival for the middle quartz group (3.7-5.3%), followed by the highest and then the lowest group; the relative risks, taking the middle quartz group as 1, were 1.18 and 1.10 for the low and high quartz groups respectively.

3.11.4 Cancers of the digestive system (Table 15.2)

Formal analysis of the age-groups 35-64 yielded a test statistic for the difference between dust exposure categories which lay between the theoretical 15% and 10% significance points. The risk for the highest exposure group was estimated as 1.64 times that of the lowest group, and this is consistent with pattern in Table 12 (see section 3.9.3). However, no significant association was found between survival and % quartz.

3.11.5 Bronchitis and emphysema (Table 15.3)

The results of the formal analysis for this cause-group showed no clear association of mortality with increasing exposure to dust, but suggested a differing relationship within each age-group from 35-64: the apparent interaction between the effects of age and dust was significant at better than the 10% level. The test for the differences between the % quartz categories also exceeded the 10% level, and the estimates of relative risk showed a similar pattern to those for mortality from all internal causes.

3.11.6 <u>Pneumoconiosis</u> (Table 15.4)

Iterative computations based on the age-groups 35-64 showed poor convergence. The analysis was repeated omitting age-group 35-44, where there were few deaths. In the remaining two groups there was a highly significant association of decreased survival with increasing cumulative exposure to dust. The relative risks for the middle and high exposure groups were estimated as 8.9 and 16.8 times the lowest groups respectively. Differences between the quartz categories were highly significant; estimates of the relative risk for the middle and high % quartz categories relative to the low category were 0.59 and 0.44 respectively.

3.11.7 <u>Other respiratory diseases</u> (Table 15.5)

The formal analysis showed no significant association between mortality from this group of causes and either cumulative exposure to dust or % quartz.

3.11.8 <u>Comments</u>

The apparent associations between % quartz and mortality from all internal causes, bronchitis and emphysema, and pneumoconiosis are not clear cut. For reasons explained below, it is considered unlikely that these effects are due directly to the contribution of quartz to exposure to respirable mine dusts.

Table 16.1 shows the contribution of each colliery to the initial risk-set for each of the quartz groupings, with the collieries roughly ordered by increasing % quartz. It is apparent that there are similarities between collieries from the same regions, and that the groupings according to % quartz strongly reflect these regional similarities.

Given such a clear inter-regional difference between the distributions of % quartz, it is not possible to separate in these analyses effects due to % quartz differences and regional differences. Indeed, the numerical patterns which presented themselves as associations between mortality and % quartz are sufficiently unlikely for the hypothesis that they are due to some other regionally-distributed factor to be preferred.

Table 16.2 shows that regionally associated effects of this kind are unlikely to have distorted the analyses with respect to mixed dust exposure. Certainly there are differences between collieries in the maximum dust exposure accumulated by each man prior to death or end of follow-up. But the Table does not display the same sort of regional agreement as Table 13.1, and there is a much greater degree of overlap between the collieries in the distributions of dust exposures.

4. DISCUSSION

Each member of the study-group is at risk, while on study, from a multitude of causes, but will die (and provide an uncensored survival time) from at most one cause. Data on less common causes of death are therefore relatively sparse; and this is accentuated when the study-group is split up to allow for, or to investigate, differences in cause-specific mortality experience between the sub-groups. The standard errors quoted for the survivor function estimates in the Tables of results reflect in part the low frequencies of deaths from particular causes.

Some of the computer programs that were required for the more complex modelling described in the Appendix became operational only after the main analyses were well advanced. For this reason it has not yet been possible to perform formal tests of significance on all the trends identified in the Tables. However, the standard errors quoted for the estimated survival probabilities provide quantitative guidance regarding the plausibility of apparent patterns.

Miners with the earliest signs of progressive massive fibrosis at the start of the study (category A) had unambiguously higher mortality over 22 years than their colleagues with no PMF. This is not a surprising result in view of the well established high fatality rate for men with category B or C (COCHRANE, 1973) and the progressive nature of the disease. Special attention has to be drawn to the finding nevertheless, because earlier studies of British coalminers (JACOBSEN, 1976 and COCHRANE et al, 1979), over shorter periods, have failed to show clear-cut evidence of increased mortality for men with 'A' shadows.

An important new finding from this study is the consistent pattern of lower survival rates for men with category 1 simple pneumoconiosis initially, compared with those whose radiographs were classified as category 0. The trend is not maintained in all age-groups for men with categories 2 and 3, and this may be connected with likely progression of radiological signs from category 1 during the follow-up period, as noted in section 3.6.9. We intend to study this suggestion in the future using more complex methods of analysis.

In the earlier phase of this study, JACOBSEN (1976) reported that survival rates among miners who had developed simple pneumoconiosis before reaching 35 years of age were significantly lower than for those with no pneumoconiosis. It was noted then that an independent survey in South Wales (COCHRANE,1973) had also reported slightly lower survival rates for miners less than 35 years with category 2 or 3 simple pneumoconiosis. Moreover, an even more marked contrast in the same direction was evident in the Welsh survey data for the 35 to 44 age-group.

COCHRANE and his colleagues (1979) described the latter result as an "oddity" in their data, and argued that it could not be interpreted as meaning that "the younger a man in whom pneumoconiosis appears, the worse the prognosis"; their justification was, apparently, that the contrast was considerably less marked in their 25 to 34 age-group. Our interim appraisal of results from the present study* suggested that they were consistent with the hypothesis that miners who develop simple pneumoconiosis at a young age include a disproportionately high number who are particularly susceptible to respiratory disease. On examination of the more detailed evidence now available, it is necessary to qualify this conjecture. Amongst the men with simple pneumoconiosis in the age-group 25 to 34 there were 21 deaths in 22 years of follow-up. In categories 2 and 3 only one death was attributed to pneumoconiosis, while four were from ischaemic heart disease and one from rheumatic endocarditis. The remaining 15 deaths in category 1 men were from a mixture of causes, including three from lung cancer, three from cardiovascular disease and four from respiratory diseases (including two from pneumoconiosis).

There is therefore no evidence from these data of excess respiratory deaths among those with simple pneumoconiosis at an early age, but there remains relatively high mortality from all internal causes for young men with simple pneumoconiosis initially. The pooled survival estimate over 22 years for those with categories 1, 2 and 3 in the 25-34 year age-group is 90.1% (se 2.04%), as compared with 93.8% for those with category 0 (Table 9.1). The difference is statistically significant ($0.04 < P < 0.05$), and the results suggest that the mortality risk for those with simple pneumoconiosis in this age-group was about 60% higher than that experienced by the young men with no radiological signs initially.

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* MILLER and JACOBSEN (1980); unpublished paper presented to a meeting of the Working Parties on Chronic Respiratory Diseases and Industrial Medical Services - Coal and Steel: Luxembourg, 3 to 5 November 1980.

Our analysis of the importance of dust exposure before start of follow-up is broadly consistent with earlier observations from this study, which were based on a smaller sample of miners from the same collieries and shorter (14 to 18 year) follow-up periods (JACOBSEN, 1976). The previously reported relationship between increasing exposure to respirable dust and deaths attributed to bronchitis and allied respiratory disease is again evident. The trend, and a similar pattern for deaths certified as due to pneumoconiosis, are now reflected in a fairly unambiguous trend in general mortality (all non-violent causes) with increases in our estimates of exposures that occurred before the field research began, that is, in the 1950s and earlier.

There remains also a suggestion of reduced lung cancer mortality in simple pneumoconiotics, but the evidence is not strong. The absence of any observed relationship between lung cancer mortality and estimates of exposure to respirable mine dust is also consistent with the earlier observations (JACOBSEN, 1976).

The earlier work on part of these data indicated increasing mortality attributed to cancers of the digestive system with increasing exposure to dust among men with no radiological signs at the start of follow-up. Such a trend is again apparent from the extended study, but it is not possible without further analysis to separate associations with dust exposure from associations with the resultant pneumoconiosis.

A recent review of international trends in lung and stomach cancer statistics (MEYER et al, 1980) postulates that an inverse relationship between the occurrence of these malignancies may be connected with factors influencing pulmonary clearance mechanisms. The observations from our study of coalminers' mortality appear to be broadly consistent with the suggestion, although further analysis would be required in order to explore the hypothesis in greater detail.

Analyses relating mortality to the contribution of quartz in the composition of respirable dust have proved inconclusive, but another question has arisen from the results. Although a trend was observed of increasing mortality attributed to bronchitis and emphysema with increasing estimated exposure to dust prior to first survey, the reanalysis of 3.11 failed to show a similar effect when the exposure variable was modelled as increasing over the follow-up period. The apparent conflict of results may be due to the smaller sample size in the later, more complex, analysis exacerbating the problems caused by grouping. However, the suggested existence of an interaction between age and dust may be indicative of a qualitative difference between the estimates of exposure before the first survey and those based on actual measurement during the PFR; older men will in general have a greater proportion of their dust exposure estimates calculated from their past employment histories.

Given the correlations between age and exposure estimates, and the relationship between the inter-survey dust concentrations and those assumed relevant to the past histories, it would seem that any further investigation of the role of dust in mortality attributed to bronchitis and emphysema, or to any other cause, can only be accomplished by careful modelling under the formulation of Cox's proportional hazards model with continuous covariates. This approach is attractive for another reason. The analysis of mortality in terms of % quartz recognises that equal masses of dust from different sources, and with different mineral compositions may not present equal hazards to miners. So far, we have explored this possibility only in a limited way. Further analyses, which would involve fitting of individual regression coefficients to continuous covariates may be helpful for the investigation of quantitative relationships between mortality and dust, and variations in these relationships between collieries. Development and adaptation of computer software to perform the calculations required for such analyses as efficiently as possible has received much attention in recent years, and programs for the purpose are now becoming available (e.g. THOMAS, 1980).

The NCB's Pneumoconiosis Field Research has produced extensive data on men working in a selection of British coalmines over a period of time. The addition of cause-specific mortality data to the radiological, medical, anthropometric and occupational dust exposure data already held opens the way for continuing more detailed studies of questions on miners' mortality. In particular, it is hoped that further analyses will shed light on any relationship between pneumoconiosis and heart disease; on quantitative relationships between deaths from bronchitis and emphysema and exposure to respirable dust; on evidence linking stomach cancer to pulmonary clearance; and on a more detailed distinction between the identification of variables useful as long-term prognostic indicators and the investigation of time-dependent factors.

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The work would not have been possible without the co-operation of the staff of the Records Branch of the Department of Health and Social Security, Newcastle; the Southport and Titchfield centres of the Office of Population Censuses and Surveys; the Scottish General Register Office, Edinburgh; and the Compensation Branch of the National Union of Mineworkers.

TABLE 1: **Definitions of groups of causes of death**

Cause Group No.	Name used in this report	ICD Three-digit Codes: 6th and 7th revisions	ICD Three-digit Codes: 8th revision	No. of Deaths (as known at 1.8.80)	Total
1.	Lung Cancer	162, 163	162	853	
2.	Stomach Cancer	151	151	382	
3.	Cancers of the Digestive Organs (excluding stomach)	150; (152...159)	150; (152...159)	432	
4.	Other Cancers	(140...205) - (150...159) -(162,163)	(140...209) - 162 -(150...159)	529	
5.	Bronchitis and Emphysema	(500...502)	(490...492)	947	
6.	Pneumoconiosis	001, 523, 524	010, 515, 516	398	
7.	Other Respiratory Diseases	(470...527) + 241 -(500...502) - (523,524)	(460...519) - (490...492) -(515,516)	552	
8.	Ischaemic Heart Disease	420, 422	(410...414)	3195	
9.	Other Cardiovascular Diseases	(400...468) - 420 - 422	(390...458) - (410...414)	1768	
11.	Other Internal Causes	(All internal causes) - (Cause groups 1...9)		640	
	All Internal Causes	(001...799)	(000...799)		9696
10.	All External Causes	(800...999)	(800...999)	406	
	All Causes	(001...999)	(000...999)		10102

TABLE 2: Follow-up status of the study group at 1.8.80

Tracing Status	Scotland	England & Wales	Total
Alive	3 204	16 247	19 451
Dead	1 613	8 489	10 102
Total Traced	4 817	24 736	29 553
Believed deceased, no details	4	6	10
*Embarked	-	250	250
Untraced	348	963	1 311
Outstanding	79	408	487
Total Not Traced	431	1 627	2 058
Total	5 248	26 363	31 611

* i.e., left the United Kingdom.

TABLE 3: Deaths confirmed at 1.8.80 by colliery and calendar year

REGION	COLLIERY	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
SCOTLAND	J	0	0	8	3	9	7	10	10	13	10	10
	O	0	3	13	7	12	14	11	24	11	28	25
	P	0	10	5	9	12	12	9	17	12	25	13
	S	0	4	7	2	4	8	10	8	8	12	19
NORTHERN	D	0	0	2	9	11	6	5	6	8	5	10
	M	0	1	9	5	9	12	14	12	9	8	11
	T	0	0	4	10	10	12	15	14	14	16	19
	Y	0	0	8	13	14	11	8	4	12	6	16
	Z	0	0	0	5	9	7	9	3	8	8	15
E & W RIDINGS	G	0	0	6	5	7	3	8	4	14	9	6
	K	0	0	0	0	7	4	11	8	11	9	12
	X	0	0	1	9	7	11	4	14	9	8	14
N. WESTERN	A	0	0	0	2	3	1	6	2	3	5	6
N. MIDLANDS	Q	0	1	3	3	6	4	8	6	5	3	8
MIDLANDS	C	0	0	6	8	12	15	22	10	14	13	17
	N	0	0	0	0	0	4	9	6	9	7	4
S. EASTERN	B	0	0	1	6	7	3	8	4	6	7	4
N. WALES	L	0	0	3	18	7	6	13	17	8	11	9
S. WALES	E	0	0	5	5	4	12	10	6	5	9	14
	F	0	0	0	4	7	8	8	8	11	9	8
	H	0	0	0	2	2	3	4	9	2	7	6
	I	0	3	9	9	5	3	7	6	4	6	5
	V	0	2	5	10	8	12	13	11	21	16	18
	W	0	0	1	2	5	5	3	4	3	6	8

TABLE 3: (continued)

REGION	COLLIERY	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
SCOTLAND	J	10	18	13	9	14	17	27	14	15	16	10
	O	22	20	19	26	31	27	31	41	22	10	17
	P	22	18	15	24	16	18	19	18	26	20	18
	S	11	7	14	10	18	20	14	13	14	9	15
NORTHERN	D	21	20	8	12	14	12	12	18	24	18	13
	M	19	12	17	16	17	27	21	20	28	22	29
	T	17	27	34	26	20	37	24	40	34	40	38
	Y	16	30	18	20	36	22	24	26	31	35	26
	Z	16	26	17	21	31	37	25	22	29	30	36
E & W RIDINGS	G	16	8	17	25	21	21	21	25	26	24	36
	K	17	12	26	22	24	24	17	31	22	27	28
	X	21	19	20	22	33	23	24	22	26	33	36
N. WESTERN	A	10	5	6	6	6	7	9	6	6	6	12
N. MIDLANDS	Q	12	10	13	17	12	17	22	23	17	16	19
MIDLANDS	C	18	28	27	19	31	28	43	45	37	37	42
	N	6	15	9	7	17	23	14	16	20	27	23
S. EASTERN	B	9	16	21	15	18	20	20	17	25	28	22
N. WALES	L	14	16	25	22	22	20	22	23	26	30	24
S. WALES	E	12	10	10	10	15	18	19	20	24	14	14
	F	14	17	12	19	21	24	15	19	26	20	20
	H	7	10	12	18	15	20	14	18	16	15	10
	I	6	8	8	16	10	7	13	8	15	11	14
	V	18	24	31	20	22	32	16	25	29	32	25
	W	10	10	14	6	3	12	9	11	21	15	12

TABLE 3: (continued)

REGION	COLLIERY	1975	1976	1977	1978	1979	1980	TOTAL
SCOTLAND	J	16	18	18	19	24	10	348
	O	15	17	27	26	21	7	527
	P	17	17	13	27	21	6	439
	S	15	13	9	18	13	4	299
NORTHERN	D	14	17	17	22	13	4	321
	M	27	32	24	25	31	8	465
	T	42	31	38	39	41	20	662
	Y	43	28	35	49	25	10	566
	Z	22	36	29	32	32	7	512
E & W RIDINGS	G	35	26	35	33	25	11	467
	K	25	37	26	36	33	10	479
	X	36	30	17	35	37	8	519
N. WESTERN	A	8	10	17	13	13	6	174
N. MIDLANDS	Q	19	33	16	27	22	6	348
MIDLANDS	C	48	50	37	41	42	10	700
	N	18	27	19	27	20	11	338
S. EASTERN	B	23	36	34	21	22	8	401
N. WALES	L	14	29	28	31	33	7	478
S. WALES	E	19	14	16	15	11	5	316
	F	34	22	28	32	32	7	425
	H	16	19	17	21	20	5	288
	I	12	15	9	16	13	3	241
	V	29	23	38	27	33	6	546
	W	8	20	19	17	14	5	243

TABLE 4: Deaths up to 22 years from first survey by cause-group and colliery

REGION	COLLIERY	CAUSE GROUP 1 Lung Cancer	2 Stomach Cancer	3 Cancers - Digestive Organs	4 Other Cancers	5 Bronchitis and Emphysema	6 Pneumo-coniosis	7 Other Respiratory Diseases	8 Ischaemic Heart Disease	9 Other CVD	11 Other Internal	TOTAL
NORTHERN	D	45 17.3	11 4.2	14 5.4	19 7.3	26 10.0	1 0.4	6 2.3	80 30.8	39 15.0	19 7.3	260
	M	29 8.3	14 4.0	18 5.2	21 6.0	26 7.5	4 1.2	34 9.8	113 32.5	61 17.5	28 8.0	348
	T	43 8.3	23 4.5	23 4.5	29 5.6	55 10.7	35 6.8	28 5.4	148 28.7	98 19.0	34 6.6	516
	Y	36 8.8	17 4.1	17 4.1	16 3.9	56 13.6	15 3.6	23 5.6	143 34.8	63 15.3	25 6.1	411
	Z	39 9.2	18 4.2	9 2.1	27 6.4	42 9.9	1 0.2	25 5.9	144 34.0	84 19.8	35 8.2	424
E&W RIDINGS	G	28 8.4	13 3.9	19 5.7	20 6.0	31 9.2	6 1.8	17 5.1	110 32.8	66 19.7	25 7.5	335
	K	35 9.0	15 3.8	31 8.0	17 4.4	36 9.2	9 2.3	32 8.2	122 31.3	69 17.7	24 6.2	390
	X	38 9.0	16 3.8	22 5.2	21 5.0	52 12.4	19 4.5	24 5.7	129 30.7	69 16.4	30 7.1	420
N. WESTERN	A	20 15.0	3 2.3	9 6.8	10 7.5	13 9.8	13 9.8	6 4.5	43 32.3	11 8.3	5 3.8	133
N. MIDLANDS	Q	20 8.2	9 3.7	12 4.9	16 6.5	28 11.4	1 0.4	17 6.9	66 26.9	58 23.7	18 7.4	245
MIDLANDS	C	38 6.8	29 5.2	24 4.3	36 6.4	54 9.6	23 4.1	34 6.1	162 28.9	114 20.4	46 8.2	560
	N	35 10.8	14 4.3	16 4.9	24 7.4	27 8.3	12 3.7	22 6.8	104 32.0	52 16.0	19 5.8	325
S. EASTERN	B	40 12.9	10 3.2	20 6.4	23 7.4	30 9.6	6 1.9	11 3.5	96 30.9	60 19.3	15 4.8	311
N. WALES	L	27 7.3	19 5.1	16 4.3	18 4.8	53 14.2	5 1.3	26 7.0	114 30.6	79 21.2	15 4.0	372
S. WALES	E	10 4.2	10 4.2	10 4.2	11 4.6	31 13.0	21 8.8	10 4.2	63 26.4	57 23.8	16 6.7	239
	F	14 4.1	11 3.2	16 4.6	16 4.6	45 13.0	27 7.8	16 4.6	123 35.6	61 17.7	16 4.6	345
	H	11 4.6	7 2.9	4 1.7	8 3.3	30 12.5	4 1.7	11 4.6	91 37.9	58 24.2	16 6.7	240
	I	10 5.5	8 4.4	2 1.1	13 7.1	25 13.7	11 6.0	12 6.6	56 30.6	32 17.5	14 7.6	183
	V	26 6.5	21 5.2	20 5.0	21 5.2	52 13.0	21 5.2	14 3.5	126 31.5	74 18.5	25 6.2	400
	W	6 3.0	6 3.0	16 8.1	10 5.1	11 5.6	14 7.1	6 3.0	89 45.2	33 16.8	6 3.0	197
TOTAL		550 8.3	274 4.1	318 4.8	376 5.6	723 10.9	248 3.7	374 5.6	2122 31.9	1238 18.6	431 6.5	6654 100.0

Key: No. of deaths / % of row total

TABLE 5: Deaths up to 22 years from first survey by age and cause-group

AGE AT FIRST SURVEY	CAUSE-GROUP 1 Lung Cancer	 2 Stomach Cancer	 3 Cancers - Digestive Organs	 4 Other Cancers	 5 Bronchitis and Emphysema	 6 Pneumo-coniosis	 7 Other Respiratory Diseases	 8 Ischaemic Heart Disease	 9 Other CVD	 11 Other Internal	TOTAL
< 25	2 3.4	3 5.1	1 1.7	7 11.9	1 1.7	0 0.0	2 3.4	18 30.5	9 15.2	16 27.1	59
25 - 34	31 9.2	15 4.5	27 8.1	17 5.1	12 3.6	5 1.5	9 2.7	146 43.6	41 12.2	32 9.6	335
35 - 44	108 10.8	45 4.5	51 5.1	76 7.6	76 7.6	25 2.5	40 4.0	389 38.8	125 12.5	68 6.8	1003
45 - 54	219 9.1	112 4.7	108 4.5	146 6.1	267 11.1	96 4.0	133 5.6	774 32.3	429 17.9	113 4.7	2397
55 - 64	166 6.9	81 3.4	106 4.4	108 4.5	321 13.3	107 4.4	157 6.5	697 28.9	498 20.6	171 7.1	2412
65+	24 5.4	18 4.0	25 5.6	22 4.9	46 10.3	15 3.4	33 7.4	98 21.9	136 30.4	31 6.9	448
TOTAL	550 8.3	274 4.1	318 4.8	376 5.6	723 10.9	248 3.7	374 5.6	2122 31.9	1238 18.6	431 6.5	6654

Key: No. of deaths / % of row total

TABLE 6: Regionally standardised mortality ratios by colliery

REGION	COLLIERY	NO. TRACED	1953-72 NO. OF DEATHS	1953-72 SMR %	1973-79 NO. OF DEATHS	1973-79 SMR %	1953-79 NO. OF DEATHS	1953-79 SMR %
SCOTLAND	J	1193	217	82	121	74	338	79
	O	1368	387	105	133	70	520	93
	P	1432	300	79	133	68	433	75
	S	824	203	90	92	83	295	88
NORTHERN	D	855	203	98	114	92	317	96
	M	1398	267	86	190	99	457	91
	T	1668	373	85	269	102	642	91
	Y	1660	315	82	241	95	556	87
	Z	1589	288	75	217	90	505	81
E & W RIDINGS	G	1544	242	62	214	95	456	74
	K	1487	257	77	212	102	469	86
	X	1509	287	80	224	109	511	91
N. WESTERN	A	734	89	92	79	109	168	99
N. MIDLANDS	Q	1268	190	78	152	96	342	85
MIDLANDS	C	1795	393	69	297	91	690	77
	N	1109	166	74	161	102	327	85
S. EASTERN	B	1271	207	77	186	116	393	92
N. WALES	L	1181	282	90	189	108	471	97
S. WALES	E	698	208	93	103	99	311	95
	F	1090	230	77	188	112	418	89
	H	808	165	77	118	91	283	82
	I	664	148	86	90	89	238	87
	V	1669	333	79	207	87	540	82
	W	739	133	85	105	107	238	94

TABLE 7.1: Survival estimates at 22 years by colliery: all internal causes

NORTHERN	Age < 25 yrs	25 - 34 yrs	35 - 44 yrs	45 - 54 yrs	55 - 64 yrs	65 + yrs
D	167 98.8 2 0.86	139 96.4 5 1.58	179 78.5 38 3.09	226 54.4 102 3.33	122 21.5 95 3.74	22 17.7 18 8.25
M	356 98.6 5 0.63	274 91.8 22 1.68	286 77.5 64 2.48	321 58.2 133 2.77	139 23.4 108 3.62	22 10.3 19 6.83
T	239 97.9 5 0.94	293 93.2 20 1.48	420 83.3 70 1.82	425 53.4 197 2.43	274 22.7 210 2.55	17 17.6 14 9.25
Y	290 98.3 5 0.77	346 93.9 21 1.30	455 77.5 101 1.97	378 59.9 150 2.54	189 28.8 132 3.33	2 - 2 -
Z	236 98.3 4 0.84	348 94.8 18 1.20	394 85.0 59 1.80	353 58.0 147 2.64	226 23.9 168 2.89	32 9.9 28 5.43
E & W RIDINGS						
G	238 98.7 3 0.73	440 95.0 22 1.05	363 85.6 52 1.84	293 61.2 112 2.87	173 32.6 114 3.62	37 13.5 32 5.62
K	242 98.8 3 0.71	336 93.4 22 1.35	358 82.5 62 2.02	315 59.0 127 2.79	201 25.3 148 3.10	35 15.2 28 6.25
X	303 99.7 1 0.34	338 95.5 15 1.13	264 83.6 43 2.28	338 49.6 168 2.74	235 27.3 168 2.93	31 19.4 25 7.10
N. WESTERN						
A	248 99.2 2 0.57	183 91.1 16 2.13	143 83.0 24 3.16	106 51.0 51 4.90	51 27.4 37 6.25	3 - 3 -
N. MIDLANDS						
Q	282 98.6 4 0.71	327 95.4 15 1.17	289 84.7 44 2.12	243 64.1 87 3.08	114 25.6 83 4.15	13 7.7 12 7.39
MIDLANDS						
C	236 99.2 2 0.60	297 94.9 15 1.28	348 82.6 60 2.04	508 61.7 192 2.17	330 31.8 222 2.58	76 5.7 69 2.74
N	187 97.8 4 1.07	189 93.0 13 1.86	242 79.7 49 2.59	310 59.5 125 2.80	162 27.8 116 3.54	19 5.3 18 5.12
S. EASTERN						
B	212 100.0 0 0.00	292 94.5 16 1.34	313 81.5 57 2.21	297 57.8 123 2.90	133 29.1 93 3.97	24 8.3 22 5.64
N. WALES						
L	211 98.1 4 0.95	195 91.2 17 2.03	232 86.2 32 2.27	294 59.7 117 2.88	214 19.9 169 2.77	35 5.7 33 3.92
S. WALES						
E	63 98.4 1 1.60	165 90.8 15 2.27	157 78.3 34 3.29	181 51.8 86 3.75	114 22.6 86 3.97	18 5.6 17 5.40
F	143 98.6 2 0.99	230 92.1 18 1.78	252 79.6 51 2.55	257 52.1 123 3.12	164 30.4 111 3.66	44 9.1 40 4.33
H	120 98.3 2 1.18	129 90.7 12 2.56	209 84.6 32 2.51	189 61.3 73 3.55	144 26.1 105 3.68	17 5.9 16 5.71
I	103 97.1 3 1.66	145 91.7 12 2.29	169 82.1 30 2.97	146 58.4 60 4.11	91 23.1 70 4.42	10 11.7 8 10.92
V	297 98.3 5 0.75	374 93.5 24 1.28	438 84.6 67 1.73	355 58.6 145 2.63	165 25.6 122 3.41	40 5.2 37 3.57
W	98 98.0 2 1.43	195 91.2 17 2.03	200 82.9 34 2.67	166 52.2 79 3.89	73 20.4 58 4.73	7 - 7 -

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 7.2: Survival estimates at 22 years by colliery: lung cancer

NORTHERN	Age < 25 yrs.	25 - 34 yrs.	35 - 44 yrs.	45 - 54 yrs.	55 - 64 yrs.	65 + yrs.
D	167 99.4 1 0.61	139 98.5 2 1.02	179 94.3 9 1.86	226 87.9 21 2.51	122 86.8 11 3.85	22 95.1 1 4.76
M	356 100.0 0 0.00	274 99.6 1 0.39	286 98.4 4 0.81	321 94.6 14 1.40	139 86.6 9 4.57	22 90.9 1 8.67
T	239 100.0 0 0.00	293 99.0 3 0.60	420 97.1 11 0.86	425 95.3 15 1.21	274 91.0 13 2.74	17 94.1 1 5.71
Y	290 100.0 0 0.00	346 99.7 1 0.29	455 97.7 9 0.76	378 94.3 17 1.36	189 92.5 9 2.58	2 - 0 -
Z	236 100.0 0 0.00	348 99.1 3 0.51	394 98.3 6 0.68	353 94.9 14 1.35	226 88.8 15 2.92	32 95.7 1 4.16
E & W RIDINGS						
G	238 99.6 1 0.42	440 99.3 3 0.41	363 98.5 5 0.65	293 95.8 10 1.29	173 94.0 8 2.09	37 94.6 1 5.26
K	242 100.0 0 0.00	336 98.5 5 0.68	358 97.8 7 0.82	315 95.9 10 1.28	201 92.1 11 2.59	35 85.9 2 9.31
X	303 100.0 0 0.00	338 99.4 2 0.43	264 97.6 6 0.99	338 91.9 20 1.76	235 97.7 4 1.15	31 69.0 6 11.63
N. WESTERN						
A	248 100.0 0 0.00	183 98.3 3 0.96	143 97.7 3 1.32	106 89.1 8 3.71	51 84.9 5 6.40	3 - 1 -
N. MIDLANDS						
Q	282 100.0 0 0.00	327 99.4 2 0.45	289 98.2 5 0.81	243 96.5 7 1.31	114 90.5 6 3.82	13 100.0 0 0.00
MIDLANDS						
C	236 100.0 0 0.00	297 99.0 3 0.60	348 97.4 8 0.89	508 96.5 13 0.97	330 93.8 12 1.82	76 96.2 2 2.72
N	187 100.0 0 0.00	189 99.4 1 0.56	242 98.1 4 0.93	310 93.7 16 1.54	162 89.6 12 2.97	19 89.2 2 7.24
S. EASTERN						
B	212 100.0 0 0.00	292 99.6 1 0.36	313 96.9 9 1.03	297 93.3 16 1.64	133 87.6 13 3.46	24 75.0 1 21.65
N. WALES						
L	211 100.0 0 0.00	195 100.0 0 0.00	232 98.2 4 0.91	294 95.6 10 1.36	214 90.7 11 3.11	35 90.1 2 7.21
S. WALES						
E	63 100.0 0 0.00	165 99.4 1 0.63	157 97.9 3 1.19	181 98.6 2 0.95	114 94.4 3 3.33	18 93.9 1 5.87
F	143 100.0 0 0.00	230 100.0 0 0.00	252 98.6 3 0.80	257 97.4 5 1.14	164 96.0 5 1.81	44 97.6 1 2.41
H	120 100.0 0 0.00	129 100.0 0 0.00	209 99.5 1 0.52	189 98.8 2 0.86	144 89.2 8 3.85	17 100.0 0 0.00
I	103 100.0 0 0.00	145 100.0 0 0.00	169 100.0 0 0.00	146 95.9 5 1.83	91 90.6 5 4.79	10 100.0 0 0.00
V	297 100.0 0 0.00	374 100.0 0 0.00	438 97.5 10 0.78	355 96.0 11 1.21	165 96.8 4 1.67	40 95.2 1 4.65
W	98 100.0 0 0.00	195 100.0 0 0.00	200 99.5 1 0.53	166 97.5 3 1.43	73 96.2 2 2.67	7 - 0 -

Other causes of death are treated as censored.

Key:

initial risk set	survival %
no. of deaths	s.e. %

TABLE 7.3: Survival estimates at 22 years by colliery: pneumoconiosis

NORTHERN	Age < 25 yrs	25 - 34 yrs	35 - 44 yrs	45 - 54 yrs	55 - 64 yrs	65 + yrs
D	167 100.0 0 0.00	139 100.0 0 0.00	179 100.0 0 0.00	226 100.0 0 0.00	122 98.8 1 1.15	22 100.0 0 0.00
M	356 100.0 0 0.00	274 100.0 0 0.00	286 100.0 0 0.00	321 98.8 3 0.68	139 98.9 1 1.10	22 100.0 0 0.00
T	239 100.0 0 0.00	293 99.7 1 0.34	420 99.8 1 0.24	425 96.0 14 1.06	274 89.4 18 2.62	17 92.6 1 7.13
Y	290 100.0 0 0.00	346 100.0 0 0.00	455 99.8 1 0.23	378 98.2 5 0.81	189 92.3 8 2.69	2 - 0 -
Z	236 100.0 0 0.00	348 100.0 0 0.00	394 100.0 0 0.00	353 100.0 0 0.00	226 99.4 1 0.62	32 100.0 0 0.00
E & W RIDINGS						
G	238 100.0 0 0.00	440 100.0 0 0.00	363 100.0 0 0.00	293 100.0 0 0.00	173 95.8 6 1.70	37 100.0 0 0.00
K	242 100.0 0 0.00	336 100.0 0 0.00	358 99.4 2 0.42	315 98.1 4 0.93	201 98.2 3 1.02	35 100.0 0 0.00
X	303 100.0 0 0.00	338 100.0 0 0.00	264 99.1 2 0.62	338 96.6 9 1.12	235 95.4 6 2.00	31 87.1 2 9.10
N. WESTERN						
A	248 100.0 0 0.00	183 99.4 1 0.60	143 99.2 1 0.82	106 96.7 3 1.89	51 73.1 8 8.88	3 - 0 -
N. MIDLANDS						
Q	282 100.0 0 0.00	327 100.0 0 0.00	289 100.0 0 0.00	243 100.0 0 0.00	114 98.8 1 1.17	13 100.0 0 0.00
MIDLANDS						
C	236 100.0 0 0.00	297 100.0 0 0.00	348 99.7 1 0.32	508 97.1 11 0.87	330 96.4 8 1.31	76 94.0 3 3.36
N	187 100.0 0 0.00	189 100.0 0 0.00	242 100.0 0 0.00	310 97.5 7 0.93	162 95.2 5 2.23	19 100.0 0 0.00
S. EASTERN						
B	212 100.0 0 0.00	292 100.0 0 0.00	313 100.0 0 0.00	297 99.1 2 0.62	133 95.6 4 2.21	24 100.0 0 0.00
N. WALES						
L	211 100.0 0 0.00	195 100.0 0 0.00	232 100.0 0 0.00	294 98.7 3 0.74	214 98.2 2 1.23	35 100.0 0 0.00
S. WALES						
E	63 100.0 0 0.00	165 98.7 2 0.91	157 98.7 2 0.94	181 94.9 7 1.90	114 88.1 7 4.56	18 72.4 3 13.91
F	143 100.0 0 0.00	230 100.0 0 0.00	252 98.7 3 0.74	257 95.2 10 1.50	164 87.3 11 3.88	44 91.2 3 5.02
H	120 100.0 0 0.00	129 100.0 0 0.00	209 99.5 1 0.52	189 100.0 0 0.00	144 97.0 2 2.11	17 86.7 1 12.41
I	103 100.0 0 0.00	145 99.3 1 0.71	169 98.1 3 1.09	146 97.0 3 1.72	91 93.2 4 3.48	10 100.0 0 0.00
V	287 100.0 0 0.00	374 100.0 0 0.00	438 99.0 4 0.50	355 95.5 12 1.27	165 95.00 4 2.70	40 93.1 1 6.65
W	98 100.0 0 0.00	195 100.0 0 0.00	200 97.8 4 1.08	166 97.6 3 1.39	73 83.4 7 6.66	7 - 0 -

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 7.4: Survival estimates at 22 years by colliery: bronchitis and emphysema

NORTHERN	Age < 25 yrs	25 - 34 yrs	35 - 44 yrs	45 - 54 yrs	55 - 64 yrs	65 + yrs
D	167 100.0 0 0.00	139 99.2 1 0.74	179 98.7 2 0.89	226 92.8 12 2.06	122 87.5 9 4.31	22 75.8 2 15.60
M	356 99.7 1 0.29	274 100.0 0 0.00	286 98.9 3 0.65	321 95.4 12 1.31	139 87.1 10 4.08	22 100.0 0 0.00
T	239 100.0 0 0.00	293 99.6 1 0.36	420 99.0 4 0.52	425 92.8 22 1.51	274 82.5 27 3.30	17 92.6 1 7.13
Y	290 100.0 0 0.00	346 99.7 1 0.31	455 96.6 14 0.90	378 93.7 20 1.38	189 80.2 21 4.08	2 - 0 -
Z	236 100.0 0 0.00	348 99.7 1 0.31	394 98.7 5 0.59	353 94.5 16 1.35	226 87.0 18 3.04	32 74.0 2 16.62
E & W RIDINGS						
G	238 100.0 0 0.00	440 100.0 0 0.00	363 99.4 2 0.43	293 93.6 16 1.57	173 87.8 12 3.44	37 96.4 1 3.57
K	242 100.0 0 0.00	336 100.0 0 0.00	358 99.4 2 0.45	315 95.1 12 1.39	201 87.0 17 3.10	35 66.2 5 14.41
X	303 100.0 0 0.00	338 100.0 0 0.00	264 98.0 5 0.88	338 94.8 14 1.37	235 78.0 29 3.81	31 64.3 4 14.92
N. WESTERN						
A	248 100.0 0 0.00	183 100.0 0 0.00	143 98.5 2 1.08	106 91.3 7 3.19	51 90.5 4 4.57	3 - 0 -
N. MIDLANDS						
Q	282 100.0 0 0.00	327 100.0 0 0.00	289 98.5 4 0.77	243 93.0 14 1.83	114 87.3 9 4.47	13 80.0 1 17.89
MIDLANDS						
C	236 100.0 0 0.00	297 100.0 0 0.00	348 98.4 5 0.71	508 94.9 21 1.09	330 88.7 23 2.27	76 65.2 5 14.58
N	187 100.0 0 0.00	189 100.0 0 0.00	242 97.6 5 1.05	310 97.1 7 1.10	162 87.0 12 3.82	19 60.6 3 21.67
S. EASTERN						
B	212 100.0 0 0.00	292 100.0 0 0.00	313 99.3 2 0.52	297 95.9 9 1.34	133 81.3 17 4.31	24 86.8 2 8.90
N. WALES						
L	211 100.0 0 0.00	195 98.9 2 0.76	232 98.6 3 0.79	294 93.2 16 1.66	214 77.4 25 4.35	35 32.1 7 17.59
S. WALES						
E	63 100.0 0 0.00	165 100.0 0 0.00	157 97.8 3 1.25	181 91.4 12 2.42	114 75.8 16 5.70	18 100.0 0 0.00
F	143 100.0 0 0.00	230 99.6 1 0.45	252 97.7 5 1.02	257 87.2 24 2.48	164 88.1 12 3.46	44 87.5 3 7.08
H	120 100.0 0 0.00	129 99.2 1 0.84	209 98.9 2 0.76	189 93.4 10 2.02	144 81.3 16 4.65	17 92.9 1 6.88
I	103 100.0 0 0.00	145 99.3 1 0.72	169 96.7 5 1.46	146 93.1 8 2.36	91 78.4 10 6.45	10 87.5 1 11.69
V	297 100.0 0 0.00	374 99.4 2 0.40	438 99.5 2 0.37	355 95.2 13 1.31	165 73.9 27 4.57	40 65.1 8 11.41
W	98 100.0 0 0.00	195 99.4 1 0.55	200 99.4 1 0.60	166 98.1 2 1.36	73 78.5 7 7.55	7 - 0 -

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 8: Distribution of study group by initial radiological status and colliery

REGION	COLLIERY	RADIOLOGICAL CATEGORY AT 1ST SURVEY							TOTAL
			Simple Pneumoconiosis			Progressive Massive Fibrosis			
		0	1	2	3	A	B	C	
NORTHERN	D	819 95.8	29 3.4	4 0.5	1 0.1	0 0.0	2 0.2	0 0.0	855
	M	1225 87.6	118 8.4	33 2.4	7 0.5	10 0.7	3 0.2	2 0.1	1398
	T	1354 81.2	155 9.3	84 5.0	12 0.7	39 2.3	16 1.0	8 0.5	1668
	Y	1310 78.9	173 10.4	93 5.6	23 1.4	43 2.6	14 0.8	4 0.2	1660
	Z	1536 96.7	47 3.0	3 0.2	0 0.0	3 0.2	0 0.0	0 0.0	1589
E & W RIDINGS	G	1457 94.4	59 3.8	15 1.0	3 0.2	6 0.4	4 0.3	0 0.0	1544
	K	1297 87.2	114 7.7	56 3.8	5 0.3	13 0.9	2 0.1	0 0.0	1487
	X	1332 88.3	106 7.0	40 2.6	5 0.3	14 0.9	9 0.6	3 0.2	1509
N. WESTERN	A	656 89.4	41 5.6	22 3.0	7 1.0	2 0.3	6 0.8	0 0.0	734
N. MIDLANDS	Q	1210 95.4	50 3.9	3 0.2	2 0.2	1 0.1	1 0.1	1 0.1	1268
MIDLANDS	C	1710 95.3	58 3.2	14 0.8	2 0.1	5 0.3	6 0.3	0 0.0	1795
	N	952 85.8	93 8.4	41 3.7	4 0.4	13 1.2	4 0.4	2 0.2	1109
S. EASTERN	B	1180 92.8	53 4.2	19 1.5	2 0.2	9 0.7	6 0.5	2 0.2	1271
N. WALES	L	987 83.6	101 8.6	55 4.7	10 0.8	19 1.6	7 0.6	2 0.2	1181
S. WALES	E	521 74.6	81 11.6	37 5.3	2 0.3	21 3.0	27 3.9	9 1.3	698
	F	774 71.0	135 12.4	69 6.3	11 1.0	54 5.0	38 3.5	9 0.8	1090
	H	686 84.9	65 8.0	23 2.8	1 0.1	20 2.5	11 1.4	2 0.2	808
	I	561 84.5	57 8.6	21 3.2	2 0.3	16 2.4	5 0.8	2 0.3	664
	V	1403 84.1	122 7.3	57 3.4	10 0.6	47 2.8	25 1.5	5 0.3	1669
	W	545 73.8	82 11.1	58 7.8	9 1.2	26 3.5	17 2.3	2 0.3	739
TOTAL		21515 87.0	1739 7.0	747 3.0	118 0.5	361 1.5	203 0.8	53 0.2	24736 100.0

Key:

No. of men
% of row total

TABLE 9.1: Survival estimates at 22 years by initial radiological category: all internal causes

AGE AT FIRST SURVEY	RADIOLOGICAL CATEGORY AT 1ST SURVEY													
			Simple Pneumoconiosis						Progressive Massive Fibrosis					
	0		1		2		3		A		B		C	
< 25	4267	98.6	3	100.0	0	-	0	-	0	-	1	100.0	0	-
	59	0.18	0	0.0	-	-	-	-	-	-	0	0.0	-	-
25 - 34	5009	93.8	160	90.6	48	91.7	5	60.0	10	80.0	3	33.3	0	-
	310	0.34	15	2.32	4	4.00	2	21.91	2	12.65	2	27.22	-	-
35 - 44	4905	82.8	457	80.9	199	80.4	28	96.3	93	72.0	23	73.9	6	33.3
	840	0.54	87	1.84	39	2.81	1	3.63	26	4.65	6	9.16	4	19.24
45 - 54	4502	58.2	615	56.6	304	60.4	47	55.3	133	51.9	82	36.6	18	11.1
	1860	0.74	264	2.01	120	2.81	21	7.25	64	4.33	52	5.32	16	7.41
55 - 64	2450	27.4	445	23.6	170	26.5	34	21.3	106	20.3	84	17.1	25	4.3
	1751	0.91	338	2.02	123	3.42	26	7.15	83	3.95	68	4.16	23	4.19
65+	382	10.9	59	6.8	26	4.2	4	-	19	5.3	10	-	4	-
	334	1.62	55	3.27	24	4.09	4	-	18	5.12	10	-	4	-

Other causes of death are treated as censored.

Key:

initial risk set	survival %
no. of deaths	s.e. %

TABLE 9.2: Survival estimates at 22 years by initial radiological category: lung cancer

AGE AT FIRST SURVEY	RADIOLOGICAL CATEGORY AT 1ST SURVEY													
			Simple Pneumoconiosis						Progressive Massive Fibrosis					
	0		1		2		3		A		B		C	
< 25	4267	99.9	3	100.0	0	-	0	-	0	-	1	100.0	0	-
	2	0.03	0	0.0	-	-	-	-	-	-	0	0.0	-	-
25 - 34	5009	99.4	160	98.1	48	100.0	5	100.0	10	100.0	3	100.0	0	-
	28	0.11	3	1.10	0	0.0	0	0.0	0	0.0	0	0.0	-	-
35 - 44	4905	97.7	457	99.2	199	98.9	28	100.0	93	100.0	23	100.0	6	100.0
	103	0.23	3	0.45	2	0.79	0	0.0	0	0.0	0	0.0	0	0.0
45 - 54	4502	95.0	615	95.5	304	96.1	47	92.2	133	94.7	82	94.7	18	80.2
	176	0.37	2	0.95	9	1.28	3	4.36	5	2.35	2	3.67	2	12.79
55 - 64	2450	92.1	445	88.0	170	97.3	34	100.0	106	93.2	84	93.7	25	100.0
	118	0.75	36	2.04	4	1.35	0	0.0	4	3.40	4	3.28	0	0.0
65+	382	89.3	59	100.0	26	95.4	4	-	19	100.0	10	-	4	-
	23	2.43	0	0.0	1	4.54	0	-	0	0.0	0	-	0	-

Other causes of death are treated as censored.

Key:

initial risk set	survival %
no. of deaths	s.e. %

TABLE 9.2: Survival estimates at 22 years by initial radiological category: stomach cancer

AGE AT FIRST SURVEY	RADIOLOGICAL CATEGORY AT 1ST SURVEY													
			Simple Pneumoconiosis						Progressive Massive Fibrosis					
	0		1		2		3		A		B		C	
< 25	4267	99.9	3	100.0	0	-	0	-	0	-	1	100.0	0	-
	3	0.04	0	0.0	-	-	-	-	-	-	0	0.0	-	-
25 - 34	5009	99.7	160	100.0	48	100.0	5	100.0	10	100.0	3	100.0	-	-
	15	0.08	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	-	-
35 - 44	4905	99.2	457	99.1	199	97.9	28	100.0	93	98.8	23	100.0	6	100.0
	36	0.14	4	0.46	4	1.03	0	0.0	1	1.21	0	0.0	0	0.0
45 - 54	4502	97.6	615	97.3	304	95.1	47	100.0	133	98.5	82	100.0	18	100.0
	84	0.26	13	0.74	13	1.34	0	0.0	2	1.09	0	0.0	0	0.0
55 - 64	2450	96.3	445	93.7	170	95.6	34	83.1	106	93.3	84	97.3	25	81.8
	54	0.52	14	1.77	5	2.02	3	10.58	2	4.69	2	1.92	1	16.45
65+	382	94.8	59	91.1	26	70.1	4	-	19	100.0	10	-	4	-
	12	1.64	3	5.07	3	15.76	0	-	0	0.0	0	-	0	-

Other causes of death are treated as censored.

Key:

initial risk set	survival %
no. of deaths	s.e. %

Table 9.4: Survival estimates at 22 years by initial radiological category: bronchitis and emphysema

AGE AT FIRST SURVEY	RADIOLOGICAL CATEGORY AT 1ST SURVEY													
			Simple Pneumoconiosis						Progressive Massive Fibrosis					
	0		1		2		3		A		B		C	
< 25	4267	99.98	3	100.0	0	-	0	-	0	-	1	100.0	0	-
	1	0.02	0	0.0	-	-	-	-	-	-	0	0.0	-	-
25 - 34	5009	99.8	160	100.0	48	100.0	5	100.0	10	100.0	3	100.0	0	-
	12	0.07	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	-	-
35 - 44	4905	98.6	457	98.3	199	98.9	28	96.3	93	96.2	23	94.4	6	100.0
	62	0.18	7	0.63	2	0.80	1	3.63	3	2.18	1	5.40	0	0.0
45 - 54	4502	93.9	615	93.8	304	95.5	47	94.1	133	95.2	82	93.5	18	80.0
	216	0.40	28	1.14	12	1.28	2	4.09	5	2.13	3	3.66	1	17.89
55 - 64	2450	84.2	445	82.8	170	80.4	34	79.5	106	73.3	84	76.7	25	100.0
	233	1.01	45	2.50	16	4.61	3	11.30	15	6.36	9	7.34	0	0.0
65+	382	79.1	59	75.4	26	39.1	4	-	19	54.0	10	-	4	-
	33	3.88	4	12.99	4	24.28	0	-	3	23.47	1	-	1	-

Other causes of death are treated as censored.

Key:

initial risk set	survival %
no. of deaths	s.e. %

TABLE 9.5: Survival estimates at 22 years by initial radiological category: pneumoconiosis

AGE AT FIRST SURVEY	RADIOLOGICAL CATEGORY AT 1ST SURVEY													
			Simple Pneumoconiosis						Progressive Massive Fibrosis					
	0		1		2		3		A		B		C	
< 25	4267	100.0	3	100.0	0	-	0	-	0	-	1	100.0	0	-
	0	0.0	0	0.0	-	-	-	-	-	-	0	0.0	-	-
25 - 34	5009	100.0	160	98.7	48	97.8	5	100.0	10	100.0	3	33.3	0	-
	0	0.0	2	0.89	1	2.20	0	0.0	0	0.0	2	27.22	-	-
35 - 44	4905	99.9	457	99.0	199	97.7	28	100.0	93	90.6	23	86.4	6	50.0
	3	0.04	4	0.51	4	1.13	0	0.0	8	3.16	3	7.30	3	20.41
45 - 54	4502	99.4	615	96.8	304	94.4	47	91.6	133	88.7	82	61.3	18	40.3
	20	0.13	15	0.82	13	1.53	3	4.75	12	3.13	26	6.14	7	18.67
55 - 64	2450	98.9	445	95.4	170	88.0	34	79.8	106	73.7	84	43.9	25	8.5
	16	0.31	13	1.32	13	3.27	3	11.43	17	6.06	29	7.65	16	7.87
65+	382	98.4	59	92.5	26	90.9	4	-	19	78.3	10	-	4	-
	3	0.95	3	4.21	1	8.67	0	-	3	11.33	4	-	1	-

Other causes of death are treated as censored.

Key:

initial risk set	survival %
no. of deaths	s.e. %

TABLE 9.6: Survival estimates at 22 years by initial radiological category: other respiratory diseases

AGE AT FIRST SURVEY	RADIOLOGICAL CATEGORY AT 1ST SURVEY													
			Simple Pneumoconiosis						Progressive Massive Fibrosis					
	0		1		2		3		A		B		C	
< 25	4267	99.9	3	100.0	0	-	0	-	0	-	1	100.0	0	-
	2	0.03	0	0.0	-	-	-	-	-	-	0	0.0	-	-
25 - 34	5009	99.9	160	98.7	48	100.0	5	100.0	10	100.0	3	100.0	0	-
	7	0.05	2	0.94	0	0.0	0	0.0	0	0.0	0	0.0	-	-
35 - 44	4905	99.2	457	99.0	199	100.0	28	100.0	93	97.4	23	100.0	6	100.0
	34	0.13	4	0.49	0	0.0	0	0.0	2	1.81	0	0.0	0	0.0
45 - 54	4502	97.1	615	96.4	304	96.9	47	97.3	133	90.7	82	93.8	18	92.6
	96	0.30	16	0.91	7	1.16	1	2.67	9	2.98	3	3.66	1	7.13
55 - 64	2450	89.5	445	95.8	170	91.4	34	91.7	106	92.3	84	85.6	25	100.0
	128	0.93	11	1.31	7	3.23	2	5.66	4	4.18	5	6.53	0	0.0
65+	382	85.2	59	67.0	26	94.7	4	-	19	49.2	10	-	4	-
	22	3.50	5	15.97	1	5.12	-	-	5	18.50	-	-	-	-

Other causes of death are treated as censored.

Key:

initial risk set	survival %
no. of deaths	s.e. %

TABLE 10: Survival estimates at 17 years by radiological status and smoking habit: lung cancer

Age	NON-SMOKER						EX-SMOKER						SMOKER					
	Radiological status at second survey						Radiological status at second survey						Radiological status at second survey					
	0		Pnc		PMF		0		Pnc		PMF		0		Pnc		PMF	
<25	307	99.7	1	100.0	0	-	27	100.0	0	-	0	-	897	99.9	0	-	0	-
	1	0.33	0	0.0	-	-	0	0.0	-	-	-	-	1	0.11	-	-	-	-
25-34	485	100.0	11	100.0	0	-	121	100.0	5	100.0	0	-	1875	99.6	43	100.0	1	100.0
	0	0.0	0	0.0	-	-	0	0.0	0	0.0	-	-	7	0.15	0	0.0	0	0.0
35-44	468	100.0	69	100.0	6	100.0	282	100.0	25	100.0	2	100.0	3104	98.4	378	99.2	53	100.0
	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	48	0.23	3	0.48	0	0.0
45-54	472	98.8	121	100.0	30	100.0	293	99.6	63	98.3	14	91.9	2986	96.0	756	96.9	166	96.6
	5	0.52	0	0.0	0	0.0	1	0.37	1	1.70	1	7.77	104	0.39	20	0.69	4	1.68
55-64	278	98.1	86	100.0	26	100.0	287	97.2	86	91.7	32	96.4	2150	93.3	645	93.8	182	95.5
	4	0.92	0	0.0	0	0.0	6	1.13	6	3.33	1	3.54	102	0.66	29	1.15	5	2.06
65+	9	100.0	3	100.0	1	100.0	12	100.0	3	100.0	0	-	65	96.8	14	100.0	14	100.0
	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	-	-	2	2.29	0	0.0	0	0.0

Key

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

Table 11.1: Survival estimates at 22 years by exposure to respirable mine dust: all internal causes

AGE AT FIRST SURVEY	Estimated dust exposure to first survey (ghm^{-3}) 0-30		30-90		90-180		> 180	
< 25	2527	98.7	501	97.8	35	100.0	0	-
	33	0.23	11	0.66	0	0.0	-	-
25 - 34	1179	94.0	1850	94.3	1162	92.1	222	92.7
	70	0.69	105	0.54	91	0.80	16	1.75
35 - 44	694	84.8	1409	84.1	1750	84.1	1172	80.7
	105	1.37	223	0.98	277	0.88	226	1.16
45 - 54	302	68.1	864	61.4	1512	60.2	2311	58.4
	95	2.70	330	1.67	597	1.26	956	1.03
55 - 64	82	57.2	241	31.9	516	36.6	1081	29.9
	34	5.57	163	3.02	324	2.13	748	1.41
65+	8	37.5	17	5.9	32	3.6	83	12.2
	5	17.12	16	5.71	29	3.51	72	3.63

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 11.2: Survival estimates at 22 years by exposure to respirable mine dust: lung cancer

AGE AT FIRST SURVEY	Estimated dust exposure to first survey (ghm^{-3}) 0-30		30-90		90-180		> 180	
< 25	2527	99.9	501	100.0	35	100.0	0	-
	2	0.06	0	0.0	0	0.0	-	-
25 - 34	1179	99.3	1850	99,3	1162	99.6	222	100.0
	8	0.25	13	0.20	4	0.18	0	0.0
35 - 44	694	98.0	1409	97.7	1750	97.8	1172	98.4
	13	0.55	29	0.42	35	0.37	15	0.39
45 - 54	302	95.2	864	96.2	1512	95.5	2311	95.1
	12	1.36	27	0.72	54	0.61	88	0.51
55 - 64	82	94.6	241	92.1	516	93.5	1081	92.9
	4	2.61	12	2.28	23	1.37	47	1.09
65+	8	100.0	17	85.7	32	100.0	83	94.3
	0	0.0	1	13.23	0	0.0	3	3.32

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 11.3 Survival estimates at 22 years by exposure to respirable mine dust: stomach cancer

AGE AT FIRST SURVEY	Estimated dust exposure to first survey (ghm^{-3})							
	0-30		30-90		90-180		> 180	
< 25	2527	99.9	501	100.0	35	100.0	0	-
	2	0.06	0	0.0	0	0.0	-	-
25 - 34	1179	99.8	1850	99.6	1162	99.7	222	100.0
	2	0.12	8	0.16	3	0.16	0	0.0
35 - 44	694	99.2	1409	99.5	1750	99.1	1172	99.2
	5	0.36	7	0.20	14	0.23	8	0.27
45 - 54	302	99.2	864	98.0	1512	97.6	2311	97.5
	2	0.59	14	0.53	29	0.45	48	0.37
55 - 64	82	96.3	241	97.2	516	96.6	1081	96.3
	2	2.59	4	1.40	11	1.05	25	0.76
65+	8	100.0	17	93.9	32	89.4	83	94.6
	0	0.0	1	5.87	2	7.36	3	3.06

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 11.4: Survival estimates at 22 years by exposure to respirable mine dust: cancers of the digestive organs and peritoneum (excluding stomach)

AGE AT FIRST SURVEY	Estimated dust exposure to first survey (ghm^{-3}) 0-30		30-90		90-180		> 180	
< 25	2527	100.0	501	100.0	35	100.0	0	-
	0	0.0	0	0.0	0	0.0	-	-
25 - 34	1179	99.5	1850	99.5	1162	99.1	222	100.0
	6	0.22	9	0.17	10	0.29	0	0.0
35 - 44	694	99.4	1409	99.2	1750	99.0	1172	99.2
	4	0.32	11	0.25	16	0.24	9	0.28
45 - 54	302	97.9	864	97.5	1512	98.5	2311	97.3
	6	0.86	17	0.60	17	0.37	48	0.39
55 - 64	82	98.1	241	96.2	516	97.7	1081	94.9
	1	1.87	6	1.58	8	0.83	34	0.91
65+	8	100.0	17	90.00	32	100.0	83	85.4
	0	0.0	1	9.49	0	0.0	8	4.96

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 11.5: Survival estimates at 22 years by exposure to respirable mine dust: other cancers

AGE AT FIRST SURVEY	Estimated dust exposure to first survey (ghm^{-3}) 0-30		30-90		90-180		> 180	
< 25	2527	99.8	501	99.8	35	100.0	0	-
	5	0.09	1	0.20	0	0.0	-	-
25 - 34	1179	99.7	1850	99.8	1162	99.6	222	99.5
	3	0.15	4	0.11	4	0.18	1	0.47
35 - 44	694	98.9	1409	98.9	1750	98.5	1172	98.3
	7	0.40	14	0.28	24	0.30	18	0.40
45 - 54	302	97.1	864	96.7	1512	96.9	2311	97.1
	7	1.07	23	0.69	38	0.50	53	0.39
55 - 64	82	95.9	241	95.6	516	95.2	1081	95.5
	3	2.35	6	1.86	18	1.15	32	0.80
65+	8	100.0	17	100.0	32	88.3	83	88.0
	0	0.0	0	0.0	2	8.20	5	5.61

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 11.6: Survival estimates at 22 years by exposure to respirable mine dust: bronchitis and emphysema

AGE AT FIRST SURVEY	Estimated dust exposure to first survey (ghm^{-3}) 0-30		30-90		90-180		> 180	
< 25	2527	100.0	501	99.8	35	100.0	0	-
	0	0.0	1	0.20	0	0.0	-	-
25 - 34	1179	99.9	1850	99.8	1162	99.6	222	99.1
	1	0.09	4	0.11	4	0.19	2	0.65
35 - 44	694	99.4	1409	99.1	1750	98.8	1172	97.3
	4	0.32	12	0.27	19	0.27	28	0.50
45 - 54	302	97.0	864	94.2	1512	94.4	2311	93.8
	8	1.06	40	0.89	68	0.66	112	0.57
55 - 64	82	97.0	241	87.9	516	90.1	1081	82.8
	2	2.07	17	2.90	33	1.70	113	1.55
65+	8	75.0	17	100.0	32	83.5	83	87.7
	1	21.65	0	0.0	4	7.73	6	4.91

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 11.7: Survival estimates at 22 years by exposure to respirable mine dust: pneumoconiosis

AGE AT FIRST SURVEY	Estimated dust exposure to first survey (ghm^{-3})							
	0-30		30-90		90-180		> 180	
< 25	2527	100.0	501	100.0	35	100.0	0	-
	0	0.0	0	0.0	0	0.0	-	-
25 - 34	1179	100.0	1850	100.0	1162	99.6	222	99.5
	0	0.0	0	0.0	4	0.18	1	0.48
35 - 44	694	100.0	1409	100.0	1750	99.8	1172	98.6
	0	0.0	0	0.0	3	0.11	15	0.36
45 - 54	302	100.0	864	99.7	1512	98.1	2311	97.0
	0	0.0	2	0.19	21	0.42	58	0.40
55 - 64	82	100.0	241	99.1	516	97.3	1081	93.2
	0	0.0	2	0.65	9	0.91	44	1.06
65+	8	87.5	17	100.0	32	100.0	83	91.9
	1	11.69	0	0.0	0	0.0	4	4.02

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 11.8: Survival estimates at 22 years by exposure to respirable mine dust: other respiratory diseases

AGE AT FIRST SURVEY	Estimated dust exposure to first survey (ghm^{-3})							
	0-30		30-90		90-180		> 180	
< 25	2527	99.96	501	99.8	35	100.0	0	-
	1	0.04	1	0.20	0	0.0	-	-
25 - 34	1179	99.9	1850	99.7	1162	99.8	222	100.0
	1	0.09	5	0.12	2	0.13	0	0.0
35 - 44	694	99.4	1409	99.2	1750	99.4	1172	99.0
	4	0.31	11	0.25	9	0.19	10	0.30
45 - 54	302	98.4	864	96.8	1512	97.2	2311	96.8
	4	0.81	20	0.71	31	0.50	53	0.43
55 - 64	82	94.6	241	93.9	516	91.1	1081	93.5
	3	3.09	9	2.05	26	1.73	38	1.07
65+	8	100.0	17	92.3	32	45.2	83	85.4
	0	0.0	1	7.39	2	32.31	4	7.45

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 11.9: Survival estimates at 22 years by exposure to respirable mine dust: ischaemic heart disease

AGE AT FIRST SURVEY	Estimated dust exposure to first survey (ghm^{-3}) 0-30		30-90		90-180		> 180	
< 25	2527	99.6	501	99.2	35	100.0	0	-
	11	0.13	4	0.41	0	0.0	-	-
25 - 34	1179	97.2	1850	97.9	1162	95.9	222	95.4
	32	0.49	38	0.34	46	0.59	10	1.42
35 - 44	694	92.9	1409	92.9	1750	93.4	1172	92.6
	47	1.01	95	0.70	108	0.61	81	0.79
45 - 54	302	85.6	864	85.0	1512	84.4	2311	85.6
	38	2.18	110	1.33	201	1.02	279	0.81
55 - 64	82	82.9	241	68.1	516	73.5	1081	68.5
	11	4.76	54	3.80	99	2.38	217	1.87
65+	8	80.0	17	80.1	32	34.6	83	59.4
	1	17.89	3	10.42	9	16.1	13	10.49

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 12: Survival estimates at 22 years by radiological category and exposure to respirable mine dust: cancers of the digestive system (cause-groups 2 and 3)

AGE AT FIRST SURVEY	Radiological Classification at first survey															
	No Pneumoconiosis								Simple Pneumoconiosis							
	Estimated dust exposure to first survey (ghm^{-3})								Estimated dust exposure to first survey (ghm^{-3})							
	0-30		30-90		90-180		> 180		0-30		30-90		90-180		> 180	
<25	2525	99.9	501	100.0	34	100.0	0	-	2	100.0	0	-	1	100.0	0	-
	2	0.06	0	0.0	0	0.0	-	-	0	0.0	-	-	0	0.0	-	-
25-34	1169	99.4	1828	99.0	1048	98.8	158	100.0	9	88.9	22	100.0	108	99.0	59	100.0
	7	0.23	17	0.23	12	0.34	0	0.0	1	10.48	0	0.0	1	1.03	0	0.0
35-44	674	98.5 *	1377	98.6 *	1527	98.4 *	723	98.6 *	16	100.0	30	100.0	204	96.9 *	369	97.7 *
	9	0.49	18	0.33	22	0.33	9	0.47	0	0.0	0	0.0	6	1.23	8	0.80
45-54	291	97.3 *	834	95.4 *	1327	95.8 *	1469	95.2 *	9	88.9	28	100.0	161	98.6 *	669	93.4 *
	7	1.01	31	0.81	44	0.63	56	0.63	1	10.48	0	0.0	2	0.98	36	1.07
55-64	67	95.5 *	230	93.8 *	440	94.3 *	697	92.0 *	11	89.5	8	87.5	61	94.2 *	293	90.5 *
	2	3.12	9	2.08	17	1.41	36	1.35	1	9.96	1	11.69	2	4.14	19	2.21
65+	5	100.0	17	84.6	26	94.7	54	85.3	1	100.0	0	-	6	-	20	57.7
	0	0.0	2	10.36	1	5.12	6	5.65	-	0.0	-	-	1	-	5	14.8

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 13: Distribution at third survey of FEV_1 by age

Age at third survey	FEV_1 < 2.5	2.5-3.0	3.0-3.5	> 3.5	TOTAL
25-34	16	95	264	1138	1513
35-44	273	554	887	1184	2898
45-54	1136	1226	926	520	3808
55-64	2227	927	365	94	3613
65+	29	5	3	0	37
TOTAL	3681	2807	2445	2936	11869

TABLE 14.1: Survival estimates at 12 years by lung function: all internal causes

AGE AT THIRD SURVEY	Khosla's FEV_1 Index of Lung Function							
	≤ 0.6		0.6 - 0.7		0.7 - 0.8		> 0.8	
< 35	188	97.9	479	98.5	584	98.8	262	98.8
	4	1.06	7	0.55	7	0.45	3	0.66
35 - 44	422	91.6	739	92.0	1003	95.5	734	95.8
	35	1.36	59	1.00	45	0.65	31	0.74
45 - 54	1006	78.1	922	84.4	1034	88.6	846	90.3
	220	1.31	143	1.20	117	0.99	82	1.02
55 - 64	1563	59.2	861	70.3	718	72.1	471	73.8
	635	1.25	255	1.56	200	1.68	123	2.03
65+	23	45.7	7	71.4	3	33.3	4	75.0
	12	10.62	2	17.07	2	27.2	1	21.65

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 14.2: Survival estimates at 12 years by lung function: lung cancer

AGE AT THIRD SURVEY	Khosla's FEV_1 Index of Lung Function							
	≤ 0.6		0.6 - 0.7		0.7 - 0.8		> 0.8	
< 35	188	99.5	479	99.8	584	99.8	262	100.0
	1	0.54	1	0.21	1	0.17	0	0.0
35 - 44	422	99.5	739	98.7	1003	99.5	734	99.6
	2	0.35	9	0.42	5	0.23	3	0.24
45 - 54	1006	97.0	922	97.7	1034	98.5	846	98.5
	26	0.57	20	0.51	15	0.39	12	0.43
55 - 64	1563	94.9	861	95.7	718	97.0	471	99.0
	64	0.63	32	0.75	19	0.68	4	0.51
65+	23	100.0	7	100.0	3	100.0	4	100.0
	0	0.0	0	0.0	0	0.0	0	0.0

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 14.3: Survival estimates at 12 years by lung function: bronchitis and emphysema

AGE AT THIRD SURVEY	Khosla's FEV_1 Index of Lung Function							
	$\leqslant$ 0.6		0.6 - 0.7		0.7 - 0.8		> 0.8	
< 35	188	100.0	479	100.0	584	99.8	262	100.0
	0	0.0	0	0.0	1	0.17	0	0.0
35 - 44	422	99.0	739	100.0	1003	100.0	734	100.0
	4	0.50	0	0.0	0	0.0	0	0.0
45 - 54	1006	96.1	922	99.6	1034	100.0	846	100.0
	35	0.65	3	0.21	0	0.0	0	0.0
55 - 64	1563	92.6	861	97.9	718	99.0	471	98.8
	91	0.76	15	0.54	6	0.40	5	0.55
65+	23	100.0	7	100.0	3	100.0	4	100.0
	0	0.0	0	0.0	0	0.0	0	0.0

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 14.4: Survival estimates at 12 years by lung function: pneumoconiosis

AGE AT THIRD SURVEY	Khosla's FEV$_1$ Index of Lung Function							
	⩽ 0.6		0.6 - 0.7		0.7 - 0.8		> 0.8	
< 35	188	100.0	479	100.0	584	100.0	262	100.0
	0	0.0	0	0.0	0	0.0	0	0.0
35 - 44	422	100.0	739	99.9	1003	100.0	734	100.0
	0	0.0	1	0.14	0	0.0	0	0.0
45 - 54	1006	99.4	922	99.8	1034	100.0	846	100.0
	5	0.26	2	0.17	0	0.0	0	0.0
55 - 64	1563	97.9	861	98.9	718	99.5	471	100.0
	23	0.43	8	0.41	3	0.27	0	0.0
65+	23	100.0	7	100.0	3	100.0	4	100.0
	0	0.0	0	0.0	0	0.0	0	0.0

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 14.5: <u>Survival estimates at 12 years by lung function: other respiratory diseases</u>

AGE AT THIRD SURVEY	Khosla's FEV_1 Index of Lung Function							
	≤ 0.6		0.6 - 0.7		0.7 - 0.8		> 0.8	
< 35	188	100.0	479	100.0	584	100.0	262	100.0
	0	0.0	0	0.0	0	0.0	0	0.0
35 - 44	422	99.5	739	99.8	1003	99.9	734	100.0
	2	0.37	1	0.15	1	0.10	0	0.0
45 - 54	1006	99.0	922	99.8	1034	99.7	846	99.8
	9	0.34	2	0.16	3	0.18	2	0.18
55 - 64	1563	96.1	861	97.6	718	98.1	471	98.3
	45	0.57	16	0.58	11	0.56	7	0.65
65+	23	87.0	7	85.7	3	100.0	4	100.0
	2	8.63	1	13.23	0	0.0	0	0.0

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 14.6: Survival estimates at 12 years by lung function: ischaemic heart disease

AGE AT THIRD SURVEY	Khosla's FEV$_1$ Index of Lung Function: ≤ 0.6		0.6 - 0.7		0.7 - 0.8		> 0.8	
< 35	188	98.9	479	99.6	584	99.8	262	99.6
	2	0.76	2	0.30	1	0.17	1	0.39
35 - 44	422	96.6	739	96.6	1003	97.6	734	97.8
	14	0.89	24	0.67	24	0.49	16	0.55
45 - 54	1006	91.3	922	93.0	1034	95.0	846	94.2
	81	0.92	62	0.86	50	0.69	48	0.81
55 - 64	1563	86.0	861	89.3	718	88.0	471	88.9
	187	0.96	83	1.12	79	1.28	48	1.52
65+	23	74.5	7	83.3	3	100.0	4	75.0
	4	11.31	1	15.21	0	0.0	1	21.65

Key:

initial risk set	survival %
no. of deaths	s.e. %

Other causes of death are treated as censored.

TABLE 15.1: Survival estimates at 22 years by exposure to respirable mine dust and quartz: all internal causes

AGE AT FIRST SURVEY	Cumulative Exposure to Respirable Mine Dust (ghm^{-3})								
	< 85			85 - 225			≥ 225		
	Exposure Quartz %			Exposure Quartz %			Exposure Quartz %		
	< 3.7	3.7 - 5.3	≥ 5.3	< 3.7	3.7 - 5.3	≥ 5.3	< 3.7	3.7 - 5.3	≥ 5.3
< 25	386 98.8 3 0.69	408 99.6 1 0.38	549 97.1 8 1.03	16 96.7 4 1.63	2 98.5 2 1.05	3 99.6 1 0.36	0 - - -	0 - - -	0 - - -
25 - 34	314 92.7 11 2.14	402 92.4 15 1.93	508 96.4 9 1.20	321 89.2 32 1.81	138 94.5 16 1.34	367 93.4 31 1.15	51 95.4 11 1.38	2 95.8 2 3.10	2 95.0 8 1.73
35 - 44	163 77.1 22 4.30	336 80.4 31 3.20	362 82.7 35 2.69	381 83.5 45 2.26	461 82.5 71 1.89	420 87.1 49 1.73	218 82.5 69 1.91	78 84.3 47 2.11	103 83.6 50 2.15
45 - 54	105 58.4 37 5.24	215 64.5 41 4.54	178 54.0 67 4.16	283 60.8 94 3.16	442 61.2 169 2.33	368 55.0 110 3.20	307 54.9 163 2.61	283 61.1 149 2.49	346 62.2 187 2.18
55 - 64	24 47.4 12 10.45	36 40.4 19 8.69	60 28.1 39 6.14	94 34.0 60 4.97	172 41.8 96 3.84	87 26.8 61 4.87	121 30.4 85 4.16	132 36.2 89 4.09	211 34.3 142 3.23
65+	0 - - -	0 - - -	2 7.6 2 15.90	10 9.6 9 9.58	7 8.4 6 10.27	1 17.8 1 30.75	17 6.5 16 5.58	2 4.7 2 11.74	10 9.0 9 8.65

Other causes of death are treated as censored.

Key:

initial risk set	survival %
no. of deaths	s.e. %

TABLE 15.2: Survival estimates at 22 years by exposure to respirable mine dust and quartz: Cancers of the digestive system (cause-groups 2 and 3)

AGE AT FIRST SURVEY	Cumulative Exposure to Respirable Mine Dust (ghm^{-3})								
	< 85			85 - 225			≥ 225		
	Exposure Quartz %			Exposure Quartz %			Exposure Quartz %		
	< 3.7	3.7 - 5.3	≥ 5.3	< 3.7	3.7 - 5.3	≥ 5.3	< 3.7	3.7 - 5.3	≥ 5.3
< 25	386 100.0	408 100.0	549 100.0	16 100.0	2 100.0	3 100.0	0 -	0 -	0 -
	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	- -	- -	- -
25 - 34	314 99.2	402 100.0	508 99.6	321 97.5	138 99.3	367 98.9	51 100.0	2 100.0	2 98.8
	1 0.78	0 0.0	1 0.44	7 0.94	2 0.50	5 0.50	0 0.0	0 0.0	2 0.89
35 - 44	163 97.4	336 97.9	362 97.9	381 98.4	461 97.4	420 98.4	218 98.3	78 98.1	103 98.0
	2 1.84	3 1.25	4 1.06	4 0.79	10 0.80	6 0.67	6 0.67	5 0.84	6 0.82
45 - 54	105 98.4	215 98.3	178 96.2	283 95.6	442 94.9	368 92.4	307 94.7	283 94.2	346 95.1
	1 1.57	2 1.23	5 1.67	8 1.54	19 1.14	14 1.97	14 1.39	19 1.29	20 1.08
55 - 64	24 100.0	36 100.0	60 93.2	94 94.4	172 95.6	87 95.1	121 90.1	132 91.5	211 90.3
	0 0.0	0 0.0	2 4.81	4 2.75	5 2.00	3 2.81	7 3.74	7 3.25	13 2.68
65+	0 -	0 -	2 100.0	10 100.0	7 40.6	1 100.0	17 83.6	2 9.2	10 77.5
	- -	- -	0 0.0	0 0.0	3 22.38	0 0.0	2 10.76	1 22.01	1 19.77

Other causes of death are treated as censored.

Key:

initial risk set	survival %
no. of deaths	s.e. %

TABLE 15.3: Survival estimates at 22 years by exposure to respirable mine dust and quartz: bronchitis and emphysema

AGE AT FIRST SURVEY	Cumulative Exposure to Respirable Mine Dust (ghm^{-3})								
	< 85			85 - 225			≥ 225		
	Exposure Quartz %			Exposure Quartz %			Exposure Quartz %		
	< 3.7	3.7 - 5.3	≥ 5.3	< 3.7	3.7 - 5.3	≥ 5.3	< 3.7	3.7 - 5.3	≥ 5.3
< 25	386 100.0	408 100.0	549 100.0	16 100.0	2 100.0	3 100.0	0 -	0 -	0 -
	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	- -	- -	- -
25 - 34	314 100.0	402 100.0	508 100.0	321 99.2	138 99.6	367 100.0	51 99.2	2 98.6	2 100.0
	0 0.0	0 0.0	0 0.0	2 0.53	1 0.35	0 0.0	2 0.57	1 1.37	0 0.0
35 - 44	163 98.8	336 98.5	362 99.6	381 99.7	461 98.4	420 98.6	218 97.2	78 98.9	103 98.3
	1 1.16	2 1.06	1 0.39	1 0.34	6 0.64	5 0.64	10 0.87	3 0.61	5 0.78
45 - 54	105 92.2	215 96.2	178 96.1	283 93.0	442 93.7	368 90.9	307 93.8	283 95.0	346 95.8
	6 3.07	4 1.96	4 1.97	13 1.90	22 1.32	17 2.14	17 1.48	15 1.27	17 1.01
55 - 64	24 87.8	36 92.9	60 83.9	94 83.3	172 93.1	87 85.7	121 78.6	132 80.3	211 84.6
	2 8.14	2 4.89	5 6.79	11 4.87	8 2.42	6 5.60	16 4.96	18 4.32	22 3.17
65+	0 -	0 -	2 100.0	10 89.8	7 56.5	1 100.0	17 66.3	2 100.0	10 67.9
	- -	- -	0 0.0	1 9.70	2 23.90	0 0.0	4 14.26	0 0.0	1 26.31

Other causes of death are treated as censored.

Key:

initial risk set	survival %
no. of deaths	s.e. %

TABLE 15.4: Survival estimates at 22 years by exposure to respirable mine dust and quartz: pneumoconiosis

AGE AT FIRST SURVEY	Cumulative Exposure to Respirable Mine Dust (ghm^{-3}) < 85: Exposure Quartz % < 3.7	< 85: 3.7 - 5.3	< 85: ≥ 5.3	85 - 225: Exposure Quartz % < 3.7	85 - 225: 3.7 - 5.3	85 - 225: ≥ 5.3	≥ 225: Exposure Quartz % < 3.7	≥ 225: 3.7 - 5.3	≥ 225: ≥ 5.3
< 25	386 100.0	408 100.0	549 100.0	16 100.0	2 100.0	3 100.0	0 -	0 -	0 -
	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	- -	- -	- -
25 - 34	314 100.0	402 100.0	508 100.0	321 100.0	138 99.6	367 100.0	51 100.0	2 100.0	2 100.0
	0 0.0	0 0.0	0 0.0	0 0.0	1 0.36	0 0.0	0 0.0	0 0.0	0 0.0
35 - 44	163 100.0	336 100.0	362 100.0	381 99.1	461 100.0	420 100.0	218 98.1	78 99.6	103 99.3
	0 0.0	0 0.0	0 0.0	2 0.64	0 0.0	0 0.0	7 0.72	1 0.44	2 0.48
45 - 54	105 100.0	215 99.3	178 100.0	283 96.0	442 97.9	368 97.9	307 94.4	283 96.1	346 97.2
	0 0.0	1 0.74	0 0.0	7 1.50	7 0.80	4 1.04	16 1.38	12 1.11	12 0.81
55 - 64	24 100.0	36 100.0	60 100.0	94 95.6	172 98.4	87 95.1	121 84.1	132 92.8	211 96.2
	0 0.0	0 0.0	0 0.0	2 3.02	2 1.19	3 2.89	11 4.70	8 2.52	4 1.90
65+	0 -	0 -	2 100.0	10 100.0	7 100.0	1 100.0	17 86.1	2 100.0	10 100.0
	- -	- -	0 0.0	0 0.0	0 0.0	0 0.0	1 12.91	0 0.0	0 0.0

Other causes of death are treated as censored.

Key:

initial risk set	survival %
no. of deaths	s.e. %

TABLE 15.5: Survival estimates at 22 years by exposure to respirable mine dust and quartz; other respiratory diseases

AGE AT FIRST SURVEY	Cumulative Exposure to Respirable Mine Dust (ghm^{-3})								
	< 85			85 - 225			≥ 225		
	Exposure Quartz %			Exposure Quartz %			Exposure Quartz %		
	< 3.7	3.7 - 5.3	≥ 5.3	< 3.7	3.7 - 5.3	≥ 5.3	< 3.7	3.7 - 5.3	≥ 5.3
< 25	386 100.0	408 100.0	549 99.7	16 100.0	2 100.0	3 100.0	0 -	0 -	0 -
	0 0.0	0 0.0	1 0.28	0 0.0	0 0.0	0 0.0	- -	- -	- -
25 - 34	314 100.0	402 100.0	508 100.0	321 100.0	138 100.0	367 99.6	51 100.0	2 100.0	2 99.3
	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	2 0.31	0 0.0	0 0.0	1 0.67
35 - 44	163 100.0	336 98.9	362 98.3	381 99.2	461 99.5	420 99.2	218 99.7	78 99.3	103 99.7
	0 0.0	2 0.78	3 0.98	2 0.56	2 0.37	3 0.48	1 0.27	2 0.49	1 0.34
45 - 54	105 100.0	215 95.6	178 92.9	283 98.9	442 97.1	368 96.5	307 96.7	283 97.0	346 97.3
	0 0.0	4 2.22	7 2.62	2 0.78	9 0.95	6 1.44	9 1.08	9 0.99	10 0.85
55 - 64	24 94.8	36 94.1	60 90.1	94 92.2	172 91.3	87 83.4	121 97.5	132 95.5	211 93.7
	1 5.06	1 5.68	4 4.72	5 3.38	9 2.83	7 6.12	2 1.79	4 2.22	7 2.34
65+	0 -	0 -	2 100.0	10 100.0	7 100.0	1 100.0	17 100.0	2 100.0	10 100.0
	- -	- -	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0

Other causes of death are treated as censored.

Key:

initial risk set	survival %
no. of deaths	s.e. %

TABLE 16.1: Distribution of exposure quartz % by colliery

Colliery	Region	Exposure Quartz % < 3.7	3.7-5.3	≥ 5.3	Total
V	S. Wales	1309 83.0	267 16.9	2 0.1	1578
W	S. Wales	432 80.0	61 11.3	47 8.7	540
F	S. Wales	545 77.1	160 22.6	2 0.3	707
C	Midlands	328 29.7	728 65.9	48 4.3	1104
Y	Northern	116 9.5	913 74.4	198 16.1	1227
T	Northern	79 6.6	613 51.5	498 41.8	1190
K	E & W Ridings	0 0.0	245 26.3	688 73.7	933
Q	N. Midlands	0 0.0	127 10.5	1080 89.5	1207
X	E & W Ridings	0 0.0	2 0.2	1016 99.8	1018
TOTAL		2809 29.6	3116 32.8	3579 37.7	9504

Key:

No. of men % of row total

TABLE 16.2: Distribution of exposure to respirable mine dust by colliery

Colliery	Region	Maximum Cumulative Exposure to Respirable Mine Dust (ghm^{-3}) $\leqslant$ 85	85-225	> 225	Total
V	S. Wales	345 21.9	624 39.5	609 38.6	1578
W	S. Wales	128 23.7	243 45.0	169 31.3	540
F	S. Wales	79 11.2	123 17.4	505 71.4	707
C	Midlands	365 33.1	734 66.5	5 0.5	1104
Y	Northern	199 16.2	550 44.8	478 39.0	1227
T	Northern	289 24.3	395 33.2	506 42.5	1190
K	E & W Ridings	244 26.2	468 50.2	221 23.7	933
Q	N. Midlands	336 27.8	287 23.8	584 48.4	1207
X	E & W Ridings	142 13.9	458 45.0	418 41.1	1018
TOTAL		2127 22.4	3882 40.8	3495 36.8	9504

Key:

No. of men
% of row total

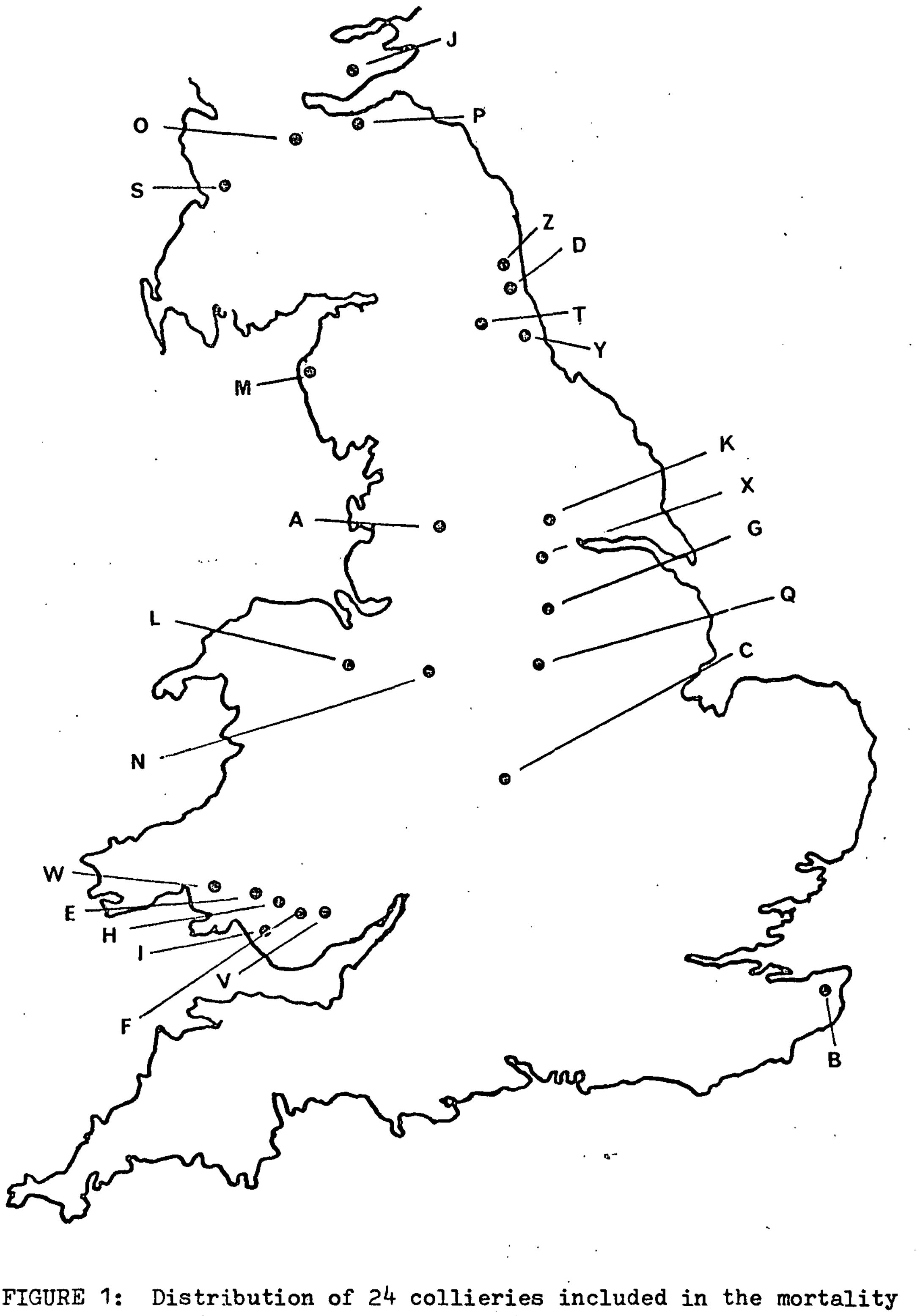

FIGURE 1: Distribution of 24 collieries included in the mortality study

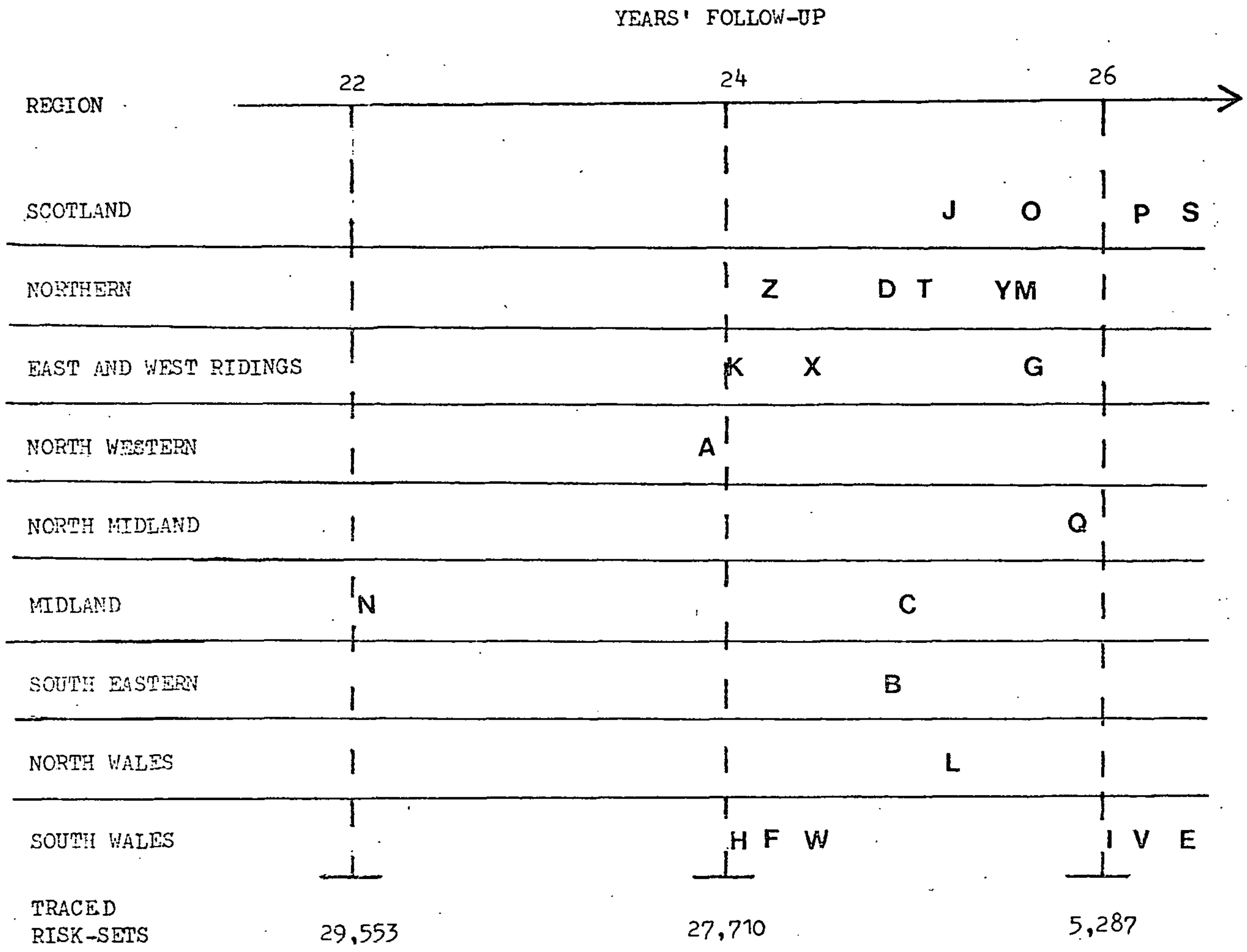

FIGURE 2: Length of follow-up available for the 24 collieries included in the mortality study, from first survey to April 1980.

FIGURE 2:

APPENDIX

Some theoretical and computational details of the statistical methods employed

The books by GROSS and CLARK (1975) and by KALBFLEISCH and PRENTICE (1980) are among several offering extensive coverage of the statistical theory and methods appropriate in the analysis of survival data. The monograph by DAVID and MOESCHBERGER (1978) considers specifically situations where multiple risks compete.

In this Appendix we record some of the key formulae, and some details of the computational methods, used for the analyses in the report.

A1 Concepts and definitions

Treating the time to death as a continuous variable T measured from some defined origin O, the survivor function S(t) is defined as the probability that the individual survives at least time t>0.

$$S(t) = \Pr(T \geq t)$$

It follows from the definition that $S(0) = 1$, $S(t)$ is a decreasing function of t, and $S(\infty) = 0$.

The hazard function $\lambda(t)$ is also known as the failure rate or force of mortality, and is defined as the instantaneous rate of failure at $T = t$ conditional on survival to time t.

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{\Pr(t \leq T < t + \Delta t \mid T \geq t)}{\Delta t}$$

$\lambda(t)$ is a non-negative function with $\int_0^\infty \lambda(u)\, du = \infty$.

Unlike the survivor function, it can be increasing or decreasing with t, constant, peaked, or J- or U-shaped.

The two functions are alternative and equivalent ways of expressing the same thing; they are related by the identities

$$\lambda(t) = -\frac{S'(t)}{S(t)}$$

$$S(t) = \exp\left[-\int_0^t \lambda(U)\, du\right]$$

Similar definitions can be applied when T is a discrete variable, with suitable changes in notation.

If $f(x)$ is any probability density function defined on the domain $x < 0$, then the complement of its cumulative distribution can be used to define a survivor function

$$S(t) = 1 - \int_0^t f(x)dx \, .$$

The negative exponential distribution defines a particularly simple hazard, taking a constant value for all values of t.

$$f(x) = \lambda \exp(-\lambda x) \Rightarrow S(t) = \exp(-\lambda t) \Rightarrow \lambda(t) = \lambda \; \forall t > 0$$

This is often referred to as the exponential survival distribution.

A2 Indirect standardisation and the SMR

Indirect standardisation was used to produce Standardised Mortality Ratios (SMRs) for each of the collieries in the study. This technique involves the calculation of the number of deaths that would be expected in a study population if it experienced the death rates observed in a reference population; the calculated "expected" number of deaths can then be compared with the number actually observed.

Population death rates for the male home population were abstracted from the statistics published annually by the Registrars General in Scotland and in England and Wales, covering the years of the study. They were stratified by 10-year age-groups and by geographical region within Britain. We denote the years of the follow-up by i = 1 ... n, and the total number of deaths in each year at a colliery γ within region j in age-group k as $d_{i\gamma(j)k}$. The population death rate appropriate for comparison is denoted μ_{ijk}. Since this refers to the estimated mid-year population, and not to the population at the start of the year, a corresponding adjustment was made to the risk-set entering each year, by calculating total times at risk $\tau_{i\gamma(j)k}$, in units of man-years. This approach also permitted adjustment for the collieries entering the study at different times. As a man progressed through the study, he was moved, as appropriate, from one age-group to the next.

The SMR for a colliery γ, expressed as a percentage, is defined as

$$\text{SMR\%} = \frac{\sum_{i,k} d_{i\gamma(j)k}}{\sum_{i,k} \Pi_{ijk}\, \tau_{i\gamma(j)k}} \times 100 = 100\frac{(\text{observed deaths})}{(\text{expected deaths})} .$$

If colliery γ had identical mortality experience to that of the population, the SMR would take the value 100%. Statistical inferences regarding an observed SMR are often made by using an approximate variance formula due to YULE (1934):

$$V(\text{SMR}) = \frac{(\text{SMR})^2}{(\text{observed deaths})} .$$

BRESLOW (1977) gives an account of statistical theory and implicit assumptions underlying the use of the SMR. He shows that under certain conditions the SMR is equivalent to the maximum likelihood estimate of the parameter in a multiplicative model relating the hazards in the study and reference populations. He also considers various types of time-dependent stratification (as exemplified here by the stratification according to age).

A3 Life-table estimation of the hazard and survivor functions

Estimates of the hazard and survivor functions were calculated by "life-table" methods, using the computer program BMDP1L (DIXON, 1979). The follow-up period was divided into periods of one year, taking the start of follow-up for the colliery concerned as time origin. The risk-set was stratified by age at the origin and by any other factor(s) of interest in particular analyses. Within each stratum, it was assumed that censoring took place with uniform probability throughout an interval. The average number of subjects τ_i exposed to the risk of dying during interval i was estimated by

$$\tau_i = n_i - \tfrac{1}{2}c_i$$

where n_i = number of subjects alive at the start of the interval
c_i = number censored during the interval.

The conditional probability of dying during the interval was estimated as

$$q_i = d_i/\tau_i$$

where d_i was the number dying in the interval. The conditional probability of surviving to the end of the interval was thus $p_i = 1 - q_i$.

The survivor function at the beginning of the i^{th} interval was estimated as

$$S_i = p_{i-1} S_{i-1}$$

where $S_1 = 1$.

An approximate formula for the standard error of S_i given by GREENWOOD (1926) was used

$$s.e.(S_i) \doteq S_i \left\{ \sum_{k=1}^{i-1} \left(\frac{q_k}{T_k p_k} \right) \right\}^{\frac{1}{2}}$$

The hazard function was estimated at the mid point of each interval as

$$\lambda_i \doteq \frac{2q_i}{h_i(1 + P_i)}$$

where h_i is the width of the interval (here $\forall h_i = 1$). The hazard estimate has approximate standard error $s.e.(\lambda_i) \doteq \left[\frac{\lambda_i^2}{T_i q_i} \left\{ 1 - \left[\frac{h_i \lambda_i}{2} \right] \right\} \right]^{\frac{1}{2}}$

GROSS and CLARK (1975) warn that the formulae for the standard errors of the hazard and survivor functions may seriously underestimate the true standard errors when the amount of censoring is large. For this reason, we took follow-up periods for the analyses which were slightly shorter than the longest available length of follow-up. Thus there was no censoring of entire collieries, and serious underestimation will not have occurred.

No distributional assumptions are made in the life-table procedures, and non-parametric methods must be used to compare estimated survivor or hazard functions. These methods have the drawback of being difficult to extend to crossed and nested classifications involving more than one factor, especially where the classifications are unbalanced; they have not been used in the present study, but are related to the family of models considered in the next section.

A4 Cox's proportional hazards model for survival data

COX (1972) presented a framework for the formal statistical analysis of survival data which included as special cases many models and tests previously considered separately. Under this framework, which is often referred to simply as "Cox's Model", the hazard function for each individual is expressed as the product of an underlying hazard function common to all individuals, and a function of unknown regression-type parameters and variable values, the latter specific to the individual. Thus if a vector of measurements $\underline{Z} = (Z_1 \ldots Z_p)$ is available for an individual, along with survival or censoring time, the hazard is written

$$\lambda(t|\underline{Z}) = \lambda_o(t)h(\underline{Z},\underline{\beta})$$

where $\underline{\beta} = (\beta_1 \ldots \beta_p)$ is a vector of unknown parameters and $h(\underline{0},\underline{\beta}) = 1$. The usual choice for h is the exponential of a linear function similar to those familiar in multiple linear regression,

$$\lambda(t|\underline{Z}) = \lambda_o(t) \exp(\underline{Z}\,\underline{\beta})$$

The hazard is thus multiplied by a constant proportion for each unit change in any Z_i. The model can also be used when one or more of the Z_i is a function of t (time-dependent covariates).

The underlying hazard $\lambda_o(t) = \lambda(t|\underline{0})$ may be specified as a parametric function, e.g. exponential (constant) hazard; maximum likelihood methods can then be used to estimate simultaneously the parameters of $\lambda_o(t)$ and the elements of $\underline{\beta}$. However COX (1972,1975) has shown that the form of the likelihood derived from the above makes it possible to make inferences about β without making any assumptions about $\lambda_o(t)$ except that it is the same for each individual. The iterative computations required to maximise the likelihood are time-consuming with large data sets, especially with time-dependent covariates and/or ties in the survival times.

A5 Holford's approximation to Cox's model

HOLFORD (1976) presented a method whereby regression models approximating those of COX (1972) could be analysed by extending the life-table procedures. The follow-up period is split into intervals as before, and the hazard function is assumed constant in each interval, and expressed for individual j in interval i as

$$\lambda_{ij} = \lambda_i \exp(\underline{Z}\,\underline{\beta})$$

If the covariates Z_j are continuous, then a considerable amount of computation is still needed to solve for $\underline{\beta}$. If however the Z_j are dummy variables indicating membership of strata, whether naturally discrete or created by grouping continuous variables, then the computation simplifies considerably, a result which has been exploited in our analysis.

A table is constructed cross-classified by interval i and by the factor(s) corresponding to the discrete variables Z_j. Into each cell are accumulated the number of deaths and the total time at risk, which are sufficient statistics for the exponential distribution. Time-dependent covariates are easily incorporated as Z_{ij}, so that a man may contribute time at risk to different strata in different intervals; the summary table can still be compiled at one pass through the data.

The assumption of a constant hazard within an interval implies an exponential distribution of deaths. HOLFORD (1980) has shown that the analysis of this model for making inferences about $\boldsymbol{\beta}$ is closely related to models derived from the Poisson and multinomial distributions, including the log-linear models increasingly used for contingency table analysis. The model is in fact a special case of Generalized Linear Model (NELDER and WEDDERBURN, 1972), and analysis of such models is explicitly catered for in both the statistical analysis computer packages GENSTAT (ALVEY et al, 1977) and GLIM (BAKER and NELDER, 1978). Alternatively, they can be solved by a general maximum-likelihood program.

Whichever program is used, the maximisation of the likelihood requires iterative computation. However, when the cells in the table are considerably fewer than the individuals it summarises, the saving in computing time can be substantial.

In the above formulation of the model the λ_i were completely arbitrary. It is possible to extend the analysis by allowing the λ_i to have a functional dependence on i. This is equivalent to fitting a parametric hazard in the form of a step function. Where the form of this function can be specified in a simple way, the fact that fewer parameters are being fitted will improve the rate of convergence of the computations.

In the present study, preliminary plots of the hazards against time suggested that the logarithm of the hazard was roughly linear in time. This is equivalent to the hazard deriving from the Gompertz family of distributions, and the statements of statistical significance arising from analyses of these models have been fitted with this constraint, that $\lambda_{ij} \propto \exp(i)$.

The usefulness of Holford's approach depends on the effect of grouping the time axis and any continuous covariates into discrete intervals. While it is theoretically preferable not to group continuous variables, the great saving in computing costs has recommended Holford's approximation. No investigation has been carried out on the effect of altering the groupings on the size and power of the tests.

A6 An alternative estimator for the hazard and survivor functions

Survival estimates analogous to those described in A3 can be calculated from the information accumulated for the analysis of A5. If in each interval i and each defined stratum k there are d_{ik} deaths from a total risk time of τ_{ik}, then standard theory for estimation in the exponential distribution leads to the estimates

$$\hat{\lambda}_{ik} = \frac{d_{ik}}{\tau_{ik}} \qquad \hat{V}(\hat{\lambda}_{ik}) = \frac{d_{ik}}{\tau_{ik}^2}$$

The survivor function at the end of the n^{th} interval is estimated as

$$\hat{S}_{nk} = \exp\left(-\sum_{i=1}^{n} \hat{\lambda}_{ik}\right)$$

An approximate variance estimator for $\hat{S}$ is derived by taking the first-order Taylor series expansion in n dimensions, whence

$$\hat{V}(\hat{S}_{nk}) \doteq \hat{S}_{nk}^2 \hat{V}\left(\sum_{i=1}^{n} \hat{\lambda}_{ik}\right)$$

$$Cov(\hat{\lambda}_{ik}, \hat{\lambda}_{lk}) = 0, \quad i \neq l$$

$$\therefore \quad \hat{V}(\hat{S}_{nk}) \doteq \hat{S}_{nk}^2 \sum_{i=1}^{n} \hat{V}(\hat{\lambda}_{ik}) = \hat{S}_{nk}^2 \sum_{i=1}^{n} \frac{d_{ik}}{\tau_{ik}^2}$$

This method is basically the same as is used in the life-table methods, except that it uses the exact times to death or censoring within an interval. The estimates produced in this way should agree well with those produced by BMDP1L; the same caveats about the approximation in the face of extensive censoring apply.

The above assumes that the estimation in each of the k strata is performed independently. However, only slight adaptation would be necessary to produce estimates of survivor functions from values of the $\hat{\lambda}_{ik}$ fitted by the model over all the strata, and therefore constrained to be proportional between strata.

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