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HISTORICAL RESEARCH REPORT

Research Report TM/94/07
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World Health Organisation
Collaborating Centre
For Occupational Health

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INSTITUTE OF OCCUPATIONAL MEDICINE

CROSS-SECTIONAL STUDY OF RISKS OF RESPIRATORY DISEASE IN RELATION TO EXPOSURES OF AIRBORNE QUARTZ IN THE HEAVY CLAY INDUSTRY

by

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EXECUTIVE SUMMARY

Aims of the Study

The National Federation of Clay Industries commissioned the Institute of Occupational Medicine to conduct an independent study to determine whether airborne dust caused a significant health risk in the non-refractory heavy clay industry, and to obtain information on the degree of risk, if present, which would help to inform decisions on dust control measures.

Field Studies

Eighteen factories in England and Scotland were studied between 1990 and 1991. 1407, mostly full shift, dust samples were collected using lapel-mounted samplers, and the mass of mixed fine dust and quartz was measured. Usual exposures to dust and quartz were characterised according to broad occupational groups. Dust concentrations in the past were assumed to be similar to current measurements, with the exception of plants where changes of kiln type had occurred, for which the assumed past dust concentrations were adjusted.

1925 workers were medically examined and provided detailed occupational histories. Chest X-rays were taken and interpreted to identify pneumoconiosis (dust in the lungs) according to standard procedures. Chronic bronchitis (persistent cough and phlegm) was identified by questionnaire. Each man's lifetime history of cumulative exposure to fine mixed dust and quartz was calculated by combining the dust

concentrations for occupational groups with the occupational history.

The data were processed, analysed and reported at the IOM headquarters in Edinburgh.

Results

A small number of men (eight) had category two or greater small spots (opacities), or large opacities in the lungs visible on the chest X-ray. These categories correspond to established pneumoconiosis, and diagnostic confusion with other, non-occupational disease, is rare at this level. The men had all worked for prolonged periods in the heavy clay industry, and only two had worked in other industries where exposure to harmful dusts had occurred.

Another seventeen men had category 1 small spots in the lungs visible on the X-ray, consistent with definite but slight abnormality or, possibly, in some cases, other disease. Thus in total twenty five men had small spots of category 1 or greater. This frequency (1.4%) is less than those found in recent studies of opencast coalminers (4.4%), hard rock quarry workers (4.7%), and non-dust-exposed postal and telecommunication workers (2.7%).

3.7% of the heavy clay workers had X-ray appearances on the borderline between normality and abnormality (category 0/1) or worse. These low categories of spots can also be caused by age, smoking and other diseases.

Men were statistically significantly more likely to have small spots of category 0/1 or greater on their X-ray if they were older, or had experienced higher lifetime exposures to dust and quartz than other men. Smoking habit was taken into account, but had little influence in this population.

Men with small spots of category 1 or greater were similarly more likely to be older and to have had higher dust exposures, though the smaller numbers of men reduced the statistical significance. The statistical analyses estimated, for example, that the risk of having category 1 or greater for a 40 year old non-smoker after 20 years work in jobs with the lowest dust concentrations would be 0.6%. He would have a 1.4% risk, if he had worked for 20 years exposed to a mixed respirable dust concentration of 2.5 mgm^{-3} (half the accepted occupational exposure standard for dusts not assigned a specific occupational exposure limit). If he had been exposed to 0.4 mgm^{-3} of quartz for 20 years, he would have a 2.1% risk.

For comparison a recent study of underground coalminers exposed to coalmine dusts (for which the health risk is well recognised but which usually contain less than 10% quartz) indicated a 2.8% risk of category 1 or greater small spots after 20 years exposure to 2.5 mgm^{-3} of mixed dust on average.

Thus the risks in proportion to degree of exposure to mixed dust appear to be no greater, and are possibly less, in heavy clay workers than in coalminers, even though the amount of quartz in the dust is higher, in some cases substantially, in the heavy clay workers. Free quartz particles were present in the airborne dust, and these only rarely appeared to be freshly fractured. Possibly the very ancient nature of the quartz particles reduces their harmfulness.

Nevertheless the estimates of risk in heavy clay workers still suggest small health risks even at quartz concentrations as low as 0.1 mgm^{-3} (over a long period), a much lower concentration than the 0.4 mgm^{-3} Maximum Exposure Limit. If confirmed, this has implications for the dust control strategy, and some further statistical analyses would be desirable to clarify the evidence for health risks in this low exposure range.

Chronic bronchitis was also found to be more frequent in those with high exposure to mixed dust than in those with low exposure. In general this effect was small in relation to the effects of smoking and non-occupational causes, but was particularly severe in kiln demolition workers.

Recommendations

It is recommended that the industry focusses on reducing respirable quartz concentrations in specific jobs and occupations where levels exceeding the Maximum Exposure Limit have been shown to occur, particularly kiln demolition workers, clean up squads, sand users and some pan mill operators and tile moulders. The most cost-effective methods of control could be implemented based on well-established principles.

The extent to which the target quartz concentrations should be below the Maximum Exposure Limit will be influenced by practicability and by the degree of and severity of health risks at low quartz concentrations. Some further statistical analysis is recommended to clarify the evidence for risks at concentrations below the exposure limit.

Medical surveillance, comprising chest radiography, questionnaire of respiratory symptoms and, preferably, simple lung function tests, is indicated for all dust exposed workers in the industry. The lung function of the kiln demolition workers and other very highly exposed groups in particular should be assessed. The interval recommended by the Health and Safety Executive for silica exposed workers is two years for chest radiography. Medical surveillance should also include the collation and reporting of health statistics on a national basis.

However, a case could be made for a lesser frequency of medical surveillance, including chest X-rays, for workers in the heavy clay industry, in view of the relatively small risks and expected slow progression of disease. A lesser frequency should be subject to review.

EXTENDED SUMMARY

1. There is a continuing debate about the limits that should be recommended for occupational exposure to crystalline silica, and especially for respirable quartz in mixed dusts. In the UK a maximum exposure limit (MEL) of 0.4 mgm^{-3} has been established for the past two years, though the World Health Organisation has identified a limit of 0.04 mgm^{-3} to prevent all health effects. Within the heavy clay industry, covering the production of most bricks, pipes and tiles, it has been suggested that the presence of other minerals in the dust, such as illite and kaolinite, may reduce the harmful effects of quartz.

Only a limited amount of information is available on dust levels, and on the frequency of pneumoconiosis in the heavy clay industry in this country, and no study has been carried out in the UK to relate respiratory health of heavy clay workers to the levels of dust and quartz in the workplace. The National Federation of Clay Industries therefore commissioned the Institute of Occupational Medicine to carry out an epidemiological study of heavy clay workers in Great Britain, to study the frequency of pneumoconiosis and chronic bronchitis in heavy clay workers, to describe the concentrations of mixed dust and quartz to which they are exposed, and to examine the risks, if any, of respiratory disease in relation to exposure to dust and quartz. Only manufacturers of non-refractory products were included, and since pneumoconiosis may occur one, two or more decades after the relevant exposure, the study preferentially included factories where conditions and working methods had changed as little as possible over the previous twenty years.

2. The aims of the study were to determine:

(i) what exposures to respirable mixed dust and quartz are currently experienced by workers in the heavy clay industry, in factories where conditions and methods have changed as little as possible in recent years? (ii) what are the estimated cumulative exposures to dust and quartz experienced by these current workers (and, if feasible, a subset of ex-workers from the same plants?) (iii) what are the frequencies of chest radiographic abnormalities and respiratory symptoms in these workers? (iv) what are the relations in current workers between cumulative exposure to respirable dust and quartz and risk of respiratory symptoms and radiographic abnormality? A consequent aim was to make recommendations to the industry about the procedures to be adopted to control any risks which may be demonstrated.

3. Following an initial pilot study of several potential sites, eighteen factories were selected (by the IOM) in England and Scotland. The sites were located in most of the main brick, tile and pipe manufacturing areas of the country and included factories using soft clays, soft mud, marls and shales. The selected factories ranged in size from large stock brick works using soft clays and employing several hundred workers to smaller works (about thirty employees) making facing bricks and special shapes using shale-based clays. Where possible works were selected in which processes had been in operation unchanged for at least twenty years, in order to maximise the likelihood of establishing clear relationships between dust exposure and respiratory health effects. Inevitably changes, especially to the

types of kiln used, had occurred during this period and, where quantifiable, these were taken account of in the analysis.

Although it had been intended to conduct a medical survey of leavers from selected works a feasibility study of two factories indicated that the benefits were outweighed by the difficulties in obtaining sufficient response from invited leavers to allow reliable conclusions to be drawn. Consequently only a small survey at one factory was carried out and resources were directed towards increasing the number and variety of factories included in the study (three additional factories, including two using the traditional soft mud process).

The eighteen sites visited consisted of eleven in Scotland and the North of England, which used shale as the raw material; six, in the Bedfordshire/Peterborough area and in south-east England using soft clays and muds; and one in the English Midlands, using a marl. The types of kiln used included Hoffman, or moving fire, kilns, continuous tunnel, intermediate and one clamp kiln, fuelled by coal, gas and oil separately or in combination. Some of the factories were of the traditional, labour intensive type, whereas others, as it turned out, had undergone many changes and improvements during the last 25 years.

4. All selected sites were visited initially, after agreement to participate had been obtained, to explain the nature of the surveys. Subsequently an occupational hygienist made a preliminary visit to each site to plan the dust sampling required to obtain representative dust and quartz concentrations in jobs performed at the site. Complete lists of the current workforce were obtained, and certain designated jobs, such as off-site lorry drivers, were excluded. Site history details were obtained during these initial visits and subsequent occupational hygiene surveys, in order to identify important changes to plant and processes, introduction of local exhaust ventilation (LEV), and respiratory protective equipment (RPE).

5. On average, dust sampling took place for five days on each site, extending to ten days for the larger sites. Information on production processes and rates at the time, wearing of RPE and the use of LEV was recorded. Most exposures to dust and quartz were measured by means of full shift personal sampling methods. A small number of static samples, in areas where people passed through, were also collected. Personal respirable dust samplers were worn on the lapel, with belt-mounted pumps. The number of valid samples collected at each site ranged from 33 to 245, 1407 in total. The number of dust samples collected from each occupational group (OG) varied, according to the perceived dustiness of the jobs, and numbers employed, from over 300 (supervisors and pre-production workers) to less than ten (brick cutters, kiln demolition). Most of the samples for the clean-up squad and kiln demolition came from one site. All dust samples were weighed and analysed for quartz content using standard on-filter methods, mostly by means of infrared spectrophotometry. Respirable dust and quartz concentrations and the percentage of the sample consisting of quartz were derived for each sample.

6. In addition, more limited analyses of dust samples from pre-production processes, e.g. crusher, mixer, at three factories were carried out to determine their particle size distribution and mineral content. One thousand particles from

each sample were analysed using Scanning Transmission Electron Microscopy, so that each particle could be characterised within a specific size range and designated as a specific mineral, where possible, according to set criteria.

7. More than 300 individual job titles were allocated during the occupational hygiene surveys to 23 occupational groups (OGs). These measurements and observation of the work processes were used to classify the workforce into twelve distinct occupational groups, within which exposures to dust and quartz were judged to be similar. These OGs consisted of, in increasing order of dustiness; 1. No direct exposure to dust, mostly office workers; 2. Supervisors, including kiln burners, workshop fitters, fork lift drivers and coal handlers; 3. Pre-production, including quarry workers, brick make operators, setters and moulders; 4. Brick cutters (fired bricks). 5. Mixed dust group, including plant fitters and general fork lift drivers; 6. Post-production, including brick layers and packers; 7. Fork lift drivers in kilns/driers; 8. Pan mill operators; 9. Labourers, general and around kilns; 10. Sand users, e.g. mixers, applicators; 11. Clean-up squad, carrying out short, intensive factory cleaning, flue cleaning; 12. Kiln demolition workers, of Hoffman kilns.

8. Individual respirable dust concentrations ranged from 0.1 mgm^{-3} to 100.1 mgm^{-3} (in a cleaner) and OG averages ranged from 0.4 mgm^{-3} (OG1) to 10.0 mgm^{-3} (OG12). 97% of concentrations were below 5 mgm^{-3}, and all kiln demolition samples were greater than this.

Quartz was detected in 97% of samples, the highest concentration being 3.8 mgm^{-3} in a general labourer at a traditional, coal-fired Hoffman site. Average OG quartz concentrations ranged from 0.04 mgm^{-3} (OG1) to 0.62 mgm^{-3} (OG12). Three per cent of all samples had quartz concentrations greater than 0.4 mgm^{-3} (the current MEL) and more than 10% were greater than the MEL in OGs 10, 11 and 12.

9. The dust and quartz concentrations followed a log-normal distribution and the few very high values contributed disproportionately to the total exposure: for example, the 14 highest values (1% of total) accounted for 20% of the total dust exposure. Occupational groups were the most important determinant of dust and quartz concentrations, although the type of kiln was also important for variation of dust concentrations: employees at works using Hoffman kilns were exposed on average to 1.5 times the dust concentration of the workforce doing similar jobs in works using other types of kiln.

10. Detailed analysis of respirable dust samples from three sites (4, 16 and 17) demonstrated that the median particle diameter was in the range 0.5 – 0.7μm. Individual quartz particles were detected in all samples but these only rarely consisted of fractured quartz grains. Mineralogical analysis, using scanning electron microscopy/energy dispersive X-ray spectroscopy methods, suggested that the proportions of particles identified as quartz were respectively 11, 12 and 21% by volume. In the sample from site 16, at which manganese was a known additive 10% of particles appeared to be manganese oxide and most other particles were contaminated with manganese.

11. Cumulative (lifetime) exposure to dust and quartz was derived for each individual attending the medical surveys. This was based on a detailed occupational history, which listed all jobs since leaving school, measurements of dust and quartz concentrations within the occupational groups at the place of work, estimated concentrations for work at other brickworks not in the study, and corrected estimates of past exposure at sites where the type of kiln had been changed.

12. All identified employees from the selected sites were invited to participate in a medical survey, at which a full size chest radiograph was obtained in a mobile X-ray unit on site; respiratory symptoms, smoking and occupational history questionnaires were administered, by trained personnel. Symptoms of chronic bronchitis (persistent cough and phlegm), wheezing and breathlessness were identified from the questionnaire. All jobs within the heavy clay industry were coded and assigned to occupational groups, previously identified by the occupational hygienists, and jobs outside the industry were assigned to noxious or non-noxious categories using well-established principles.

13. Chest radiographs were read for clinical purposes by an occupational physician who informed individual employees if there was any need to consult his or her own doctor. The radiographs were subsequently randomised and interpreted by three experienced medically trained readers according to the standard ILO (1980) international Classification of Radiographs of Pneumoconioses.

This method requires an assessment by each reader of the profusion of small spots (opacities) on the chest radiographs, according to a twelve point scale of severity. Categories 0/- and 0/0, the first and second points on the scale, would be considered normal. Category 0/1 (the third point) is on the borderline between normality and abnormality, and category 1/0, the fourth point, represents definite but slight abnormality. These assessments merely represent descriptions of the appearances (spots) on the radiograph, and do not constitute a diagnosis. Thus not all men with small opacities have pneumoconiosis, since aging, smoking and other disease can contribute to these appearances. Some men with small opacities are likely to be found in any industrial population. The focus of this study has therefore been on whether radiographic small opacities are unduly frequent in this population, and to what extent they can be shown to be associated with dust exposure as well as aging and smoking. The shape of these opacities is also described by the readers according to whether they have a rounded or irregular appearance, because different relationships may be observed between the different shapes of opacities and dust exposure, age and smoking.

Category 2/1 (the seventh point on the scale) or greater is usually understood to represent established pneumoconiosis, and the diagnostic uncertainty is small, in dust-exposed workers. Complicated pneumoconiosis can occasionally supervene, and this is recognised as large opacities.

14. 1925 subjects attended the medical surveys, 1852 men and 73 women, representing a response rate of 85%. None of the women (mostly office and canteen staff) had any radiological abnormalities and were not considered further in the analysis. Chest radiographs and other medical information were available for 1831 men, who formed the study group for subsequent analysis. The average age of the workforce was 40 years and 42% of them were current smokers.

There were few radiographic abnormalities according to the ILO classification. The frequency of small opacities category 1/0 or greater was 1.4% (median of three readers). Seven of these 25 men had category 2/1 or greater and one other man had large opacities category A, the least advanced stage of complicated pneumoconiosis. These eight men, aged from 29 to 61, had spent most of their working lives in the heavy clay industry, and currently worked at five different sites. Only two of them had worked in other industries with relevant potentially harmful exposures. 3.7% of all workers had category 0/1 (the earliest signs of abnormality) or greater. Although there was not good agreement between readers on the shape and size of small opacities, the readers agreed well on the category of profusion (over 90% agreement between pairs of readers on the simplified 4 point scale, i.e. categories 0, 1, 2, 3).

Risks of having category 0/1 or greater small opacities were found to be influenced by age, smoking and lifetime cumulative exposure to mixed respirable dust. After allowance had been made for the effects of age and smoking, the association with dust exposure was confirmed. A doubling of cumulative exposure to dust increased the risk of having category 0/1 or more by a factor of 1.4, a statistically significant effect at the 5% level. This effect was slightly reduced but was still significant when the site worked was taken into account. Similar relationships were found between category 0/1+ or greater and quartz exposure. As an example non-smoking workers currently aged 40 and exposed to a dust concentration of 2.5 mgm^{-3} for 20 years, would have a predicted prevalence of category 1/0 or greater of 1.4% (95% confidence interval 0.5, 4.0%). For similar workers the risk at low dust exposure was estimated to be 0.6%.

When these analyses were repeated for category 1/0 or greater the relationships were generally similar but, owing to the smaller numbers of abnormal cases involved, the effects were no longer statistically significant. Since there was a very close relationship between dust and quartz exposures (coefficient of correlation = 0.965) inclusion of both these variables in the analysis caused a loss of precision of the estimated effects. There was, however, stronger evidence of an effect of quartz than of mixed dust exposure, consistent with the known relationship between quartz and radiological changes. Examination of the data for men who had spent significant amounts of time working in other dusty industries indicated that they had a similar prevalence of category 1/0 or greater, 1.2%, to the whole study population. Exclusion of the three kiln demolition workers, the OG with the highest dust exposure, did not substantially alter the size and significance of the relationships between radiological abnormality and exposure to dust and quartz.

15. Chronic bronchitis was reported by 14.2% of the population, breathlessness when walking with someone of their own age by 4.4% and wheezing by 20.6%. Chronic bronchitis was more frequent among smokers (22.5%) than non-smokers (7.4%) but was not related to age. For both chronic bronchitis and breathlessness there was a statistically significant relationship with dust exposure in the population as a whole and for kiln demolition workers in particular. For example, among non-smoking, non-dust exposed workers of 40 the expected prevalence of chronic bronchitis would be 6.7% (1.6% for breathlessness) rising to 7.6% (2.5% for breathlessness) for an exposure of 40 mgm^{-3} years to dust in the heavy clay industry. Among kiln demolition workers, who experienced much higher dust levels, estimated prevalences would be 14% and 26% for exposures of 80 and 160

mgm^{-3} years respectively (3.3 and 6.6% for breathlessness).

Conclusions

16. We conclude that while most mixed dust and quartz concentrations are below regulatory limits, high exposures to dust and quartz regularly occur in some specific processes in the heavy clay industry, notably kiln demolition, clean up squads and sand users. Occasional dust concentrations greater than regulatory limits occurred in most occupational groups.

Risks of having small opacities were demonstrably influenced by cumulative exposure in the industry to mixed dust and quartz, more strongly to quartz. The frequency of such opacities was generally low. For example the frequency of category 1/0 or greater small opacities is 1.4%, compared with 4.4% in open cast coalminers, 4.7% in hard rock quarrying workers, and 2.7% in non-dust-exposed telecommunications and postal workers. Nevertheless, a few men with many years service in the industry had evidence of established pneumoconiosis. The risks in proportion to exposure to mixed dust were no greater, and were possibly less than in underground coalminers, even though the proportions of quartz were greater in the clay industry dusts.

There was also an increased risk of chronic bronchitis in relation to exposure in the industry to mixed dust. The risk was modest in general, but substantial in a small group of kiln demolition workers exposed to high dust concentrations.

Recommendations

17. On the basis of the measurements of respirable dust and quartz obtained during this study, it is recommended that the heavy clay industry focus on reducing respirable quartz concentrations in specific jobs and occupational groups where levels exceeding the MEL have been shown to occur, particularly kiln demolition workers, clean-up squads, sand users and some pan mill operators and brick and tile moulders. The most cost-effective methods of dust control could be implemented based on the well established principles.

The extent to which the quartz concentrations should be reduced below the MEL will be influenced by practicability and by the degree of health risk at low quartz concentrations. Some further statistical analyses of these risks would be informative.

Medical surveillance, comprising chest radiography, questionnaire of respiratory symptoms and, preferably, simple lung function tests, is indicated for all dust exposed workers in the industry. The lung function of the kiln demolition workers and other very highly exposed groups in particular should be assessed. The interval recommended by the Health and Safety Executive for silica exposed workers is two years for chest radiography. Medical surveillance should also include the collation and reporting of health statistics on a national basis.

However, a case could be made for a lesser frequency of medical surveillance, including chest X-rays, for workers in the heavy clay industry, in view of the relatively small risks and expected slow progression of disease. A lesser frequency should be subject to review.

1. INTRODUCTION

There is a continuing international debate on recommended occupational exposure limits for respirable quartz. In the USA the ACGIH has recommended a $0.1 mgm^{-3}$ shift average concentration (ACGIH, 1986). The maximum exposure limit (MEL) in Britain is $0.4mgm^{-3}$ (HSE, 1992). A World Health Organisation working party suggested a health-based exposure limit of $0.04mgm^{-3}$ but qualified this by commenting that none of the exposure limits was soundly based, recommending further research into the risks related to exposure to airborne quartz (WHO, 1986).

Furthermore there is some evidence to suggest that the risks associated with quartz may vary from industry to industry, since the presence of other minerals in the dust may possibly lessen the harmful effects of quartz (Walton et al, 1977). This is particularly relevant where quartz is associated with clay minerals, such as illite, kaolinite and smectite, as in the heavy clay industry.

Following discussions with the National Federation of Clay Industries of Great Britain (NFCI) and the Health and Safety Executive, a cross-sectional study of workers in the British clay industry, covering manufacture of bricks, tiles and pipes, was proposed, in order to determine the risks of respiratory disease in relation to the exposures to quartz which such workers have experienced. The study specifically excluded refractory works, which differ in some respects from the non-refractory processes which were the main focus of the study. A respiratory health risk from quartz in the refractory brick production process is already recognised.

1.1 Overview of Relevant Literature

1.1.1 Dust conditions in the heavy clay industry

Limited published data are available on exposures to airborne dust in the heavy clay industry. Although a number of papers, published between 1940 and 1990, discuss the exposure of workers to total dust, and to a lesser extent respirable dust, the value of the results quoted may be of limited use to the current study.

The respirable quartz in dust is a known cause of pulmonary disease in other industries and is therefore an important parameter to measure when assessing the health of workers in the heavy clay industry. Unfortunately many of the published papers do not report directly the exposure to respirable airborne quartz; instead the compositional analysis of either settled dust or raw materials has been quoted.

The present recommended methods for sampling for total inhalable and respirable dust are detailed in HSE (1989) (see section 2.2.3 of this report). The analytical methods to assess the quartz content of respirable dust is also fully documented in HSE (1987) (section 2.2.4). However, these sampling and analytical methods have not always been applied either in the UK or abroad. This review of previous studies shows that various methods have been used by investigators.

The use of different sampling and analytical methods makes direct comparison between studies difficult. It is only in relatively recent years that the collection of personal samples has become the norm. Many of the historical studies concentrated on those occupations deemed to be the dustiest and made no attempt to monitor persons from every occupation, thus causing bias in the estimates of exposure. Analysis of quartz content was often limited to the raw material or settled dust collected.

Trice carried out an investigation of the health of brick and tile plant workers in North Carolina (Trice, 1941). The investigators found no cases of silicosis amongst 1555 employees and offered low quartz concentrations, absence of excessive dust concentrations and a high turnover of labour by way of explanation. However, the paper does not describe the analytical methods applied and relates only to total dust measurements. Although estimates of quartz content were made on atmospheric dust and settled dust, these are of limited value in assessing the exposure to respirable quartz.

After a preliminary analysis showing a free silica content of 35-40% in clay, Keppler and Bumsted (1950) undertook a study of the entire building brick industry in Indiana. The free silica content of settled dust and raw materials was analysed by the chemical method of acid leaching. This method may overestimate the quartz content and cannot be related to personal exposure. Atmospheric dust concentration was expressed as millions of particles per cubic foot (mppcf), which would require additional information to permit conversion into respirable mass concentration of dust.

Studies have also been conducted by brick companies themselves, eg Keatinge and Potter (1949) for the Butterley Company Limited. Although this environmental and health study concluded that the dust hazard in the brickworks was not excessive, conclusions were again based on static samples and no estimates of quartz exposure were made.

In more recent times Rajhans and Bodlovsky (1972) used high volume samplers to collect respirable dust in Ontario brick plants. Dust measurements were expressed in mgm^{-3} and many of the measured dust concentrations were in excess of the relevant control limit. However, the subsequent analysis involved washing dust from one filter and redepositing it onto another to enable analysis of quartz by X-ray diffraction. There was a high degree of interference in the samples due to the presence of mica and the subsequent results are likely to be an overestimate.

Myers et al (1989) investigated the work environment in five brickworks in South Africa. Total dust, respirable dust and percentage of free silica were used as indicators of personal exposure. Although the actual methods of collection and analysis are not described the estimate of quartz exposure is thought to be accurate. Average respirable dust concentrations at five works, based on personal sampling, was $2.2mgm^{-3}$ and the mean free silica percentage was 2.1%.

Recent assessment of airborne dust monitoring has been carried out by consultants for the NFCI using gravimetric samplers at fixed locations (Personal Communication). A hand held aerosol monitor was also used to assess respirable dust concentrations; however, low dust concentrations rendered the results invalid.

1.1.2 Respiratory health problems in the heavy clay industry

A small number of studies have been performed which examined the health status of brickworkers (non-refractory). The majority are cross-sectional. The sample size in some is small and none has evaluated the health of workers who have left the industry. The studies were performed in Europe, North America and South Africa.

Two early studies provided contrasting views of the health effects of exposure to heavy clay dust. Sayers et al. (1937) observed that there was no serious dust hazard from working in the US brick and tile manufacturing industry, whereas nearly 50% of workers in an Italian tile works were found to have silicosis (Barsi, 1953).

Within the United Kingdom only one previous study has been published which relates to this industry. Keatinge and Potter (1949) performed a limited cross-sectional study in three of four brickworks of the Butterley Company. Measurements of environmental factors (including dust) were performed and are discussed in the review of previous hygiene studies. Of 144 employees one hundred were medically examined. Seventy-three had chest radiography performed. The majority of the workforce examined were under 45 years of age (82%). The authors noted that the majority of workers who underwent radiography were not exposed to a dust hazard of any magnitude. One worker had radiographic features described as early reticulation. One other who was a new entrant to the industry, a man aged 49 years, had radiological appearances of classical silicosis. Previously he had worked as a bricklayer's labourer. The average length of employment in the brick industry was only 7.88 years/worker - this suggests that a number of employees were unlikely to have had enough exposure to result in disease at the time of the study. No follow-up paper has ever been published.

The only other evidence from the United Kingdom has been compiled by the Health and Safety Executive from examination of the records of the Pneumoconiosis Medical Panels. This work, performed on behalf of the National Federation of Clay Industries, identified 12 cases over 28 years (1952-1979) in pipes, brick and tile manufacture.

Wiecek, Goscicki, Indulski and Stroszejn-Mrowca (1983) performed an analysis of occupational diseases in Poland during 1979-1980 in workers of the brick industry. Two cases of pneumoconiosis are recorded in the text as occurring in the building ceramics industry - these were found among firebrick workers. No cases were found in red brick workers.

The only other European evidence for a silicotic effect of brick dust is available from a paper reporting two cases of silicosis in brick and concrete drillers (Hodel, Schlegel and Rüttner, 1977). The quartz content of the dust ranged from 13.5 to 26.5% of dust of $<5\mu m$ diameter. The maximum quartz concentration was $1.2 mgm^{-3}$.

The North American experience reflects that of the European papers. Trice (1941) examined the health of brick and tile plant workers in North Carolina. One thousand five hundred and forty-six radiographs (495 pre-employment controls and 1051 workers) were read separately by two physicians. Neither reported any evidence of silicosis. Eighty percent of the workers did not have an excessive exposure to dust ($<150 \times 10^6$ particle.years). Only twenty workers were exposed to more than 500×10^6 particle years of dust and only one had more than 1600 $\times 10^6$ particle years of dust exposure. There was no acute hazard from the dust in relation to silicosis. With almost half the workers employed for less than 10 years they were unlikely to have accumulated a significant dust exposure, and may never have done so, given the high labour turnover rate of the industry.

Rajhans and Budlovsky (1972) reported the results of analysis of 1166 Canadian brick production workers' radiographs. Only one film showed diffuse miliary nodulation. This was in a man who had spent 13 years working in a Haematite mine and only 2 years in a tile plant. A larger proportion of the films of crushers (22%) had heavier lung markings compared to other employees (11%). The authors considered that since age, seniority and smoking habits did not differ between the two groups the larger proportion of films with heavier lung markings was associated with the higher concentration of the inhaled dust to which the crushers were exposed.

Palmer, Donaldson, Anderson, Jones and Stringer (1980) reported the results of a further study of brick and pipe makers employed in North Carolina. They showed a decrement in lung function (FVC and FEV_1) of marginal statistical significance ($P<0.1$), for Caucasian brickmakers compared to controls. Five percent (21 of 415) brickmakers had abnormal chest radiographs; 3% (21 of 673) controls had abnormality noted. The films were graded by an experienced ILO film reader but the exact ILO categorisation of these films is not recorded in the report.

The experience from South Africa is somewhat different to that so far described. Sluis-Cremer (1972) reviewed pneumoconiosis in South Africa. He quoted incidence rates of pneumoconiosis (per 1000 employees) in general industry from a 1963 South African Department of Labour Report. The incidence of silicosis in stock brick manufacture was 43 per 1000 workers. In pottery, tile and pipe manufacture the incidence was 25.8 per 1000, and in face brick manufacture it was 23 per 1000. Refractories had an incidence of 74 per 1000. Monumental masonry had the highest incidence at 123 per 1000.

The 1963 report, referred to in the previous paragraph, was based on 356 'pneumoconiotic' X-rays out of a survey population of 5531; 256 of these were put into a category 'numerous linear or reticular opacities'. The classification would be similar to irregular opacities (s, t, u) according to the ILO classification.

Two reports have examined pneumoconiosis in non-mining industries on the Witwatersrand. Webster, Cochrane and Solomon (1977) reported a case series of 287 patients referred to the National Research Institute for Occupational Diseases in less than 3 years. No cases of pneumoconiosis occurred in the three workers manufacturing building bricks. Cases occurred in silica brick manufacture (4 out of 5 investigated) and in furnace bricklayers (9 out of 11 investigated). The authors noted that certain brickyards make furnace bricks and fireclay as well as ordinary structural bricks. They indicate that it is in these yards that pneumoconiosis may be found. The second paper examined silicosis in the same area (Ehrlich, Rees and Zwi, 1988). Between 1972 and 1986, 217 cases were seen, including 46 cases of progressive massive fibrosis. Four industries accounted for 83% of the cases - foundries, ceramics factories, refractories and ore and stone crushing. Only one patient came from non-refractory brick manufacture. He had 23 years experience of loading and crushing clay in a brickyard, and had no other exposure.

Myers et al. (1989b) reported on the radiographic abnormalities in a cross-sectional study of 286 brickworkers which used internal controls based on dust exposure determinations. The brickworkers were employed in 5 yards in Cape Town. The prevalence of pneumoconiosis was approximately 4% (category 1/0 or above). Between 2% and 3% were of category 1/1 or above. The highest classification was 2/1 (one reader only). Though dust exposure was not high (mean respirable dust concentration = $2.2 mgm^{-3}$), there was an increase in pneumoconiosis prevalence with cumulative respirable dust exposure. In addition the prevalence increased with years of service (1.8% in those with ≤ 10 years, 17.4% in those with >10 years service). It should be noted that the authors had an initial population of 575 brickworkers (Myers et al. 1989a). They excluded women (n=28), those who were unable to produce acceptable spirograms (n=50), ex-smokers (n=39), cases with missing data (n=14) and those who had previous silica exposure for 2 or more years prior to working in the brickyard (n=176), (Myers and Cornell, 1989). The authors showed an effect of dust exposure on FVC and FEV_1 using multiple linear regression analysis. There was no smoking effect using this method of analysis (Myers and Cornell, 1989).

1.2 Aims and Study Design

The aim of the present study was the determination of the relationship, if any, between exposure to mixed respirable dust and quartz, and risk of respiratory disease in workers in the heavy clay industry. In order to achieve this aim the following research questions have been addressed.

1. What exposures to respirable mixed dust and free silica are currently experienced by those working on processes in the heavy clay industry which have been in operation without major change for approximately 20 years or longer? (In relatively constant processes present dust concentrations give an indication of the concentration experienced many years ago, most relevant to risks of health effects with long latency, such as pneumoconiosis).

2. What estimated cumulative exposures to respirable mixed dust and quartz (based on current exposures in occupational groups, time worked in those groups and history of changes in working methods,) have been experienced by workers currently employed in selected plants in the heavy clay industry. How feasible is a study of a group of workers who have left the industry?

3. What are the frequencies of respiratory symptoms and chest radiographic abnormalities in these workers?

4. What are the relations in currently employed workers between cumulative exposure to respirable mixed dust and quartz, and risk of respiratory symptoms and chest radiographic abnormality?

It was hoped to answer these questions by means of the following study design.

1. A cross-sectional environmental study of the airborne respirable mixed dust and quartz concentrations, to which workers are typically exposed during common operations in the heavy clay industry.

2. A cross-sectional study of the respiratory health of workers currently employed at works, in which these operations are performed, together with a feasibility study of men who have worked at a subset of those works but who have left the industry.

3. An examination of the relationships between health indices and estimated exposures to respirable mixed dust and quartz.

1.3 Pilot Studies

Prior to this study information collected in 1985 by NFCI and a series of brief visits by IOM occupational hygienists to plants selected by NFCI allowed a preliminary assessment of factors which may influence health effects in the workforce. The extent of existing records of health, personnel and environmental conditions was also evaluated. This information allowed us to identify the range of plant types, processes and raw materials, which should be included in the main study. A summary of these pilot studies is given in Appendix 1.

2. METHODS

2.1 Identification and Selection of Plants to be Studied

The principles of selection of the plants were based on the type of raw materials used, work size, end product and the main processes used during production. Since refractory works were specifically excluded from the study, plants were divided into two broad classes based on the raw material used: (a) Soft clays or marl (eg. Keuper Marl, Oxford Clay, more recent sedimentary rocks); (b) Shales, mudstones, fireclays (of carboniferous age and older). Soft clays and shales tend to contain 2–3% of calcium carbonates compared to about 30% in the marls. While this and other mineralogical differences that exist are probably unimportant with respect to likely health effects, the difference in physical properties, hardness and moisture content may produce different ranges of dust concentration in the preparatory stages of the production, irrespective of plant type or end product.

Works size may be relevant, since there could be systematic differences in conditions related to the size of the plant. Therefore, both large and small works were included in the studies.

The major end products sub-divide into (a) a wide variety of bricks; (b) tiles (roofing, flooring, etc); (c) pipes (drains, chimneys, etc). The tile and pipe products and processes are essentially similar and both types did not need to be included.

The following work processes were considered under broad classifications as a means of establishing occupational groups within the selected plants.

(a) crushing, grinding, screening
(b) wet pan grinding, mixing, pugging
(c) extracting, cutting, prefabricating, shaping, trimming
(d) hand making (bricks and tiles), dressing
(e) kiln loading, unloading, drying kilns, (shuttle, tunnel, Hoffman types)
(f) transporting (within plant) storing, maintenance, cleaning.

Some of these processes may be common to all plants, whereas others may be restricted to specific plants or types of plant. However, the final selection of eighteen plants included one large soft clay works with Hoffmann kilns, two medium size soft clay works, one medium size works using marl, two works using the soft mud process, a hand made tile works and eleven small to medium plants using harder shale-based clays producing a range of product types.

The plants were selected from the main clay mining areas of England and Scotland after consultation with industry representatives and HSE personnel. South East and Central England, Yorkshire, North East England and Central Scotland were the areas represented in the study group. Some of the works had already been identified and visited during the earlier pilot studies (see Appendix 1).

The eighteen works which participated (numbers of employees ranging from about 30 to 500) were expected to provide a study population of approximately 2000 persons. Some originally selected works did not agree to take part and were replaced with an equivalent works of approximately the same size and carrying out similar processes. Furthermore, the two works producing bricks using the soft mud process were subsequently included in the study as such works had not originally been represented. Works were also selected on the basis that some or all of the production processes had not changed substantially during the previous twenty years, to enable more reliable estimates of cumulative exposures to dust and quartz to be derived.

2.2 Occupational Hygiene Surveys

2.2.1 Site visits and histories

Preliminary visits

Following the identification and subsequent selection of brickworks to be included in the study, a preliminary visit was made to each site by an occupational hygienist. During these visits contact was made with key personnel ie. works manager and various supervisors. The opportunity was taken to explain the purpose of the survey and the wider implications of the study.

Information was collected about the work likely to be in progress at the time of the survey, shift times and the various processes in use at the site. The names of all employees and their job titles were obtained either at these preliminary visits or were subsequently sent to the IOM. Brief notes were made after each visit detailing the organisational structure of the brickworks, a summary of the processes and the number of employees in each occupation and any specific problems or points to note.

Site histories

Initial details of the history of the site were collected during the preliminary visits, the information being confirmed and expanded during the site surveys. Points noted included the following: age of plant, changes in type of kiln and fuel, changes in setting and packing procedures (eg. automation), use of sand over the years, changes in machinery (eg. type of brick-making machine), use of local exhaust ventilation (LEV), and use of respiratory protective equipment (RPE) (see Appendix 4). Where possible the dates of any changes within the plant were established. Formal records of such information were limited and much of the data obtained on site histories was gathered from employees' own recollections.

The age of the plants ranged from approximately 20 years to more than 100 years with the majority having been in existence for over 40 years. The major changes which have taken place over the lifetime of the plants prior to IOM surveys were related to the type of kiln eg. Hoffman to tunnel kiln, and the fuel used, eg. conversion from coal to gas. Associated with changes in kiln type was the degree of automation of setting and packing of bricks. The use of RPE within the industry was found to be limited and related changes were relatively few. The use of LEV was mainly associated with sand application operations and the major changes have, on the whole, taken place subsequent to the IOM's surveys.

The majority of the IOM surveys were conducted in 1990 when companies were responding to the COSHH Regulations (HSE, 1988a). The introduction of these Regulations and the change in status of the Occupational Exposure Limit (OEL) for crystalline silica from an Occupational Exposure Standard (OES) to a Maximum Exposure Limit (MEL) in 1992 have prompted many companies to install LEV systems during the last two or three years.

2.2.2 Dust sampling strategy

The various occupations present at each site were determined at the preliminary visits and the number of men in each group were confirmed. In order to maintain consistency between sites, individual jobs were classified under separate occupations which were subsequently combined into occupational groups. Selection of the men required to wear sampling equipment was made by the hygienist prior to the site survey.

A sampling plan was compiled detailing the number of samples required from each group, on each day and on each shift, where appropriate. Effort was directed towards sampling those groups where the provision of good information was felt to be important, eg. groups suspected to be exposed to high dust and/or quartz concentrations and groups where variability of exposure may have been large. However, those occupations where exposure to dust and quartz was less likely were also sampled, eg. supervisors. Whenever possible at least two samples were collected from each occupational group during the survey. In some cases this inevitably involved sampling the same person on more than one occasion.

The sampling protocol for each site stipulated the number of persons to be sampled in each occupational group on each day of the survey. However, because of practical considerations the occupational hygienist varied from the set protocol as required, in order to achieve a satisfactory spread of samples across each of the occupational groups. Additional jobs which were not always identified in the preliminary visit were included in the sampling protocol.

On average, sampling took place for five days at each site, extended to ten days at the larger sites. Sampling was mainly conducted by one occupational hygienist at each site. Where two shifts were worked two hygienists were required to work on site.

Records, using a standard proforma, were made of production techniques, levels of production, stoppages, wearing of RPE and the use of LEV. The prevailing ambient conditions were also recorded (wind speed, rainfall, overhead and ground conditions).

Personal samples were collected over a full shift for the purposes of estimating exposure to respirable dust and crystalline silica. A number of static samples were collected to evaluate the general dust and quartz concentrations in areas where people passed through but did not carry out any tasks.

2.2.3 Respirable dust sampling

The purpose of the dust sampling surveys was to determine the distribution of concentration of respirable dust and quartz to which employees in the industry are currently exposed. Up to 50 full-shift personal dust samples were collected at each site from members of each occupational group. These samples were collected using Casella cyclone samplers in accordance with the methods detailed by the Health and Safety Executive (HSE, 1989).

Persons selected to wear the samplers were asked to participate and, if they agreed, were fitted with a belt to which a sampling pump (Casella AFC 123) was attached. This drew air through the cyclone at a rate of 1.9 $l min^{-1}$, depositing the respirable dust fraction onto a preweighed 37mm Gelman GLA 5000 filter. Flow rates were checked with an external calibrated flow meter immediately prior to and after the sampling period. During the sampling period frequent checks were carried out to ensure the flow rate remained within ± 10% of the original flow. Where the flow rate was found to be deviating from 1.9 $lmin^{-1}$, but was still within 10% the flow rate was adjusted back to 1.9 $lmin^{-1}$. If the flow rate was found to lie outside the range 1.7 - 2.1 $lmin^{-1}$ the sample was rejected and, where appropriate, a new sample was collected on that person. The volume of air sampled was calculated from the recorded times and flow rates. On completion of sampling, the filters were returned to the laboratory for weighing and analysis of quartz.

2.2.4 Respirable dust and quartz analysis

Respirable Dust

The methods used generally followed those described in MDHS14 (HSE 1989). All the filters used in the various surveys were prepared identically. The filters were placed in individually numbered tins and left to stabilize for 24 hours in the laboratory balance room. After this conditioning period the filters were first weighed on a Sartorius 5 place electronic balance (reading to 0.01mg) and left to stabilize for a further 24 hours before their second weighing on the same balance. Any filters with a difference of greater than 0.05mg between the two weighings were rejected and 10% of the remainder were retained as controls.

After sample collection the sample filters, field blank filters and the appropriate laboratory control filters were again laid out in the laboratory balance room and allowed to stabilize at room temperature for 24 hours before their first reweighing, then for a further 24 hours before their second reweighing. The difference in the mean weights of the filter before and after use, corrected for the variation in the matched laboratory control filters, gave the weights of respirable dust collected. Where filters were excessively loaded with dust, and as a consequence some of the dust load was loose in the filter tins, the filters were weighed only once, as much of the dust as possible being brushed out of the filter tins and on to the filters.

Quartz: Infrared Spectrophotometry

Methods similar to those described in MDHS37 (HSE 1987) were used. The Infrared Absorption spectra of all the filters were recorded prior to sampling on a Perkin Elmer 1720X Fourier Transform Infrared Spectrophotometer (FTIR) and stored on computer disc. The spectral range recorded for analysis was from 900–650 wavenumbers cm^{-1}, covering the region of the characteristic absorbance doublet used for the respirable quartz determination at 800 and 780 wavenumbers cm^{-1}.

After sampling, the IR spectra of the filters and their dust burdens were again scanned by FTIR over the same spectral range and recorded to disc. The initial spectrum of each filter was then subtracted from that of the loaded filter to obtain the spectrum due to the collected dust. All measurements were carried out on this resultant spectrum. The peak heights of the two quartz absorbances at 800 and $780cm^{-1}$ were measured and compared to the calibration obtained from identical Gelman GLA 5000 filters loaded with standard A9950 quartz. The calibration filters were prepared by using the same types of sampling instrument and operating conditions as used in the industrial sampling to collect respirable dust from a dust cloud generated with A9950 standard reference quartz in a closed chamber.

Although it is believed that cristobalite, a form of silica produced at very high temperatures, can be found in non-refractory bricks and tiles, neither this nor the other methods described here are designed to detect the presence of this mineral in dust samples.

Quartz: X-ray Diffractometry

MDHS51/2 (HSE 1988b) describes the general method used for X-ray diffraction analysis of quartz on the filters. Filters were further analysed by the direct method of X-ray Diffraction, where the Infrared spectra suffered interference effects from the other minerals present in dusts. The diffraction patterns of the filters were scanned across the regions of the characteristic quartz diffraction peaks at 20.9°, 26.7°, 50.2° and 60.0° 2θ and the integrated peak intensities of any suitable peaks detected were measured. The intensities obtained were then compared to those measured on Gelman 5000 filters loaded as for the IR analyses with known weights of A9950 quartz to give the weights of quartz on the sample filters.

Subsidiary IR Analysis

Those filters with excessive dust loads which could not be analysed by these direct on-filter methods of Infrared Spectroscopy or X-ray Diffractometry were analysed by the Potassium Bromide (KBr) Disc method of Infrared Spectroscopy MDHS38 (HSE 1984). Weighed aliquots (up to 1mg) of the dusts were mixed with 250.0±0.1mg KBr in a pestle and mortar; a few drops of alcohol were added and the mixture was ground gently for about 10 minutes until dry. After further drying at 110°C for 1 hour the mixtures were pressed into 13mm discs and analysed by FTIR for quartz using the same measurement procedures as described earlier. Calibrations were carried out using discs made up with known weights of standard A9950 quartz. The percentages of quartz in the dusts calculated from this method were applied to the measured airborne respirable dust concentrations to calculate airborne respirable quartz concentrations.

2.2.5 Particle size and mineralogical analysis

The dust from an airborne dust sample collected on a Gelman 37mm GLA5000 5.0μm pore size filter was suspended in a 50% alcohol/water mixture. After ultrasonicating the mixture for 30 mins. suitable aliquots of the mixture were filtered onto Nuclepore 25mm 0.4μm pore size filters. Portions of these filters were then fixed onto copper grids by the Jaffe Wick process to give samples suitable for particle size analysis using Scanning Transmission Electron Microscopy (STEM). This process locates every particle, within the size range set by the operator, visible on the STEM screen, measures its size and diameter and analyses the X-rays given off by the particles when they undergo electron bombardment. Elements have characteristic X-ray emission spectra and by quantifying the emissions at different frequencies semi-quantitative analyses of individual particles can be obtained. Results are normally presented as percentages of elements in a particle. These are, however, actually the percentages of X-rays emitted which are attributable to a given element. Particles can be identified from these compositions. In the present study particles were classified as quartz, kaolin, illite/mica, rutile, calcium silicate, rust, manganese oxide, organic and other. The criteria for these classifications are shown in Table 2.1. These figures do not represent real compositions. Different elements emit X-rays at different intensities and particle morphology can also affect the emission intensity.

Samples from three different sites (4, 16, 17) in different parts of the UK, respectively, a shale-based brickworks in Scotland, a hand-made tile works in Sussex and a large stock brickworks in Bedfordshire, were analysed in this way in terms of the percentage of particles within specified size ranges and for a range of mineral classifications, such as quartz, kaolin and mica, as well as organic and other unclassified material. Consequently, each particle examined in a sample would be classified, where possible, as a particular mineral according to the criteria set for that mineral. Otherwise it will be unclassified or identified as organic material. It was not possible by this method to identify the presence of other minerals in small quantities on the surface of a quartz particle nor to distinguish a quartz particle with a freshly exposed surface from one with weathered surfaces.

2.3 Medical Survey

2.3.1 Identification and selection of subjects

Following initial consultations with management at each factory or company, a list of all persons employed on the site were provided a few weeks before the survey was due to begin. Letters of invitation to participate in the survey were distributed at the factory to all named personnel and any others who had subsequently joined the workforce. Drivers of delivery vehicles, which transported bricks or other heavy clay products off the site were not usually included in these lists. However, sales staff who were based at the factory were included, although often not available to attend the survey. Appointments were made where possible singly or in batches depending on which method was felt to minimise disruption of production.

2.3.2 Radiographic survey

Participants were seen in a mobile X-ray unit * situated in the factory yard, close to offices, in which questionnaires were administered. A full size chest radiograph was taken using a high kV (c. 125kV) technique on Siemens 150 equipment and the radiograph was developed immediately using a 3M XP510 automated processor, so that a repeat X-ray could be taken if the film quality was technically poor for any reason.

2.3.3 Respiratory symptoms questionnaire

A questionnaire of respiratory symptoms (based on the MRC [1986] questionnaire with supplementary questions about asthmatic symptoms) and smoking habits was administered by trained personnel. During the surveys employing the IOM X-ray unit this questionnaire was administered by an experienced clerk and during the other surveys the radiographer carried out this task following training by IOM personnel. A copy of the questionnaire is included in Appendix 2.

<u>Footnote</u> * IOM staff and X-ray unit examined men at sites 1 to 5 and 14 to 18. At sites 6 to 13 inclusive the X-ray unit and radiographer were provided by British Coal Radiological Services, courtesy of Dr MA Rickards. This radiographer, following training, also administered the respiratory symptoms questionnaire at these sites.

2.3.4 Occupational history questionnaire

A questionnaire was administered by another experienced clerk who ascertained details of all employment since leaving school, including job titles and description of employer's business, periods of unemployment, military service and extended periods abroad. Occupations in the heavy clay industry were recorded in a form compatible with the occupational groups identified at each site during the previous occupational hygiene surveys and each job was assigned a unique code number. Occupations outside the heavy clay industry were classified as "non-dusty/non-noxious" or "dusty/noxious" according to well-established IOM classification principles. The information from these questionnaires was subsequented combined with dust concentration data from the hygiene surveys to derive indices of exposure to dusts in the industry and periods of exposure to dusty or otherwise noxious jobs outside the industry.

2.3.5 Reading and interpretation of radiological results

Immediately after each survey the chest radiographs were interpreted clinically in association with relevant information about respiratory symptoms, chest illnesses and smoking habits. A brief medical report was sent to each person and, if he or she had given consent, to the family doctor where this was indicated. This clinical assessment was not used to establish definitive diagnoses of pneumoconiosis for the purpose of the research but was provided as a medical service to the participating employees.

All such results were treated in strict medical confidence and were not released to anyone except with the permission of the individual. (In this report the results of the research are in summary form and do not identify individual employees or the factories which participated).

Chest radiographs were subsequently randomised, divided into batches of about 100 films and classified independently by three physicians experienced in the use and interpretation of the appearances of pneumoconiosis according to the ILO classification (ILO, 1980). The readers recorded their classifications on standard recording forms (IOM versions of the ILO form), which required all relevant information about profusion and shape of small opacites, presence of large opacites, appearances of pleural thickening and costophrenic angle obliteration. Any additional comments were recorded on a tape recorder.

A selection of 200 ex-coalminers' radiographs from a previous study (previously classified by two of the three readers) were randomly distributed throughout the batches. These radiographs, some of which were known to have been classified as having established pneumoconiosis (ILO category 2 or more), were included for two reasons: firstly, to maintain the interest and concentration of the readers, who were not informed of the inclusion of the films, on the assumption that there would not be a high proportion of abnormal radiographs in the study population; secondly, for the reason stated above of providing an index of repeatability of each reader's classification. A further repeatability index was derived by re-inserting two batches each of 100 radiographs at later stages in the reading sequence (see Section 3.3.2).

2.3.6 Feasibility study of leavers

During visits to each factory an attempt was made to ascertain the suitability of using one or more sites for a study of a subset of ex-workers, who had left the industry during the previous five to ten years. This selection was largely based on whether the company kept records of leavers in a systematic and accessible manner to allow the ready identification of a representative and sufficiently large group of ex-workers. When suitable sites had been identified, medical surveys of those leavers willing to attend were planned to take place at the factories concerned.

2.4 Data Analysis

2.4.1 Data processing procedures

For each of the 18 sites in this study there are three categories of data: descriptive data for the site and its history; data from dust sampling on the site; and medical and questionnaire data obtained from participating individuals at the site.

(a) Descriptive data and histories

The descriptive data and histories were held on the original manuscript forms, with no derived classification or codes. However, the information was used when making judgements about classifications for job-histories and previous exposures.

(b) Dust measurements

At any site each dust filter was given a unique number and this was used to match the environmental data with the laboratory analysis of the dusts. Some samples were rejected from the study by the Occupational Hygienist, for a variety of reasons, for example, pump failure, detached tubing, but the decision to reject was not based upon the analysis results.

Analyses of the sampled dust were made by mineralogists at the IOM. If during the compositional analysis the quartz-doublet was not detected, then the value 0.0 was assigned. If it was detected but was too small to measure, ie. was less than 0.01 mgm^{-3}, then an arbitrary 'small' value of 0.002 mgm^{-3} was assigned, in order to facilitate comparisons following logarithmic transformation.

Data from dust samples were keyed to computer using the KE-III data entry package. The data were keyed only once, ie. there was no verification entry. Validity checks were applied to the data using a combination of GENSTAT-5 and FORTRAN-77 programs. Amongst these checks was a recalculation of the volumes of air from times and flow rates, and quartz percentages from the corresponding concentrations. As these had initially been calculated as part of the laboratory analysis the values could be compared to identify errors of miscalculation or from key-entry. Missing value codes were assigned where appropriate, in particular for those filters for which a dust mass could be determined but a quartz analysis was not practicable. However, the samples were not excluded as a result.

(c) Medical survey data

Data from the medical survey were entered key-to-disk through a FORTRAN 77 program written for the purpose. All data were entered twice, by two different operators, and the two files were compared using the Prime "CMPF" utility. Any discrepancies between the two files were resolved by consulting the manuscript data. The data were validated using programs written in GENSTAT 5. Suspect values were checked against manuscript records, and where necessary appropriate codes for missing or unreliable data were created.

At two sites, site 12 (in 1969) and site 13 (in 1974), there had been such a substantial change to the site that any job history prior to the change was coded as if it had been at a site not in the survey.

2.4.2 Statistical methods

Environmental data

Differences in measured dust and quartz concentrations between occupational groups and between sites were examined by means of two-way tables. The statistical significance of group and site differences was tested using analysis of variance of the log concentrations. These results helped assess which occupational groups could be combined for the calculation of exposure indices.

Estimation of indices of cumulative exposure to dust and quartz

(a) Mixed dust

An index of cumulative exposure is essentially a summation of a worker's past exposure over his or her working life. Two types of data were combined in the estimation procedure: first, smoothed estimates of dust concentration specific to occupational groups within site, which were obtained from the analysis of variance referred to above; second, occupational histories of individual subjects which had been expressed as periods worked within occupational groups (with start and end dates available) by site. Estimated dust concentrations appropriate to these periods were derived from the smoothed estimates, by applying weighting factors to take account of changes in kiln type at each site. Each period gave rise to an increment of exposure, obtained by multiplying the duration of the period by the weighted dust concentration. Finally these increments were summed over subjects' working lives.

Periods in the occupational histories of some workers had been spent at sites other than the 18 surveyed in this study. The contribution of these periods to the cumulative exposure was calculated using dust concentrations averaged over appropriate study sites. In addition, time worked in seven categories of employment outside the heavy clay industry was also accumulated and held on computer file. Full details of all these procedures are given in Appendix 6.

In addition, two alternative forms of cumulative exposure were examined in relation to the prevalence of radiological abnormality to test the hypothesis that exposure acquired in the more distant past might be more strongly associated with the prevalence of radiological abnormality than recent exposures. These were: (1) an index in which the exposure at a previous time point is weighted by the time elapsed since its acquisition; (2) a similar form of exposure, where the weighting is according to the square root of elapsed time (see Appendix 6 for details).

(b) Quartz

The analysis of occupational hygiene data also produced smoothed estimates of the percentage quartz in dust, by occupational group within site. Estimates of quartz concentration, appropriate to occupational groups within sites during previous time periods, were obtained by multiplying the retrospective estimates of dust concentration, by the smoothed percentage quartz estimate for the occupational group and site. Thus, there is an implicit assumption that the percentage quartz in dust remained constant over time.

As in the case of dust exposure, three indices of cumulative quartz exposure were calculated. Details of the estimation procedure for quartz exposures are given in Appendix 6.

Medical data

A basic description of the study group was provided by frequency distributions of study subjects by age, sex, smoking habit and site.

Each X-ray film was read by three readers. A summary classification of the profusion of simple pneumoconiosis and the size of large opacities, if present, was obtained from the median of the three readings, treating profusion as a variable with 12 values (0/- to 3/+), and large opacities as one with 4 values (O, A, B, C). Frequency distributions of films by median reading and site, age and smoking category, gave a summary description of the X-ray data. Cross-tabulation was used to examine the repeatability of individual readers' classifications, and also the extent of reader agreement.

Dichotomous variables indicating the presence of chronic bronchitis and breathlessness were defined in terms of questionnaire responses. Tabulation of means, expressed as percentages, by age, smoking, and site, gave a description of the prevalences of these conditions.

Exposure-response analysis

The dependence of radiological abnormality upon three indices of cumulative dust exposure, age, and smoking habit was investigated by descriptive methods (graphs and tables) and multiple logistic regression analysis. Two dichotomous variables (category 0/1 or higher, category 1/0 or higher) were analysed. Goodness of fit of regression equations was examined by comparing observed with predicted prevalences according to the method described by Hosmer and Lemeshow (1989). Possible associations with quartz exposure were investigated using the same methods. The analysis of respiratory symptoms variables was carried out similarly, except that quartz exposure was not investigated.

3. RESULTS

3.1 Response and Participation

3.1.1 Response of companies

Originally 16 factories, selected by the IOM for the study, were approached by NFCI to obtain agreement to participate. Fourteen of these agreed to take part. One shale works did not reply to repeated invitations and was not replaced; in addition, a larger works using marl withdrew and was replaced by a similar but smaller works. Furthermore, owing to the recession in the construction industry causing considerable loss of employees (about 400) from the selected large stock brick works, two additional works from the same company were recruited into the study, in order to make up for the reduced numbers. However, further redundancies occurred immediately before and during our surveys at these sites, causing further unplanned losses.

Following the initial selection and agreement to participate the NFCI requested that the soft mud process be represented in the study. Consequently the management of two small works in SE England were asked and agreed to take part. Agreement to participate was given by this final group of 18 factories (in ten companies) on the understanding that they would not be identified in the report and that they would each receive an individual report on the dust and quartz analyses resulting from the environmental survey (Table 3.1).

3.1.2 Response of current workers

Two thousand four hundred and twenty eight employees were originally identified as being employed at all eighteen sites, of whom 1934 were examined. Of the 494 identified employees who were not examined 138 refused; in addition 60 were off sick and 61 were on holiday or unable to be seen because of work commitments. Of the remainder, 159 had left the industry, been made redundant (including 79 at one plant during the survey), been transferred to another site or retired; 15 others were variously sales reps., drivers and other non production personnel who were rarely on the site; and finally 61 were not seen for unknown reasons. The response rate has been calculated on the basis of the 1934 examined as a percentage of those identified (2428) less the 159 who had left before the surveys began, i.e. 85.2%. The reasons for non-attendance are presented site by site in Table 3.2. Subsequently another nine people were excluded from the final study population as they were considered not to have fulfilled the criteria of company employees based at the selected site.

3.1.3 Response of leavers

Sites 17 and 18 were identified as potentially suitable for inclusion in a study of leavers. However, for reasons more fully explained in Appendix 5, this study was only pursued to a limited extent, principally because of the low response rate from those identified at one of the sites. See Appendix 5 for further details.

3.2 Occupational Hygiene Survey

3.2.1 Characteristics of the selected brick and tile works

The 18 sites selected for this study can be divided into categories depending upon size, age, raw material, type of kiln and fuel and the processes used. The sites ranged in size from about 30 to over 500 employees. The majority of sites surveyed used shale as the raw material, while six used soft clay and one used a marl. The age of the sites visited ranged from over 100 years to less than 20 and included both modern and traditional methods of work.

The kiln types in use at the times of the surveys included "Hoffman" or moving fire kilns, continuous tunnel, intermediate and one clamp kiln. The types of fuel used in these kilns included coal, gas alone or gas with some coal added, oil or oil and coal. A variety of combinations of kiln type and fuel type were encountered.

Some of the sites were traditional and labour intensive where the layout and methods of work had changed little with time. Other sites had undergone a great number of changes and improvements and some had even moved location within the last 25 years.

The major changes identified related mainly to type of kiln, type of fuel or degree of automation. Other changes were identified, such as location of activity, use of local exhaust ventilation (LEV) or respiratory protective equipment (RPE). However, the latter involved less widespread changes affecting smaller numbers of persons at specific sites.

3.2.2 Derivation of occupational groups

Over 300 individual job titles were allocated during the occupational hygiene surveys to describe the current tasks within the industry. All of the current jobs were then allocated by an occupational hygienist to 23 occupational groups (OGs). These are listed in Table 3.3. Information from the occupational history questionnaires subsequently provided additional titles mainly for jobs outwith the industry and small adjustments were then made to the OGs if this was indicated. These 23 occupational groups were further combined to produce 12 occupational groups for analyses. A total of 1407 measured concentrations of respirable dust were available for subsequent analyses in all occupational groups.

These combined groups, listed in Table 3.4, are described further on the following basis:

Group 1: those persons who have no direct contact with dust within their job. The group includes office workers and managers at the plants, canteen workers, drivers who work away from the site, sales reps., financial director, nursing managers, etc.

Group 2: those having potentially low exposure to dust within their normal jobs. The majority of jobs within this group are supervisory in nature; however, the group also includes kiln burners, as this job currently entails little contact with dust or brick products.

Group 3: a pre-production group including quarry workers and those persons involved in setting and moulding operations. This group also contains the brick maker machine operators and moulders. In all these jobs the material being handled is mixed with water and is often in the form of a brick.

Group 4: brick cutters, consisting of those persons who have direct contact in cutting fired bricks for display purposes. Grog plant attendants who also have contact with dust from cut or damaged bricks are included in this group.

Group 5: a mixed dust exposure group, including fitters who work in the plant and fork lift truck drivers who have general duties around the setting sheds and yards. These persons will be exposed to dust from both fired bricks and unfired material.

Group 6: post production operators, including those involved in packing operations and also in brick laying. This group includes the brick layers involved in repairing kilns and kiln cars but not the dedicated kiln demolition squad.

Group 7: forklift drivers who are associated only with work within the driers and/or the kilns.

Group 8: those persons who directly work in the pan mill area including machine mixers, pan mill operators, screens attendants, grinding operators etc.

Group 9: labourers, including general labourers and spare men, those operators invoved in wicket sealing, erection and dismantling and the general factory cleaners. (The labourer is often involved in the factory cleaning and acts as spareman).

Group 10: all operators who have contact with sand ie. sand blasting, sand and stain applicators, mixer men, slurry men and sand preparation operators.

Group 11: the clean up squad, which was peculiar to site 17, and the flue cleaners.

Group 12: the kiln demolition squads who move from site to site, but were only present at site 17 during these surveys.

3.2.3 Respirable dust and quartz concentrations

A total of 1465 personal airborne dust samples were collected of which 1407 were available for dust analysis and 1403 were analysed for crystalline silica content. Four percent of samples were rejected, the most common reasons being pump failure, flow variation and dislodged tubing. The number of samples available ranged from 33 - 245 per site. The number of samples collected for each occupational group varied greatly. Some occupational groups had large numbers of samples with samples from each site, eg. supervisors (336) and pre-production workers (301), while only a few samples from a limited number of sites were taken in other occupational groups, eg. brick cutters (10), because such work was only performed at these sites. The 28 samples collected for OGs 11 (clean up squad) and 12 (kiln demolition workers) were almost entirely from one site.

Respirable mixed dust concentrations

The respirable full-shift dust concentrations, shown in Table 3.5 according to site, are given in further detail in Appendix 3b. Individual concentrations ranged from 0.1 - 100.1 mgm^{-3} with average dust concentrations for each of the 12 combined OGs ranging from 0.4 mgm^{-3} for the no direct exposure group to 10.0 mgm^{-3}

for kiln demolition workers. Most (97%) concentrations lay below 5 mgm^{-3} and the average dust concentration was less than 5 mgm^{-3} for each OG with the exception of two groups; clean-up squad and kiln demolition workers. The maximum concentration measured was for a person carrying out clean-up tasks at Site 17, a traditional works operating a coal fired Hoffman kiln.

Because of differences in hardness and moisture content, it might be expected that shale-based clays and soft clays would give rise to different ranges of dust concentration in the preparatory stages of production. In practice the average dust levels for pre-production workers (quarry, setting, moulding) were similar for those employed at soft clay (1.0 mgm^{-3}) and at shale-based works (0.9 mgm^{-3}) whereas men working directly in the pan mill area experienced higher dust concentrations (average 2.0 mgm^{-3}) if they worked with shale compared to those at soft clay and marl works (1.1 mgm^{-3}). In the post-production phase (mostly packers and brick layers) the shale workers had somewhat lower exposures (0.9 mgm^{-3}) than the soft clay group (1.5 mgm^{-3}). Overall the soft clay and marl works were dustier (1.6 mgm^{-3}) than the shale works (1.0 mgm^{-3}) before account is taken of the distribution of dust samples across different OGs.

There were 3% of samples with a concentration exceeding 5 mgm^{-3}, the accepted occupational exposure standard for respirable dusts not assigned a specific occupational exposure limit. With the exception of site 4, less than 10% of results at each site were above this concentration and eight sites had no samples as high as this. Occasional exposures to 5 mgm^{-3} and more were observed among all OGs except the brick cutters and those not directly exposed to dust (OGs 1 and 4); among demolition workers, 100% exceeded 5.0 mgm^{-3} (Table 3.6).

On comparing the results with a figure of 2.5 mgm^{-3}, half this standard, four sites had greater than 10% of results above this figure, significant exposures also being found among general labourers, pan mill operators, FLT (kiln) drivers, post production and brick cutters.

Respirable quartz concentrations

Quartz was detected and quantified in 97.0% of the full-shift personal samples analysed and ranged from 0.01 - 3.80 mgm^{-3}. However, in a further 2.4%, quartz was detected but was not quantifiable, in which case a nominal value of 0.002mgm^{-3} was assigned. Only in 0.6% of samples was quartz not detected. The average quartz concentration for the occupational groups ranged from 0.04 mgm^{-3} for those with no direct exposure to 0.62 mgm^{-3} for kiln demolition workers. The maximum individual concentrations were experienced by persons carrying out general labouring activities and factory cleaning. The highest average concentrations were reached for OGs representing kiln demolition, clean up squad and sand users (Table 3.6). Further details are given in Appendix 3b.

In comparison to the differences in respirable dust levels described above, quartz concentrations were very similar for pre-production workers at shale and soft clay works (0.10 and 0.11 mgm^{-3} respectively), more than twice as high for pan mill workers (0.23 and 0.09 mgm^{-3}) and slightly greater for post-production workers at shale works (0.11 mgm^{-3}) than at the soft clay and marl works (0.08 mgm^{-3}). Generally shale works had slightly lower quartz concentrations (0.10 mgm^{-3}) than the remainder (0.13 mgm^{-3}).

Most (97%) individual concentrations lay below 0.4 mgm^{-3} and the average quartz concentration of each OG was less than 0.4 mgm^{-3} with the exception of the kiln demolition workers. However, the maximum concentration was measured on a general labourer who worked at a traditional, coal fired Hoffman site (site 17).

Three OGs had more than 10% of results above 0.4 mgm^{-3}: sand users, clean up squad and demolition workers. Moulders (in the pre-production OG) and general kiln operatives (in the post-production OG) also had significant numbers of quartz concentrations greater than 0.4 mgm^{-3}. When compared with a concentration of 0.1 mgm^{-3}, the OEL until 1991, all OGs with the exception of the no direct contact group had more than 10% of results higher than this. More than 10% of samples exceeded 0.1 mgm^{-3} at all sites, while only site 4 had more than 10% of results exceeding 0.4 mgm^{-3} (Table 3.5[b]).

Variation of respirable dust and quartz concentrations

The dust and quartz concentrations were found to follow a log-normal distribution with a few unusually high or low, but technically valid, values. The data were therefore analysed using the logarithms of the concentrations using a method designed to reduce the overall influence of outlying values. It was found that the highest dust concentration (100 mgm^{-3}) contributed to over 5% of the total dust exposure measured in the whole study; the top three observations accounting for 10% and the top 14 (1% of the total samples) for 20% of the total dust exposure. Most of these high observations came from within two occupational groups (clean up squad and kiln demolition) at site 17. Similarly, the highest few quartz concentrations accounted for a disproportionately large amount of the total quartz exposure.

Analysis of variance of the dust concentrations, quartz concentrations and percentage quartz in dust is shown in Tables 3.7–3.9. The principal findings relating to dust concentration indicate that the statistically most significant differences are between occupational groups (significant at 0.1% level). There is also strong evidence (at 0.5% level of significance) that there are differences between kiln types. Employees at works using coal and gas fired Hoffman kilns were exposed on average to one and a half times the dust concentration of the remaining workforce. Remaining site to site variation is itself much larger than week to week and even day to day variation. Table 3.7 also shows that there were significant differences for occupational groups according to kiln type, site and week. Such variations are small, however, and should even out over an employee's occupational history.

In contrast the quartz concentrations were mainly influenced by occupational group, with some site to site variation not explained by differences in kiln types, or week to week or day to day variation (Tables 3.8 and 3.9).

3.2.4 Mineralogical and particle size analyses

The particle size distributions of respirable dust samples collected at sites 4, 16 and 17 are summarised in Table 3.10(a). The size distributions of the three samples were similar and were typical of respirable dusts. The number median diameters were 0.71 μm, 0.50 μm and 0.68 μm for sites 4, 16 and 17 respectively.

The mineralogical compositions of these samples, as assessed by STEM/EDXS, are summarised in Table 3.10(b). Individual quartz particles were detected in all samples (also see later in this section). The highest proportion (10% by number, 21% by volume) was found in the sample collected at site 17. Fewer quartz particles were detected at site 16 (3%) than at site 4 (7%) but the mass proportions (estimated from particle volumes) were similar at these two sites. There were other major differences in the compositions of the three samples. Manganese oxide was added to the feedstock at site 16 and most particles appeared to be contaminated to some extent by manganese. Around 10% of the particles were classified as manganese oxide although some of these may have been other minerals coated in manganese or manganese oxide. Manganese is a strong X-ray emitter and because of this the analytical technique may have over-estimated the contamination. Quantitative manganese analysis indicated that this sample contained 1.5% manganese. The sample from site 16 also had a much lower proportion of kaolinite and a higher proportion of organic material than the other two samples, for which there is no obvious explanation. The low percentage of kaolinite may be associated with manganese contamination. There was also a relatively large proportion of unclassified particles in that sample.

The samples for this analysis were collected at fixed points for small portions of the working shift. The volume proportions of quartz measured by SEM/EDXS were 11.1%, 11.5% and 21.2% for sites 4, 16 and 17 respectively. The proportions of quartz measured by X-ray diffractometry in personal respirable dust samples collected on the same day in the same general working area were respectively 17%, 20–25% and 6% for the three sites. The differences in results for each site reflect the differences between the methods, the short sampling time for the samples analysed by SEM/EDXS and the different types of sample.

The samples from plants 16 and 17 were re-examined to characterise the nature of quartz grains. Quartz grains were readily distinguished in both samples. The quartz in the sample from plant 16 was dominated by sedimentary grains enclosed by quartz overgrowths. Their surfaces were dominated by ideal crystal faces. There were a few sedimentary quartz particles, some tiny quartz crystals and, rarely, fractured quartz grains. Quartz from plant 17 consisted overwhelmingly of rounded sedimentary grains. Some had overgrowths, a few of which were virtually perfect quartz crystals.

Further information is in Appendix 3(C).

3.2.5 Site information relevant to retrospective exposure estimates

Information about each site was obtained both from factory and the occupational hygienist's observations. Many factors at each site may influence the actual exposure of individuals to dust and quartz, eg. type of kiln, production rates, machinery, working methods, material used, local exhaust ventilation (LEV), respiratory protective equipment (RPE), etc.

Within the working lifetime of persons currently employed at the 18 sites these factors may have changed. Each change will influence the exposure of an individual to a greater or lesser degree. In considering the evaluation of retrospective estimations of exposure only those factors thought to have a major influence on exposure have been addressed. The 12 groups detailed in Table 3.4 have been considered individually at each site. In some cases it has been necessary to address specific occupations/tasks within these groups. Information on use of RPE and changes of possible relevance to dust exposure is detailed in Appendix 4.

In practice, when trying to estimate previous concentrations, the information available was only sufficiently detailed and comprehensive about the types of kiln operated at sites in the past to allow adjustments to current dust and quartz concentrations to be made. It was not possible to use the information on RPE, LEV and automation of processes in the same way.

3.2.6 Estimation of cumulative dust and quartz exposure

Estimated dust exposures for each site and occupational group were based on a two-way table of estimated dust concentrations, which was derived from all the available dust concentration measurements and is described in detail in Appendix 6.

In summary, average site cumulative dust exposures ranged from 6.2 to 23.5mgm^{-3} years and the average cumulative dust exposures for each site are shown in Table 3.11. The cumulative quartz exposures ranged from 0.64 to 3.30 mgm^{-3} years and are also shown in Table 3.11.

3.3 Results of Medical Survey

3.3.1 Numbers and characteristics of the study population

One thousand nine hundred and twenty five (1925) subjects attended the medical surveys at 18 sites; 1852 men and 73 women. Several participants at site 14 did not have a chest radiograph taken during the survey. This arose because a chest X-ray service had been provided six months before our survey and many of those who had had a radiograph taken did not wish to have another. Although several of the previous radiographs were subsequently obtained for assessment, seventeen were not available. In the feasibility study of leavers 21 ex-workers attended for examination (for further details see Appendix 5).

In addition to the above, two men were excluded because their radiographs were judged to be unreadable by at least one film reader and therefore a median profusion of small opacities classification could not be obtained. Two other men were excluded from the analysis: one because of absence of smoking data and one had an incomplete occupational history. This left 1831 men available for analysis. Their ages and smoking habits are shown in Table 3.11.

Site 17 had the largest and site 4 the smallest workforce. Site 17 also had the oldest workforce (average age 43.2 years) and site 9 had the youngest (average age 31.3 years). The average age of the whole study population was 40.0 years and ranged fairly uniformly from 16 to 65 years. A few older men were employed as gardeners and a chauffeur on two sites.

The proportion of smokers varied considerably from factory to factory; ranging from 31% at sites 5 and 18 to 65% at site 1. On average 42% smoked, 37% had never smoked and 21% were ex-smokers.

3.3.2 Radiographic results

Film quality, inter- and intra-reader agreement

All three of the epidemiological film readers classed over 97.5% of the radiographs as having 'good' or 'acceptable' quality. Most of the other classifications were 'poor', but readable; however one film was classed as 'unacceptable' by all three readers and another by one of the readers.

One batch of a hundred radiographs was read twice by each reader and another hundred were read three times without the film readers' knowledge. Intra-reader consistency of reading was tested on both batches of films (readings two and three for the thrice read films). The proportion of films identically classified for quality on repeat reading ranged from 84 to 94%. Similarly 90-94% of films were identically classified on the 12 point scale of profusion of small opacities, largely due to the relatively small number of abnormally classified films.

For purposes of inter-reader comparison the second and first readings respectively of the two batches of 100 films referred to above were used. Pairwise agreement between the three readers ranged from 82-91% on the 12 point scale of classification and from 91-94% on the 4 point scale, indicating that most of the disagreements on the 12 point scale were small.

Prevalence of radiographic small opacities

The proportion of films classified within each category of profusion of small opacities according to the ILO classification scheme is shown in Table 3.12 for all 1913 participants with valid radiographs. These comprised 1906 of the 1935 attenders - 1835 males and 71 females - plus another seven subjects who were X-rayed, but are not considered part of the defined study population. Reader 2 classed a relatively low proportion as abnormal compared to reader 10, who reported a much higher proportion as category 0/1 or greater (11.2%) than the other two readers. Reader 15 read the highest classification, category 3/2 in one film, and also read the greatest proportion (1.6%) above category 1/1.

Shape of small opacities

Each reader classified small opacities according to their shape (rounded or irregular). Such a classification allows the predominant shape of opacity to be recorded if opacities of both shapes are present on the same lung field. Of the 42 films classified as abnormal by reader 2 57% were classed as rounded or predominantly rounded. Readers 10 and 15 classified respectively 27% and 78% of their abnormal films in this way. Because of the lack of consistency in the classification of shape the difference in shape of small opacities has not been addressed further.

Large opacities

Nine radiographs showed one or more large opacities (category A, B or C) in the opinion of one or other of the three readers. However, they all agreed on the presence of large opacities on only one film.

Median profusion of small opacities

The opinions of the three readers on each film were summarised by the median value, ie. the middle value in increasing order of profusion score. Table 3.13 shows the distribution of median profusion for films from 1831 males by site. Overall, 96.3% of all films had a median profusion of 0/0, 2.3% (42 men) had category 0/1, representing the earliest signs of abnormality (pneumoconiosis), and a further 1.4% (25 men) were classified as category 1/0 or greater. There were seven cases between categories 2/1 to 2/3 inclusive. Category 0/1 can represent the effects of age, smoking or other diseases as well as pneumoconiosis. The higher the category of small opacities, the more likely they are to represent pneumoconiosis.

At seven sites (4, 7–10, 13, 14) no abnormalities were reported, whereas 13.3% of site 5 employees had small opacities category 0/1 or more. Only 6 sites (1, 5, 12, 15–17) had any films with category 1/0 or greater profusion; sites 5 and 15 both had the highest frequency of 6.7% of employees thus affected.

Effect of respirable dust and quartz exposure on prevalence of radiological abnormality.

This section presents the radiographic abnormality (median profusion of small opacities) in relation to age, smoking history and cumulative dust and quartz exposures. Table 3.14 shows the prevalence of category 0/1 or higher among men by age and cumulative dust exposure. The prevalence rises with age from zero for those aged 24 or less to 8.5% for men aged 55 or over. The prevalence also rises with increasing cumulative dust exposure from 0.4% among men exposed to less than 5 mgm^{-3} years to 10.3% for those exposed to 40 mgm^{-3} years or more. A relationship with exposure is only apparent in the oldest age group. The prevalence of category 1/0 or higher in relation to age and dust exposure is shown in Table 3.15. A similar pattern to that observed for category 0/1+ is seen, 4.3% being the prevalence both in the oldest age group and the group with the highest dust exposure. Further subdivision by site would be misleading because of the relatively small numbers of abnormal films.

Tables 3.16 and 3.17 show the relationships between median profusion category 0/1+ and 1/0+ and cumulative exposure to quartz. An effect is clearly shown in the oldest group for category 0/1+ but other age-related exposure effects are less obvious.

The prevalence of radiological abnormality was increased by smoking (table not shown): for category 0/1+ prevalence was 4.5% for current smokers, 4.2% for ex-smokers and 2.4% for non-smokers. There was very little difference for category 1/0+, ranging from 1.0% to 1.7% for non-smokers and current smokers respectively.

The seven men with category 2/1 or greater had worked in the heavy clay industry for between 9 and 37 years and were aged 29–61 years (average age 50). They currently worked at five different sites and had been employed in a range of jobs (variously as pan mill operator, setter, wicket erector, kiln burner, shovel driver, fork lift truck driver, kiln demolition worker). Only two of the men had spent time in jobs in other industries, which could be considered to constitute a respiratory health hazard (10 years as a caster in an aluminium works and 1½ years in an iron foundry). In addition one other man aged 60 with large opacities category A had spent most of his working life, 35 years, as a conveyor operator at quarries in the heavy clay industry.

3.3.3 Respiratory symptoms

The analysis of respiratory symptoms has been confined initially to symptoms or conditions representing; chronic bronchitis, breathlessness and wheeze. Chronic bronchitis is defined in the standard manner as the presence of persistent cough with persistent phlegm for at least 3 months in the year (ie. YES to questions 1 or 2 and 3 plus YES to questions 4 or 5 and 6); breathlessness is defined as shortness of breath walking with other people of the same age on level ground (YES to question 10); and wheeze is defined as attacks of wheezing or whistling in the chest at any time in the last 12 months (YES to question 12). On average the prevalence of these symptoms was 14.2% for chronic bronchitis, 4.4% for breathlessness and 20.6% for wheeze.

Effect of age and smoking habit

The prevalence of chronic bronchitis did not change with age, whereas the frequency of breathlessness more than doubled in the oldest age group and wheeze tended to decrease slightly with age (Table 3.18). As expected the prevalence of bronchitis was much greater in smokers (23%) than non–smokers (7%) and was higher still in heavy smokers compared with lighter smokers (Table 3.19). Breathlessness, although less frequently reported, followed a similar pattern but ex–smokers reported breathlessness slightly more frequently (6%) than current smokers (5%). The presence of wheeze varied across the smoking categories (Table 3.19).

Effect of respirable dust and quartz exposure on the prevalence of respiratory symptoms

The prevalences of chronic bronchitis and breathlessness are shown in relation to ranges of cumulative respirable dust exposure in Table 3.20. A slight increase in prevalence is noted in the most dust exposed group for bronchitis and a stronger association is apparent for breathlessness in this group. The relationship of breathlessness with dust exposure is to a large extent accounted for by the greater age of the most dust–exposed groups.

3.4 Exposure Response Relationships

The prevalence of radiological abnormality and respiratory symptoms has been further investigated in relation to cumulative dust and quartz exposures by means of logistic regression analysis. The results of this analysis are summarised here. The effects of cumulative exposures and other variables are expressed in the form of estimated odds ratios (OR), which, for studies such as this with low levels of abnormality, are close to proportions.*

For example a prevalence of 13.4% (the highest figure shown in Table 3.14) is equivalent to a proportion of 0.134, and corresponds to an odds of 0.124/(1–0.134) = 0.155. At levels of prevalence no greater than this, such as those found in this study, the agreement between odds and proportions is even closer. Hence, for practical purposes, odds and proportions can be regarded as interchangeable. If it is stated, for example, that the estimated effect of a 10–year increase in age is to increase the odds of category 0/1+ by a factor of 2 (i.e. odds ratio, or OR = 2), the practical interpretation is that a 10–year increase in age multiplies the proportion of men with category 0/1 and above, by 2 (i.e. the prevalence rate doubles).

Footnote:

* Odds ratio =

$$\frac{\text{No. of men in high exposure group with abnormality}}{\text{No. of men in high exposure group without abnormality}} \div \frac{\text{No. of men in low exposure group with abnormality}}{\text{No. of men in low exposure group without abnormality}}$$

3.4.1 Profusion of small opacities category 0/1+

Logistic regression analyses of the effects of age, smoking, dust and quartz exposure were performed. They showed an effect of age (odds increased by a factor of 2.1:1 per 10 years of age; 95% confidence interval [CI], 1.69 - 2.63) statistically significant at the 5% level, but not of smoking. Adjustment for smoking did not lower the effect of age.

Having adjusted for age the OR for the estimated effect of dust exposure = 1.38 per doubling of exposure (95% CI = 1.13 - 1.69). Following further adjustment for the effects of smoking and site slightly reduces the estimated dust effect: OR = 1.29 (95% CI = 1.02 - 1.64), still statistically significant. Similarly the effect of quartz, following adjustment for age and smoking, is statistically significant (OR = 1.41 per doubling of exposure [95% CI, 1.15 - 1.73]). Inclusion of a site effect slightly reduces the quartz effect (OR = 1.33, 95% CI = 1.05 - 1.67), still statistically significant, however. There was no evidence of interaction effects between dust exposure and age, smoking habit or site, nor between quartz exposure and these factors. Odds ratios estimated from two statistical models incorporating exposure (dust and quartz respectively), age, smoking and site, are given in Table 3.21.

Another way to express these effects is in the form of predicted prevalences. For example, the predicted prevalence of category 0/1+ for non-smoking workers, initially aged 20, with no direct exposure to dust (exposure to average dust concentration of 0.4 mgm^{-3}) would be 0.7% after 10 years employment. Non-smokers exposed for 10 years to 2.5 mgm^{-3} would have a predicted prevalence of 1.6% (95% CI, 0.8, 3.1%) rising to 3.8% (95% CI, 2.0, 7.0%) after 20 years. Exposure to 5 mgm^{-3} over the same time periods would increase these predicted prevalences to 2.1% (95% CI, 1.0, 4.6%) and 5.1% (95% CI, 2.4, 10.7%).

Similarly, for exposure to quartz at 0.1 mgm^{-3} the predicted prevalence would be 1.0% (95% CI, 0.6, 2.0%) for such a worker after 10 years and 2.6% (95% CI, 1.5, 4.3%) after 20 years.

There was a very high correlation (0.965) between individuals' exposures to respirable dust and to quartz. This high correlation greatly complicates the task of identifying whether it is the overall respirable dust exposure, or its quartz component specifically, which bears the principal underlying relationship with radiological abnormality. One aspect of this problem is a loss of precision in the estimated effects of both variables when included together in the regression analyses. Estimated ORs, adjusted for smoking but not for site, are no longer statistically significant: for dust exposure the OR is reduced to 0.96 (95% CI, 0.53, 1.73) whereas the OR for quartz exposure increases slightly to 1.46 (95% CI = 0.81, 2.62).

This would be consistent with an association with quartz exposure, allowing for dust exposure, rather than vice versa. This divergence of the dust and quartz effects is further increased when site effects are included in the model. However, because of wide confidence intervals (for quartz, OR = 4.44 [95% CI = 1.02, 19.25]) the reliability of the estimate of this effect is poor.

Table 3.22 shows the time worked in other industries outside the heavy clay industry under seven category headings. The effect of each of these was examined singly, adjusting for age, smoking and site. Only the number of years worked in construction and other (not already specified) industrial work had a statistically significant effect on prevalence of category 0/1+ profusion. Furthermore, only this variable had more than a trivial effect on the dust or quartz regression coefficients, which both increased on adjustment for time in the construction industry.

Exclusion and separate analysis of those men who had spent time in other noxious (dust exposed) industries (260 men in categories 1-5 in Table 3.22) indicated that their prevalence of category 0/1+ (3.8%) and 1/0+ (1.2%) was very similar to that of the whole study population (3.6% and 1.4% respectively). The magnitude of dust and quartz effects, although no longer statistically significant following adjustment for age, smoking and site, is slightly greater than in the study population as a whole.

In the complementary subset of 1571 men with no record of having worked in noxious industries, the effects of dust and quartz, allowing for age and smoking, were slightly less than in the study group as a whole, but still statistically significant at the 5% level. Allowing additionally for site, the magnitude of the effects was essentially unchanged, but they fell just short of statistical significance.

Exclusion of the three men (kiln demolition workers at site 17) with the highest dust exposures, who might have contributed disproportionately to the dust and quartz effects, had very little effect on the size of the odds ratios, which remained statistically significant.

3.4.2 Profusion of small opacities 1/0+

When the above analyses for category 0/1+ were repeated for category 1/0+ a generally similar picture emerged but, owing to the smaller numbers involved, the effects were found to be no longer statistically significant. For example, following adjustment for age and smoking the OR for quartz exposure is 1.53 per doubling (95% CI, 1.08 - 2.15), which is reduced to 1.38 (0.95 - 2.02) when adjusted for site effects. Table 3.23 gives odds ratios estimated from two statistical models incorporating exposure (to dust and quartz respectively), age, smoking and site. Adjusting quartz exposure for the effects of dust increased the odds ratio to 1.94 (0.77 - 4.88) and further adjustment for site effects increased the OR further to 2.89 (0.29 - 28.68) both effects being not statistically significant. Thus an effect of quartz over and above that of dust exposure cannot be established in this instance. However, the relative magnitude of the two effects, dust and quartz, suggests that it is quartz, rather than dust, which is associated with radiological abnormality. (Note that the quartz-adjusted OR for dust is actually negative, at 0.45, for doubling). Again, it was possible to show that the effects of dust and quartz were not explicable in terms of a confounding effect of time in other industries. Overall, in most respects, the effects identified and described above for category 0/1+ are also suggested for category 1/0+.

As an example, the predicted prevalence of category 1/0+ in non-smoking workers, initially aged 20, exposed to 2.5 mgm^{-3} of respirable dust for 10 years, would be 0.4% (95% CI, 0.1, 1.3), rising to 1.4% (95% CI, 0.5, 4.0) after 20 years exposure. A similar worker exposed to the average dust concentration (0.4 mgm^{-3}) observed in the 'no direct exposure' group would have a predicted prevalence of 0.6%. Similarly, among workers exposed to respirable quartz at an average concentration of 0.1 mgm^{-3}, predicted prevalences would be 0.2% (95% CI, 0.1, 0.8) and 0.9% (95% CI, 0.4, 2.1) respectively for these same periods.

The goodness of fit of the models used in this regression analysis was tested using the method of Hosmer and Lemeshow (1989). None of the chi-square statistics indicated a lack of fit of any of the models to the data, and the observed and expected prevalences of radiological abnormalities are very similar.

3.4.3 Respiratory symptoms

Table 3.24 and 3.25 show the odds ratios associated with the effect of a 40 mgm^{-3} year increase in cumulative dust exposure on prevalences of chronic bronchitis and breathlessness respectively. Because of the significantly greater cumulative dust exposures observed among kiln demolition workers these men have been considered separately.

There is a statistically significant effect (at 5% level) of exposure to dust on the presence of chronic bronchitis for all heavy clay workers combined (OR = 1.5; CI = 1.1 - 2.0) and for kiln demolition work alone (OR = 1.6; CI = 1.1 - 2.7), having allowed for smoking, site and time worked in other industries. However, although the effect of exposure to dust in all jobs in the industry other than kiln demolition work is not significant (OR = 1.3; CI = 0.8 - 2.0) the data are consistent with a general effect of exposure to dust in the heavy clay industry (Table 3.24). Because of the small numbers and the relatively large confidence intervals the results of the kiln demolition workers should be treated with caution.

For breathlessness there is again a statistically significant (at 5%) effect of exposure to dust in general and to dust in kiln demolition work separately (Table 3.25). As for chronic bronchitis the effect of dust exposure in all jobs in the industry other than kiln demolition work is insignificant (OR = 1.6; CI = 0.8 - 3.3), although the data are again consistent with a general effect of dust exposure.

These odds ratios can again be expressed in the form of predicted prevalences. Consider, for example, a non-smoker aged 40 (at the end of the exposure period), not exposed to any hazardous jobs outside the heavy clay industry. If he had had no exposure to dust, the frequency with which chronic bronchitis (equivalent figures for breathlessness in brackets) would be reported is 6.7% (1.6%). For a worker with 20 mgm^{-3} years exposure to dust in the heavy clay industry this rises to 7.2% (2.0%), using an OR of 1.1 (1.6), and to 7.6% (2.5%) for 40 mgm^{-3} years exposure. For a kiln demolition worker with 80 mgm^{-3} years exposure this rises further to 14% (3.3%), using an OR of 1.5 (1.4), and to 26% (6.6%) for 160 mgm^{-3} years exposure. However, the actual risks might be much greater or much smaller than the above because of the wide confidence intervals.

3.5 Summary of Results

1. Individual mixed respirable dust concentrations ranged from 0.1 to 100.1 mgm^{-3}. 97% of the individual concentrations were less than 5 mgm^{-3} (the currently accepted occupational exposure standard). 92% of all individual samples were less than half this level, but occasional values above this were observed in the majority of factories.

Occupational group average concentrations ranged from 0.4 mgm^{-3} to 10.0 mgm^{-3}. For only two of the defined broad occupational groups were the average dust concentrations greater than 5 mgm^{-3}, clean up squad and kiln demolition workers. For the other ten occupational groups, the average dust concentrations were less than half this level.

2. Individual respirable quartz concentrations ranged from undetectable to 3.8 mgm^{-3} (in a general labourer). 97% of all individual quartz concentrations were less than 0.4 mgm^{-3} (the current Maximum Exposure Limit). 67% of individual samples were less than 0.1 mgm^{-3}, the level above which medical surveillance is recommended (and the Occupational Exposure Limit until 1991).

Occupational group average quartz concentrations ranged from 0.04 mgm^{-3} for the no direct exposure group to 0.62 mgm^{-3} for kiln demolition workers. Three occupational groups had more than 10% of individual values above 0.4 mgm^{-3}, sand users, clean up squad and kiln demolition workers, and the average quartz concentrations for these groups were over 0.2 mgm^{-3}. Moulders (pre-production) and general kiln operators (post production) also had significant numbers of quartz concentrations greater than 0.4 mgm^{-3}.

All occupational groups with the exception of the no direct exposure group had more than 10% of individual values greater than 0.1 mgm^{-3} and more than 10% of samples exceeded 0.1 mgm^{-3} at all sites.

3. The prevalence of category 0/1 (representing appearances bordering on abnormality) or greater profusion of small opacities in the study population was 3.7% (67 men) and for category 1/0 or greater (representing definite but slight abnormality) the prevalence was 1.4% (25 men). Seven men had category 2/1 or greater, representing established pneumoconiosis and one other man had category A large opacities. Category 0/1 small opacities can often be the result of age, smoking and other disease, as well as pneumoconiosis. With higher categories of profusion of opacities the likelihood of pneumoconiosis is greater.

4. Chronic bronchitis was observed in 14.2% of the workforce: it was unrelated to age but ranged from 7% among non-smokers to 35% in heavy smokers. Four percent of men reported breathlessness (when walking with others of the same age), which was slightly more prevalent in men over 55 years and among current and ex-smokers.

5. Small opacities were associated with lifetime exposure to dust and (more strongly) to quartz. Having adjusted for age, smoking and site effects the increased risk (odds ratio) for the effect of dust exposure on prevalence of category 0/1+ was 1.29 for doubling of exposure (95% confidence interval = 1.02 - 1.64) and for quartz was 1.33 per doubling of exposure (CI = 1.05 - 1.67). Adjustment for dust and quartz exposure together increased the estimated odds ratio for quartz to 4.44 per doubling of exposure (95% CI = 1.02 - 19.25). However, the high correlation between the exposures reduced the reliability of the estimated effect, as can be seen from the wide confidence interval. Although limited by smaller numbers, similar results were observed for those with category 1/0+.

As an example, the predicted prevalence of category 1/0 or greater in a 40 year old non-smoker after 20 years exposure to a dust concentration of 2.5 mgm^{-3} would be 1.4% (0.6% for someone working in the 'no direct exposure' group). The same man exposed to 0.4 mgm^{-3} of quartz for 20 years would have a predicted prevalence of 2.1%.

6. Of seven categories of industry outside the heavy clay industry, only time worked in a combined group of "construction, other industrial, fishing and armed forces" had a statistically significant effect on the risk of radiological abnormality, both 0/1+ and 1/0+. Allowing for this effect, the effects of dust and quartz exposure in the heavy clay industry were slightly increased. For 0/1+, they

remained statistically significant: for 1/0+, were close to significance. A separate analysis showed that the prevalence of 0/1+ and 1/0+ was similar among men with and without a previous history of work in other noxious industries.

7. The prevalence of both chronic bronchitis and breathlessness was related to cumulative exposure to dust among all workers in the industry, although this effect was in large part attributable to kiln demolition work. For a cumulative exposure of 40 mgm^{-3} year the odds ratio for chronic bronchitis among all heavy clay workers, allowing for smoking, site and previous jobs, is 1.5 (95% CI = 1.1 - 2.0) and for breathlessness the OR = 1.5 (95% CI = 1.1 - 2.2).

As an example, the predicted prevalence of chronic bronchitis would be 14% for a 40 year old non-smoker with 80 mgm^{-3} years exposure to dust (equivalent to a dust concentration of 4 mgm^{-3} for 20 years, about the average measurement for the three dustiest OGs). The same man would have a predicted prevalence of breathlessness equal to 3.3% for the same dust exposure.

4. DISCUSSION

4.1 Dust Exposure in the Heavy Clay Industry

Nearly 1400 personal, and about 80 static, samples were taken at 18 different brick and tile works during the course of this study. Consequently the average respirable dust concentrations observed in the different occupational groups in this study are likely to be generally representative of the conditions at these and similar plants in the UK. These plants were mostly included on the basis of continuous operation for twenty years or more, although two plants (8 and 13) were commissioned on their present sites in 1974. However, even at long running sites there have been changes to kiln type, fuel supply to kilns, LEV and RPE, etc. As stated elsewhere in this report, the date at which the kilns were changed from Hoffman/Intermittent to the tunnel type is regarded as the most significant event to influence the dust exposure history of the workforce and has been taken into account when estimating past history of exposure.

Occasionally high dust levels recorded during the surveys were observed in most occupational groups. The highest dust concentrations in six of these OGs occurred at site 17 and the six other highest concentrations were observed at five different sites, all of which were in the top third in order of dustiness.

The range of dust levels at all 18 sites (0.5 - 2.5 mgm^{-3} on average) appears somewhat lower than the mean respirable dust levels reported from five South African brickworks (2.2 mgm^{-3}) by Myers et al (1989[a]). These workers reported concentrations of 1 mgm^{-3} for a low dust exposure group (cf 0.4–0.6 mgm^{-3} for our OGs 1 and 2), 2.2 mgm^{-3} for a medium exposure group (cf 1.0–1.5 mgm^{-3} for OGs 3 and 6) and 6.7 mgm^{-3} for a high exposure group (cf 1.2–6.9 mgm^{-3} for OGs 5, 7, 9 and 11 in the present study).

Another recent study (Buringh et al 1990) reported respirable dust concentrations as high as 8.8 mgm^{-3} out of 144 personal samples from four works and an estimated average concentration of about 1.6 mgm^{-3} before any dust controls had been introduced. The general conditions in the British heavy clay industry appear to be no worse and if anything slightly better than dust conditions reported in other countries in the last few years.

The gathering of such a large number of dust samples from so many OGs and sites has allowed the dust conditions in OGs at sites where measurements were not obtained to be estimated with a considerable degree of confidence. Furthermore, historical information regarding changes to type of kiln has given a reasonable basis for assigning dust and quartz concentrations to jobs at study and non-study sites in earlier years for the estimation of individual cumulative dust exposures (see Appendix 6).

4.2 Quartz Exposures in the Heavy Clay Industry

The average quartz concentration of 0.11 mgm^{-3}, based on measurements from all plants in this study, is greater than most respirable quartz standards used in other countries and until recently in the UK. This upper limit of 0.1 mgm^{-3} was exceeded in 33% of samples in the present study (Table 3.5[b]) and on at least one occasion in all OGs, and at all sites.

Percentage quartz in the dust samples varied about equally from job to job (6–20%) and across sites (5–21%). These variations will depend on the feedstock and processes carried out at each plant. The range of % quartz observed in this study could therefore be taken throughout the industry as representative of the content of respirable dust. This seems to be consistent with the 15% representative value reported for the Dutch brick industry (Buringh et al 1990) but considerably higher than the 2% reported recently for South African brickworks (Myers et al, 1989[a]).

Three percent of all samples were found to have quartz concentrations above the UK maximum exposure limit of 0.4 mgm^{-3} (a value which should not in any circumstances be exceeded under current legislation), as many as 18% of the 33 samples at one site (Table 3.5[b]). At this site (now closed) four of the six samples above the MEL were collected in the pan mill area and other jobs sampled had well above average quartz concentrations. Sand was used in setting bricks and a previous HSE survey had indicated that considerable levels of respirable dust were being generated in some jobs at the site. Two thirds of the sites had at least one sample with a quartz concentration greater than the MEL, most of these being confined to pan mill workers, general labourers, sand users, clean-up and kiln demolition workers.

In the analysis of dust samples by SEM/EDXS for quantification of size and mineralogical composition a particle is classified as a given mineral on the basis of the percentages of X-rays emitted from the particle attributable to selected elements. These percentages are not the same as the elemental composition of the mineral concerned. The intensity of X-ray emission differs between elements (in general, the lower the atomic number the lower the intensity), the technique is only semiquantitative and in a mixed mineral dust, particles are invariably contaminated to some extent, by other mineral and non-mineral substances.

In the present study the criteria for classifying particles from sites 4 and 17 were similar to those used in studies of coalmine dusts and underground railway tunnel dust (Addison et al. 1990; Robertson et al. 1992; Cullen et al. in press). The sample collected at site 16 indicated considerable contamination by manganese. An allowance was therefore made for this in the criteria for classifying particles from this site as quartz.

Using these analytical definitions quartz particles were identified in respirable dusts at each site. The proportions were different from those measured on full shift personal samples collected on workers close to the sampling point. However, such differences are only to be expected considering the different techniques and the different sampling strategies. This work demonstrates that free quartz particles are present in respirable airborne dusts found in the heavy clay industry. SEM/EDXS does not, however, analyse thin layers of surface contamination. The results of particle analysis from the present study do not demonstrate that the quartz identified is any more or less hazardous than quartz found in other situations. Surface contamination has been shown to reduce the fibrogenicity of quartz (eg Le Bouffant, 1977) and, from the sources of the minerals, it is reasonable to expect that the surfaces of quartz particles could be contaminated.

4.3 Respiratory Health Effects

This study has generally confirmed the industry's expectations of a low frequency of radiological abnormality within the current workforce of the heavy clay industry. Although radiographic surveys of brick and tile works have been carried out by several companies in the UK, there have been no published reports on the presence of radiographic abnormalities of employees in the UK since Keatinge and Potter's study in 1949. They observed only two men out of 73 with any degree of chest radiographic abnormality (minimal changes only). In addition a 49 year old former bricklayer's labourer, who had just joined the industry, was reported to have had radiographic changes indistinguishable from those of classical silicosis.

Sayers et al (1937) observed that there was no serious dust hazard from working in the US brick and tile manufacturing industry. In contrast nearly 50% of workers at an Italian tile works were found to have silicosis (Barsi, 1953). The prevalence of pneumoconiosis in the present study tends towards the lower end of this range (1.4% with category 1/0 or greater) and is considerably lower than the 4% prevalence (1/0 or more) reported among 268 black brickworkers in South Africa (Myers et al 1989[b]). The latter authors did, however, previously exclude 176 men who had spent two or more years exposed to siliceous dusty conditions. Although their prevalence figure is likely to be an underestimate for the workforce as a whole, an earlier South African study by Sluis-Cremer (1972) of stock brick workers identified an incidence of 43 per 1000 workers (4.3%). In the USA 5% of brickworkers had abnormal radiographs although exact categories were not reported (Palmer et al, 1980).

In the present study eight men were classified, according to the median reading, as having category 2/1 or greater or large opacities, which are considered to be established pneumoconiosis. It is of considerable concern that a 29 year old man who had worked in the heavy clay industry for 13 years in post-production areas, and was currently employed at site 5, one of the less dusty sites, should have this degree of radiological abnormality (category 2/3, the highest level observed in this study). Furthermore, small opacities of category 1 represent definite but slight abnormality. However, some of these appearances can be the result of age, smoking or other disease, as well as pneumoconiosis but the demonstrated relationships with dust exposure confirm that they include cases of pneumoconiosis. These results suggest that such abnormalities can occur, although there may not be a general problem in the heavy clay industry.

In the context of recent studies of workers exposed to mineral dusts containing silica, this population of brick and tile workers have a lower prevalence of small opacities category 1/0 or greater (1.4%) than, say, opencast mineworkers (4.4%, Love et al. 1992) and hard rock quarry workers (4.7%, Agius et al. 1992) investigated by us in other recent epidemiological studies. As part of one of these studies, radiographs from a group of postal and telecommunication workers, not thought generally to be exposed to noxious dusts during their jobs, were examined and a prevalence of 2.8% was found. Although some of those with significant radiological abnormalities had previously been employed in dusty jobs, including brickworks, the currently employed brickworkers in this study have an even lower prevalence, suggesting that there are relatively few individuals with significant clinical abnormality among the current workforce.

1.4% of non-smokers aged 40 exposed to an average dust concentration of 2.5 mgm^{-3} for 20 years would be expected to have category 1/0 or more according to the exposure response relationship predicted from this study, compared to 0.6% of those working in the group exposed to the lowest dust concentration. In comparison a recent study of the dust related risks of radiological changes in coalminers (Hurley and Maclaren, 1987) showed that there was a 2.8% probability that a coalminer would have simple pneumoconiosis of category 1 or above following 20 years exposure to dust of medium rank at an average concentration of 2.5 mgm^{-3}, these exposures being equivalent to 50 mgm^{-3} years. Given the high quartz concentrations experienced by a significant proportion of the workforce in the heavy clay industry, this relatively low prevalence might be considered surprising. However, the presence of clay minerals, and specifically the release of aluminium or other ions, on the surface of well weathered particles containing quartz, is thought to reduce the toxicity of inhaled quartz (Le Bouffant et al, 1982). Illite seems to be a particularly effective mineral in this respect, whereas kaolin is less so. Nevertheless, the estimated exposure response relationship for quartz suggest significant risks of radiological abnormality even at concentrations of 0.1 mgm^{-3} of quartz. Some detailed analysis of the rates at low exposures would be advisable.

Fourteen percent of the study population had chronic bronchitis, slightly more than we have recently reported among opencast miners (13%, Love et al. 1992) and wool textile workers (9%, Love et al. 1988) but lower than a recent study of underground coalminers (22%, Lloyd et al. 1986). In contrast only 7% of South African brickworkers were reported to have chronic bronchitis (Myers et al. 1989), although their definition of this condition was not clear.

Breathlessness was less frequently reported by this workforce, 4% on average, than by the brick workers studied by Myers and Cornell (1989) (9%), although again their definition is not entirely clear. We have also observed a prevalence of 9.5% among male wool textile workers (Love et al, 1988), indicating the rather low frequency with which the symptom is reported in the heavy clay industry in this country.

If less healthy men leave an industry preferentially, a study only of current workers may underestimate the frequency of ill health. The average age (40 years) and the wide age range and distribution of the study population does not suggest that this is a younger than expected workforce.

The results of a small feasibility study of leavers from one factory, reported in Appendix 5, are insufficient to allow firm conclusions to be drawn on this point. The response rate among these leavers indicated that more extensive studies of leavers would be unlikely to achieve sufficient response to be informative. Given the generally low prevalence of respiratory disease in the current population and the lack of reports of significant numbers of cases seeking industrial injuries compensation from pneumoconiosis arising from working in the heavy clay industry, the exclusion of leavers is unlikely to have seriously influenced qualitatively the estimates of health risks in the industry.

Although our analysis has identified a relationship between respiratory health and exposure to quartz-containing dust, the study provides limited information as to whether this is more closely associated with respirable dust as a whole or with the quartz content in particular, because of the very high correlation between the two exposure indices. This statement seems to be borne out when comparing the respirable dust and quartz concentrations in Appendix Tables A3.1 and A3.3. The much higher than average quartz levels among pan mill operators at sites 4 and 6 are closely mirrored by the increased dust levels, indicating that there is a general dust, and therefore quartz, problem in certain areas. Review of the abnormal chest radiographs by an experienced chest physician indicated that the pattern of small opacities was not typical of other recognised occupational lung conditions such as coalworkers' pneumoconiosis or classical silicosis and may represent a mixed dust type of pneumoconiosis.

The exposure response relationship for chronic bronchitis in this population is not very strong and, although there is a consistency in the general relationship, the group of kiln demolition workers demonstrated a particularly severe effect. Dust exposures of over 100 mgm^{-3} years (10 mgm^{-3} for 10 years) should not be unexpected in this group, which though small in number are potentially exposed to a considerable risk of chronic bronchitis (and pneumoconiosis, if this exposure was to be sustained).

4.4 Medical Surveillance

Medical surveillance is indicated for all those regularly exposed to dust, especially including those exposed to concentrations of respirable quartz greater than 0.1 mgm^{-3}. The examination should include full size chest radiographs to detect pneumoconiosis, and should be interpreted by a physician experienced in the recognition of pneumoconiosis. Additionally chronic bronchitis and smoking history should be assessed by questionnaire. Performance of simple lung function tests would be desirable, especially on the kiln demolition workers and clean up men. The HSE recommends two-yearly examination for silica-exposed workers, though the low health risks in this industry so far demonstrated may suggest that a lesser frequency would be adequate. The results should be summarised (respecting individual confidentiality) for management and other interested parties, and collated for the industry generally to monitor the success of prevention strategies. Individuals should be informed in confidence of the results of their examinations.

4.5 Toxicity of Quartz in the Heavy Clay Industry

The nature of respirable dust containing quartz in brickworks is qualitatively different from that found in, say hard rock quarries and some mines. Bricks and tiles are made of sedimentary material, consisting of very fine particles held together by physical forces. During processing, these fine particles containing surfaces millions of years old are released as dust. Quartz-containing particles in this material will probably be covered in clay minerals but, although new quartz grows, it is unlikely to be reactive because of its slow growth. In quarries, however, quartz particles are likely to be broken allowing fresh quartz surfaces to be exposed. In coalmines both types of process can be found: dirt bands within a coal seam containing sedimentary quartz, which are not associated with high frequencies of pneumoconiosis or silicosis (eg Davis et al. 1991; Hurley et al. 1982) and sandstone roofs and floors which, if cut into, can give rise to high levels of such disease (Seaton et al. 1981).

4.6 Control of Dust in the Heavy Clay Industry

What does this imply for measures to protect the health of the workforce of factories manufacturing non-refractory bricks, pipes and tiles? Although the recently introduced quartz MEL of 0.4mgm^{-3} was exceeded on several occasions in a number of different occupational groups, these tended to be in a few well recognised activities (kiln demolition, clean up squad, sand users) or single isolated measurements in one group at one site. Control of these activities by changing the way the job is carried out, enclosure of the process and the use of respiratory protection, as appropriate, should be considered to reduce quartz levels to below the MEL.

In some areas of the plant persons may be exposed to materials which have a higher quartz content than that found in the general dust of the brickworks. The material used to face bricks may contain substantial quantities of sand and the use of good control measures is imperative. In new works where LEV systems are often an integral part of the equipment there is less reliance on the use of RPE than in older plants where control measures may be of a more piecemeal nature.

Some of the materials used in the production of bricks contain substances which may have been assigned an individual occupational exposure limit. Control measures implemented should be capable of reducing exposure to below these specific limits.

Although the composition of the feed material used to produce the green bricks is relatively standard, variations may occur over time. Significant increases in quartz content should be noted and checks made to ensure that control measures can reduce exposure to below the MEL.

Until a few years ago it appears that the control measures used within the industry were of a basic nature. However, the introduction of the COSHH Regulations, just prior to the surveys, has seen an increasing use of control measures, particularly LEV systems. Study of the most cost-effective dust control measures currently in use in the industry would provide useful guidance for employers.

Judgements on the extent to which quartz concentrations should be controlled below the MEL are influenced by the practicability of achieving low concentrations as well as the degree of the health risks. The study has demonstrated exposure response relationships for quartz which imply significant health risks as a result of prolonged exposure to concentrations of quartz as low as 0.1 mgm^{-3}, and some further analysis of the relationships, and supporting data over the low exposure range would be desirable.

Similarly there is a need to control dust levels to prevent excessive prevalence of chronic bronchitis, which in this study was shown mainly to be of significance in relation to kiln demolition workers, a small group employed in very dusty jobs. Control of dust (and quartz) levels for the purposes of minimising the risk of pneumoconiosis should therefore also considerably reduce the prevalence of chronic bronchitis in the at risk population.

5. RECOMMENDATIONS

1. On the basis of the measurements of respirable dust and quartz obtained during this study, it is recommended that the heavy clay industry focus on reducing respirable quartz concentrations in specific jobs and occupational groups where levels exceeding the MEL have been shown to occur, particularly kiln demolition workers, clean-up squads, sand users and some pan mill operators and brick and tile moulders. The most cost-effective methods of dust control could be implemented based on the well established principles.

The extent to which the quartz concentrations should be reduced below the MEL will be influenced by practicability and by the degree of health risk at low quartz concentrations. Some further statistical analyses of these risks would be informative.

2. Medical surveillance, comprising chest radiography, questionnaire of respiratory symptoms and, preferably, simple lung function tests, is indicated for all dust exposed workers in the industry. The lung function of the kiln demolition workers and other very highly exposed groups in particular should be assessed. The interval recommended by the Health and Safety Executive for silica exposed workers is two years for chest radiography.

3. Medical surveillance should also include the collation and reporting of health statistics on a national basis.

4. However, a case could be made for a lesser frequency of medical surveillance, including chest X-rays, for workers in the heavy clay industry, in view of the relatively small risks and expected slow progression of disease. A lesser frequency should be subject to review.

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Table 2.1 Criteria for mineral classification

	% OF X-RAYS EMITTED FROM PARTICLE									
	Carbon	Oxygen	Aluminium	Silicon	Sulphur	Potassium	Calcium	Titanium	Manganese *	Iron
Quartz	< 25%	10-100	< 7	25-100	< 10	< 5	< 5	< 7	< 15	< 7
Kaolinite	< 25	10-100	7.5-100	10-100	< 10	< 5	< 8	< 5	< 15	< 5
Illite/Mica	< 25	10-100	7.5-100	10-100	< 10	5-20	< 7	< 5	< 15	< 5
Rutile	< 25	15-100	< 5	< 5	< 5	< 5	< 5	10-100	< 15	< 10
Pyrite	< 25	< 15	< 10	< 10	10-100	< 5	< 5	< 5	< 15	10-100
Lime	< 25	15-100	< 10	< 10	< 5	< 5	45-100	< 8	< 15	< 8
Calcite	10-100	10-100	< 15	< 10	< 5	< 5	35-100	< 8	< 15	< 8
Calcium silicate and sulphate	< 25	10-100	< 20	5-50	< 50	< 7	5-50	< 5	< 15	< 5
Iron oxide	< 25	10-50	< 10	< 10	< 5	< 5	< 5	< 5	< 15	30-100
Organic	10-100	5-100	< 15	< 15	< 5	< 5	< 5	< 5	< 15	< 5
Manganese Oxides*	< 25	10-100	< 10	< 10	< 5	< 5	< 5	< 5	15-100	< 10

*Classification and Criteria applied only to particles from site 16. Manganese was not present in significant quantities in the samples from sites 4 and 17.

Table 3.1 **Selected Brick and Tile Works**

SITE NO	MATERIAL	AGE OF SITE (years)	NO ON SITE (approx)
1	Shale	>100	45
2	Shale	40	95
3	Shale	44	76
4	Shale	43	35
5	Shale	c.60 (23)*	63
6	Shale	c.85 (22)	68
7	Shale	26 (19)	86
8	Shale	65 (17)	124
9	Shale	c.100 (13)	131
10	Marl	c.90 (26)	122
11	Shale	c.90 (25)	122
12	Soft Clay	c.140 (21)	377
13	Soft Clay	19	177
14	Soft Mud	56	60
15	Soft Mud	200	38
16	Soft Clay	c.100	112
17	Soft Clay	94	582
18	Shale	135 (11)	115
TOTAL			2428

* years ago when change to tunnel kilns was made.

Table 3.2 Numbers of employees examined and reasons for non-attendance for all sites participating in the medical surveys.

SITE	NO. OF PEOPLE IDENTIFIED	NO. EXAMINED	REFUSED	SICK	HOLIDAY OR WORK COMMITMENTS	LEFT COMPANY OR RETIRED	ITINERANT STAFF	UNKNOWN	TOTAL NON-ATTENDERS
1	45	36	1	3	2	3	0	0	9
2	95	58	10	1	1	25	0	0	37
3	76	64	1	3	1	7	0	0	12
4	35	27	0	2	1	5	0	0	8
5	63	45	10	5	3	0	0	0	18
6	68	54	7	2	5	0	0	0	14
7	86	80	1	3	2	0	0	0	6
8	124	97	12	5	6	2	2	0	27
9	131	107	13	9	1	1	0	0	24
10	122	100	12	1	3	6	0	0	22
11	122	88	10	7	10	3	4	0	34
12	377	278	6	6	0	87	0	0	99
13	177	138	17	4	9	9	0	0	39
14	60	41	4	1	12	2	0	0	19
15	38	37	1	0	0	0	0	0	1
16	112	102	3	3	0	0	0	4	10
17	582	477	30	5	5	9	9	47	105
18	115	105	0	0	0	0	0	10	10
All	2428	1934	138	60	61	159	15	61	494

Table 3.3 Occupational Groups (OGs) in Heavy Clay Industry

OG No	GROUP TITLE	DESCRIPTION
1	No direct contact	Office based, work off site
2	Quarry workers	Quarry workers with low exposure to dust eg. oilers, dumper drivers etc.
3	Kiln burners	
4	W/shop based fitters and general FLT drivers, and supervisors, foremen	FLT drivers operating in general yard area, includes w/shop based fitters
5	Quarry workers	All persons carrying out duties at the quarry
6	Coal handlers	Persons employed to transport and handle coal at Hoffman kilns
7	Brick cutters	Persons preparing bricks for display boards
8	Brick make operators, setters	Persons included in activities associated with mixed, unfired material
9	Bricklayers	General bricklaying around site including general work on kilns and kiln cars
10	Factory fitters	Fitters who operate on the plant
11	Packers	Packers associated with Hoffman kilns
12	FLT Drivers	FLT drivers working in general areas including setting areas
13	Packers	Packing jobs outwith the kiln
14	Moulders	Moulding tiles
15	FLT drivers (Kilns/driers)	FLT drivers operating only within kilns or driers
16	Kiln labourers	General workers based around the kilns

17	Pan Mill operators	Persons working in the pan mill area
18	Wicket men	Persons included in erecting, sealing and dismantling wickets
19	Strapak operators	Packers using automatic system
20	Factory cleaners	Workers included in general cleaning duties around factory
21	Sand operators	Persons handling sand, eg sand mixers, applicators, sand and stain men etc.
22	Clean-up squad	Persons directly involved in short term intensive factory cleaning tasks, flue cleaner
23	Kiln demolition	All persons involved in the demolition/repair of Hoffman kilns

Table 3.4 Combined Occupational Groups*

OG No	TITLE	Table 3.2 Occ. Groups Combined
1	No direct exposure	1
2	Supervisors	3, 4, 6
3	Pre-production	2, 5, 8, 14
4	Brick cutters	7
5	Mixed dust work	10, 12
6	Post production	9, 11, 13, 19
7	Forklift drivers/kilns	15
8	Pan mill operators	17
9	Labourers	16, 18, 20
10	Sand users	21
11	Cleaning squad	22
12	Kiln demolition	23

* listed in increasing order of average dust concentration

Table 3.5(a) Number of samples (for dust)*, with the average and maximum respirable concentrations for dust and quartz, and percentage quartz in the dust at each site. (Sites are presented in decreasing order of average dust concentrations).

SITE	NO. OF SAMPLES	AVERAGE DUST CONC. (mgm^{-3})	MAXIMUM DUST CONC. (mgm^{-3})	AVERAGE QUARTZ CONC. (mgm^{-3})	MAXIMUM QUARTZ CONC. (mgm^{-3})	AVERAGE QUARTZ %	MAXIMUM QUARTZ %
17	245	2.5	100.1	0.17	3.8	9	34
4	33	2.1	11.5	0.29	1.5	15	29
12	151	1.6	10.0	0.10	0.5	6	22
8	72	1.3	51.1	0.07	0.5	13	40
1	71	1.3	3.6	0.09	0.5	7	24
5	65	1.2	9.2	0.11	0.7	10	16
14	45	1.2	6.1	0.07	0.7	9	100a
13	70	1.1	6.1	0.06	0.3	6	19
16	55	1.1	4.7	0.21	0.6	21	35
9	80	1.1	5.6	0.11	0.5	11	23
6	46	0.9	6.0	0.12	1.2	11	37
2	65	0.9	3.2	0.05	0.3	5	17
3	54	0.8	2.6	0.11	0.4	15	56b
7	74	0.8	10.8	0.10	1.3	14	50c
18	88	0.7	2.5	0.06	0.2	9	72a
15	45	0.7	2.3	0.08	0.3	12	31
10	70	0.5	2.6	0.06	0.4	10	21
11	78	0.5	1.8	0.07	0.3	15	35
All sites	1407	1.3	100.1	0.11	3.8	10	100

*The number of samples for quartz and percentage quartz is occasionally one or two lower, because of six missing quartz values).

a High % value could be due to spectral interference from other minerals in the dust

b Obtained on a crusher operator

c Could be erroneously high because of very small dust mass (0.02 mg).

Table 3.5(b) The percentage of dust samples above 2.5 and 5mgm^{-3} and percentage of quartz samples above 0.1 and 0.4mgm^{-3} for each site.

SITE NO.	% OF DUST SAMPLES ABOVE 2.5	% OF DUST SAMPLES ABOVE 5.0	% OF QUARTZ SAMPLES ABOVE 0.1	% OF QUARTZ SAMPLES ABOVE 0.4
17	17	7	43	7
4	18	12	76	18
12	19	3	42	1
8	3	3	14	3
1	6	0	24	3
5	9	5	28	5
14	11	2	11	2
13	9	1	20	0
16	4	0	80	9
9	5	1	46	1
6	4	4	41	4
2	5	0	15	0
3	2	0	43	0
7	1	1	28	1
18	0	0	16	0
15	0	0	27	0
10	1	0	11	1
11	0	0	24	0
All sites	8	3	33	3

Table 3.6 The percentage of dust samples above 2.5 and 5 mgm^{-3} and percentage of quartz samples above 0.1 and 0.4 mgm^{-3} for each occupational group.

OCCUPATIONAL GROUP		% DUST SAMPLES ABOVE 2.5	% DUST SAMPLES ABOVE 5.0	% QUARTZ SAMPLES ABOVE 0.1	% QUARTZ SAMPLES ABOVE 0.4
1	No Dir	0	0	6	0
2	Superv	1	0	12	1
3	Pre Pr	4	1	30	3
4	Brk Cut	10	0	30	0
5	Mixed	3	1	21	2
6	Post Pr	11	1	51	0
7	Flt Kln	20	0	57	0
8	Pan Mil	11	7	60	6
9	Gen La	10	3	38	4
10	Sand	32	17	57	17
11	Cln Up	52	12	83	17
12	Demol	100	100	100	100
	All groups	8	3	33	3

Table 3.7 Analysis of variance table for dust sampling data.

Mean differences for	Degrees of freedom (Number of groups -1) (a)	Sum of squares (of differences of groups from mean) (b)	Mean square * (b ÷ a)
Occupational Group	11	220	19.96
Type of Kiln (Tunnel vs. others)	1	59	59.16
Remaining site to site variation	16	74	4.62
Remaining week to week variation	3	1	0.28
Remaining day to day variation	66	43	0.65
Mean differences for occupational group according to			
kiln type	10	15	1.51
site	96	100	1.04
week	17	15	0.85
day	258	98	0.38
Residual (unexplained variation)	928	388	0.42
Total	1406	1013	0.72

Note: The above table is based on a modified version of the Normal distribution analysis of the log of the dust sampling data.

* Mean square values are compared with other appropriate mean squares (usually the residual mean square) to derive an F value to indicate the degree of statistical significance of their differences. Since more than one comparison can be made, it is not appropriate to list these F values.

Table 3.8 **Analysis of variance table for quartz sampling data.**

Mean differences for	Degrees of freedom (Number of groups -1) (a)	Sum of squares (of differences of groups from mean) (b)	Mean Square* (b ÷ a)
Occupational Group	11	272	24.72
Type of Kiln (Tunnel vs. others)	1	0	0.19
Remaining site to site variation	16	175	10.92
Remaining week to week variation	3	3	0.92
Remaining day to day variation	66	74	1.11
Mean differences for occupational group according to			
kiln type	10	19	1.89
site	96	150	1.57
week	17	23	1.38
day	258	164	0.63
Residual (unexplained variation)	924	520	0.56
Total	1402	1400	1.00

Note: The above table is based on a modified version of the Normal distribution analysis of the quartz sampling data.

* Mean square values are compared with other appropriate mean squares (usually the residual mean square) to derive an F value to indicate the degree of statistical significance of their differences. Since more than one comparison can be made, it is not appropriate to list these F values.

Table 3.9 Analysis of variance table for percentage quartz in dust.

Mean differences for	Degrees of freedom (Number of groups - 1) (a)	Sum of squares (of differences of groups from mean) (b)	Mean Square* (b ÷ a)
Occupational Group	11	1528	139
Type of Kiln (Tunnel vs. others)	1	2328	2328
Remaining site to site variation	16	16271	1017
Remaining week to week variation	3	85	28
Remaining day to day variation	66	2211	34
Mean differences for occupational group according to			
kiln type	10	651	65
site	96	3739	39
week	17	120	7
day	258	5062	20
Residual (unexplained variation)	922	15515	17
Total	1400	47510	34

Note: The above table is based on a modified version of the Normal distribution analysis of the percentage quartz in the dust. Despite the modification, residual plots still showed departures from Normality. The same general pattern of results was shown when several different transformations were used.

Table 3.10(a) Particle size analysis of samples of respirable dust from three sites: 4, a shale based brickworks; 16, a hand made tile works; 17, a large stock brickworks.

	% particles within each size range					
	SITE 4		SITE 16		SITE 17	
dia. range (μm)	% in size range	Cumulative % less than upper boundary	% in size range	Cumulative % less than upper boundary	% in size range	Cumulative % less than upper boundary
0-0.25	14.2	14.2	16.9	16.9	12.1	12.1
0.25-0.50	23.5	37.7	33.3	50.2	26.3	38.4
0.50-0.75	14.8	52.5	15.2	65.4	16.0	54.4
0.75-1.00	13.5	66.0	7.7	73.1	10.8	65.2
1.00-2.00	22.3	88.3	17.7	90.8	20.8	80.0
2.00-3.00	6.2	94.5	5.3	96.1	6.7	92.7
3.00-4.00	3.1	97.6	2.3	98.4	3.5	96.2
4.00-5.00	1.8	99.4	0.5	98.9	2.4	98.6
5.00-6.00	0.3	99.7	0.4	99.3	0.8	99.4
6.00-7.00	0.2	99.9	0.5	99.8	0.4	99.8
7.00-8.00	0.1	100	0.0	99.8	0.1	99.9
>8.00	0	100	0.1	99.9	0.1	100

Table 3.10(b) Mineralogical analysis of respirable dust samples from pre-production areas of three sites, 4, 16 and 17, using STEM/EDXS (% of particles classified into each type of mineral)

Mineral	% IN SAMPLE					
	Site 4		Site 16		Site 17	
	by number	by volume	by number	by volume	by number	by volume
Quartz	6.8	11.1	3.3	11.5	10.0	21.2
Kaolinite	53.8	47.4	4.2	19.2	27.8	43.5
Illite/ Mica	10.4	21.9	N.D	N.D	7.9	14.3
Pyrite	N.D	N.D	N.D	N.D	0.4	0.1
Calcium silicate	N.D	N.D	N.D	N.D	1.2	1.3
Manganese oxide	N.D	N.D	10.0	13.3	N.D	N.D
Organic	6.7	2.3	20.5	27.1	7.3	1.3
Unclassified	22.3	17.3	61.9	28.7	45.5	18.3

N.D = not detected, less than 2 particles in 1000 particles counted

Table 3.11 Numbers of men, age, smoking habits and cumulative dust and quartz exposures at 18 brick and tile works

Site	No of men	Mean Age	% Non Smoker	% Ex Smoker	% Current Smoker	Mean cumulative exposures (mgm^{-3} years)	
						Dust	Quartz
1	34	41.5	20	15	65	16.5	1.39
2	54	38.0	28	13	59	10.0	0.65
3	63	40.0	35	11	54	11.1	1.54
4	25	38.4	36	20	44	23.3	3.30
5	45	40.1	49	20	31	14.2	1.43
6	52	40.6	35	21	44	10.3	1.17
7	77	36.4	49	16	35	7.6	1.02
8	90	38.9	31	17	52	8.4	1.05
9	104	31.3	39	13	48	7.3	0.80
10	90	37.8	46	20	34	6.2	0.64
11	81	37.8	28	26	46	6.6	0.95
12	274	41.2	29	27	44	21.3	1.65
13	130	40.7	30	27	43	16.3	1.35
14	38	35.8	50	16	34	11.3	0.89
15	30	42.1	27	23	50	8.9	1.04
16	88	41.3	28	24	48	13.6	2.82
17	460	43.2	43	21	36	23.5	2.07
18	96	38.1	48	21	31	10.5	1.01
All	1831	40.0	37	21	42	15.5	1.51

Table 3.12 Profusion of small opacities on 1913 radiographs, by reader (% in brackets) comprising 1835 men, 71 women and 7 subjects subsequently excluded from the analysis

READER	X-RAY PROFUSION CATEGORY 0/0	0/1	1/0	1/1	1/2	2/1	2/2	2/3	3/2	TOTAL
2	1869	26	8	4	2	1	0	1	0	1911*
	(97.8)	(1.4)	(0.4)	(0.2)	(0.1)	(0.0)	(0.0)	(0.0)	(0.0)	
10	1698	161	26	17	1	0	7	2	0	1912
	(84.2)	(8.4)	(1.4)	(0.9)	(0.0)	(0.0)	(0.4)	(0.1)	(0.0)	
15	1852	11	13	7	6	12	9	1	1	1912
	(96.9)	(0.6)	(0.7)	(0.4)	(0.3)	(0.7)	(0.5)	(0.0)	(0.0)	

* one film was considered to be unacceptable by this reader.

Table 3.13 Distribution of 1831 male workers at 18 heavy clay sites, by site and median profusion of radiological abnormality.

SITE NO.	PROFUSION CATEGORY 0/0	0/1	1/0	1/1	1/2	2/1	2/2	2/3	All
1	31	2	0	0	0	0	1	0	34
2	53	1	0	0	0	0	0	0	54
3	61	2	0	0	0	0	0	0	63
4	25	0	0	0	0	0	0	0	25
5	39	3	1	1	0	0	0	1	45
6	51	1	0	0	0	0	0	0	52
7	77	0	0	0	0	0	0	0	77
8	90	0	0	0	0	0	0	0	90
9	104	0	0	0	0	0	0	0	104
10	90	0	0	0	0	0	0	0	90
11	80	1	0	0	0	0	0	0	81
12	271	1	0	0	0	1	1	0	274
13	130	0	0	0	0	0	0	0	130
14	38	0	0	0	0	0	0	0	38
15	27	1	1	0	0	0	1	0	30
16	84	1	3	0	0	0	0	0	88
17	422	24	4	7	1	1	1	0	460
18	91	5	0	0	0	0	0	0	96
All sites	1764	42	9	8	1	2	4	1	1831
	(96.3%)	(2.3%)	(0.5%)	(0.4%)	(0.1%)	(0.1%)	(0.2%)	(0.1%)	

Table 3.14 Percentage of men with median profusion of small opacities category 0/1 or higher, by age and cumulative exposure to mixed respirable dust.

Age	Dust exposure (mgm^{-3} years)					
	0 - 4.9	5 - 9.9	10 - 19.9	20 - 39.9	40 -	All
-24	0.0 0 149	0.0 0 61	0.0 0 3	-	-	0.0 0 213
25-34	0.6 1 171	1.2 2 160	1.3 2 157	0.0 0 23	0.0 0 1	1.0 5 512
35-44	0.0 0 74	3.6 3 83	4.0 6 152	2.3 3 130	0.0 0 6	2.7 12 445
45-54	0.0 0 67	9.3 5 54	4.4 3 69	10.2 15 147	7.1 3 42	6.9 26 379
55-	2.7 1 37	0.0 0 19	7.4 4 54	9.5 10 105	13.4 9 67	8.5 24 282
All	0.4 2 498	2.6 10 377	3.4 15 435	6.9 28 405	10.3 12 116	3.7 67 1831

(Key to table entries:

percent prevalence of small opacities
number affected number at risk)

Table 3.15 Percentage of men with median profusion of small opacities category 1/0 or higher, by age and cumulative exposure to mixed respirable dust.

Age	Dust exposure (mgm^{-3} years)					
	0 - 4.9	5 - 9.9	10 - 19.9	20 - 39.9	40 -	All
-24	0.0 0 149	0.0 0 61	0.0 0 3	-	-	0.0 0 213
25-34	0.0 0 171	0.0 0 160	0.6 1 157	0.0 0 23	0.0 0 1	0.2 1 512
35-44	0.0 0 74	1.2 1 83	1.3 2 152	0.0 0 130	0.0 0 6	0.7 3 445
45-54	0.0 0 67	1.8 1 54	1.4 1 69	3.4 5 147	4.8 2 42	2.4 9 379
55-	0.0 0 37	0.0 0 19	5.6 3 54	5.7 6 105	4.5 3 67	4.3 12 282
All	0.0 0 498	0.5 2 377	1.6 7 435	2.7 11 405	4.3 5 116	1.4 25 1831

(Key to table entries:

percent prevalence of small opacities
number affected number at risk)

Table 3.16 Percentage of men with median profusion of small opacities category 0/1 or higher, by age and cumulative exposure to quartz.

Age	Quartz exposure (mgm^{-3} years)					
	0.00 - 0.49	0.50 - 0.99	1.00 - 1.99	2.00 - 3.99	4.00 -	All
-24	0.0 0 158	0.0 0 47	0.0 0 8	-	-	0.0 0 213
25-34	0.6 1 166	1.1 2 179	1.4 2 139	0.0 0 26	0.0 0 2	1.0 5 512
35-44	1.3 1 79	3.3 3 90	3.3 5 153	2.8 3 109	0.0 0 14	2.7 12 445
45-54	2.8 2 71	9.1 5 55	2.7 2 73	11.2 16 143	2.7 1 37	6.9 26 379
55-	2.9 1 34	4.4 1 23	4.8 3 62	8.3 8 96	16.4 11 67	8.5 24 282
All	1.0 5 508	2.8 11 394	2.8 12 435	7.2 27 374	10.0 12 120	3.7 67 1831

(Key to table entries:

percent prevalence of small opacities
number affected   number at risk)

Table 3.17 Percentage of men with median profusion of small opacities category 1/0 or higher, by age and cumulative exposure to quartz.

Age	Quartz exposure (mgm^{-3} years)					
	0.00-0.49	0.50-0.99	1.00-1.99	2.00-3.99	4.00-	All
-24	0.0 0 158	0.0 0 47	0.0 0 8	-	-	0.0 0 213
25-34	0.0 0 166	0.0 0 179	0.7 1 139	0.0 0 26	0.0 0 2	0.2 1 512
35-44	0.0 0 79	1.1 1 90	1.3 2 153	0.0 0 109	0.0 0 14	0.7 3 445
45-54	1.4 1 71	0.0 0 55	1.4 1 73	4.2 6 143	2.7 1 37	2.4 9 379
55-	0.0 0 34	4.4 1 23	3.2 2 62	4.2 4 96	7.5 5 67	4.3 12 282
All	0.2 1 508	0.5 2 394	1.4 6 435	2.7 10 374	5.0 6 120	1.4 25 1831

(Key to table entries:

percent prevalence of small opacities
number affected   number at risk)

Table 3.18 Prevalence of respiratory symptoms by age group

Age (Yr)	% with chronic bronchitis	% with breathlessness	% with wheeze	No. of men
<24	15.7	3.7	19.8	217
25-34	15.6	3.3	22.2	514
35-44	13.6	3.1	22.9	449
45-54	13.4	4.4	17.3	387
55+	12.6	8.7	19.0	285
All	14.2	4.4	20.6	1852

Table 3.19 Prevalence of chronic bronchitis, breathlessness and wheeze by smoking habit

Smoking category	% with chronic bronchitis	% with breathlessness	% with wheeze	No of men
Never smoked	7.4	2.2	12.5	687
Gave up smoking 5+ years ago	8.2	6.7	16.0	268
Gave up smoking up to 4 years ago	12.7	5.9	17.0	118
Current smoker - light	8.4	3.9	18.2	203
- moderate	21.8	6.5	29.6	321
- heavy	34.8	4.7	39.5	253
all smokers	22.5	5.2	29.8	777
All	14.2	4.4	20.6	1850

Table 3.20 Prevalence of chronic bronchitis and breathlessness by cumulative dust exposure (mgm^{-3} years)

Cumulative dust exposure	% with chronic bronchitis	% with breathlessness	% with wheeze	No. of men
0 - 4.9	13.9	4.4	19.5	502
5 - 9.9	13.4	2.9	20.7	381
10 - 19.9	15.6	2.8	21.5	437
20 - 39.9	12.8	5.8	18.6	413
40+	17.8	10.2	28.0	118
All	14.2	4.4	20.6	1851

Table 3.21 Odds ratios (with 95% confidence intervals) of profusion of small opacities category 0/1 or higher, estimated in logistic regression models.

Term in regression equation	Index of exposure: Dust	Index of exposure: Quartz
Cumulative exposure (per doubling)	1.3 (1.0, 1.6)	1.3 (1.0, 1.7)
Age (per 10 years)	1.8 (1.4, 2.4)	1.8 (1.3, 2.3)
Smoking (relative to non-smokers)		
Ex 1-10	1.7 (0.5, 5.5)	1.7 (0.5, 5.6)
11-20	1.7 (0.7, 4.2)	1.8 (0.7, 4.3)
21-	0.5 (0.1, 2.0)	0.5 (0.1, 2.0)
Current 1-10	1.5 (0.6, 3.5)	1.5 (0.6, 3.5)
11-20	2.3 (1.1, 4.8)	2.3 (1.1, 4.8)
21-	2.2 (0.9, 5.4)	2.2 (0.9, 5.4)
Site* (relative to site 1)		
2	0.3 (0.0, 3.6)	0.4 (0.0, 4.1)
3	0.4 (0.1, 2.8)	0.3 (0.0, 2.2)
5	2.7 (0.6,13.2)	2.5 (0.5,12.4)
6	0.3 (0.0, 2.9)	0.2 (0.0, 2.6)
11	0.2 (0.0, 2.8)	0.2 (0.0, 2.1)
12	0.1 (0.0, 0.6)	0.1 (0.0, 0.6)
15	1.5 (0.2, 9.4)	1.4 (0.2, 8.3)
16	0.7 (0.1, 3.8)	0.5 (0.1, 2.7)
17	0.9 (0.2, 3.6)	0.9 (0.2, 3.4)
18	1.1 (0.2, 5.3)	1.0 (0.2, 5.1)

* sites where none of the men were category 0/1 or higher are not listed.

Table 3.22 Years worked in industries other than the heavy clay industry

Category	Number of men	Average years worked (by these men)
Quarries	23	3.4
Underground mining	84	9.7
Other mining	71	4.2
Asbestos work	16	4.8
Other noxious or dusty jobs	126	6.4
Agriculture, forestry, farming	303	8.0
Construction, other industrial, fishing, armed forces	1306	8.2

Table 3.23 Odds ratios (with 95% confidence intervals) of profusion of small opacities category 1/0 or higher, estimated in logistic regression models.

Term in regression equation	Index of exposure	
	Dust	Quartz
Cumulative exposure (per doubling)	1.4 (0.9, 2.0)	1.4 (1.0, 2.0)
Age (per 10 years)	2.4 (1.5, 3.9)	2.4 (1.5, 3.8)
Smoking (relative to non-smokers)		
Ex 1-10	0.6 (0.1, 5.3)	0.6 (0.1, 5.4)
11-20	0.6 (0.1, 3.1)	0.6 (0.1, 3.2)
21-	0.2 (0.0, 2.1)	0.2 (0.0, 2.1)
Current 1-10	1.3 (0.4, 4.2)	1.3 (0.4, 4.2)
11-20	1.3 (0.4, 4.1)	1.3 (0.4, 4.0)
21-	0.9 (0.2, 4.5)	0.9 (0.2, 4.6)
Site* (relative to site 1)		
5	3.6 (0.3,42.9)	3.4 (0.3,40.4)
12	0.3 (0.0, 3.3)	0.3 (0.0, 3.4)
15	3.5 (0.3,48.7)	3.1 (0.2,41.6)
16	1.8 (0.2,20.7)	1.2 (0.1,14.0)
17	0.9 (0.1, 8.4)	0.9 (0.1, 8.1)

* sites where none of the men were category 1/0 or higher are not listed

Table 3.24 Odds ratios for chronic bronchitis with a 40 mgm^{-3} year increase in dust exposure following successive addition of other explanatory factors, using three different models

Other factors added in the model	Exposure to heavy clay dust	Exposure to dust in kiln demolition
MODEL 1		
None	1.2 (1.0,1.6)	-
Smoking	1.3 (1.0,1.8)*	-
Smoking, time in other industries	1.3 (1.0,1.8)*	-
Smoking, current site, time in other industries	1.5 (1.1,2.0)*	-
MODEL 2		
None	-	1.4 (1.0,2.0)*
Smoking	-	1.5 (1.0,2.1)*
Smoking, time in other industries	-	1.5 (1.1,2.2)*
Smoking, current site, time in other industries	-	1.6 (1.1,2.7)*
MODEL 3		
None	1.0 (0.7,1.5)	1.4 (1.0,2.0)*
Smoking	1.2 (0.8,1.8)	1.5 (1.0,2.2)*
Smoking, time in other industries	1.1 (0.8,1.7)	1.5 (1.1,2.2)*
Smoking, current site, time in other industries	1.3 (0.8,2.0)	1.7 (1.1,2.8)*

* odds ratio is significantly different from 1.0 at the 5% level.

Table 3.25 Odds ratios for breathlessness associated with a 40 mgm^{-3} year increase in dust exposure following successive addition of other explanatory factors, using three different models

Other factors added in the model	Exposure to heavy clay dust	Exposure to dust in kiln demolition
None	1.6 (1.2,2.1)*	-
Age	1.5 (1.1,2.0)*	-
Age, smoking	1.5 (1.1,2.0)*	-
Age, smoking, time in other industries	1.5 (1.1,2.0)*	-
Age, smoking, time in other industries	1.5 (1.1,2.2)*	-
None	-	1.4 (0.9,1.9)
Age	-	1.4 (1.0,2.0)*
Age, smoking	-	1.4 (1.0,2.0)*
Age, smoking, time in other industries	-	1.4 (1.0,2.0)*
Age, smoking, current site, time in other industries	-	1.5 (1.0,2.1)*
None	2.3 (1.3,4.1)*	1.4 (1.0,2.0)
Age	1.6 (0.8,3.0)	1.4 (1.0,2.0)
Age, smoking	1.5 (0.8,2.9)	1.4 (1.0,2.1)
Age, smoking, time in other industries	1.6 (0.8,3.1)	1.4 (1.0,2.1)
Age, smoking, current site, time in other industries	1.6 (0.8,3.3)	1.5 (1.0,2.2)

* Odds ratio is significantly different from 1.0 at the 5% level.

APPENDIX 1

Pilot Study

The pilot study consisted of an examination of data on the heavy clay industry provided by the National Federation of Clay Industries, visits to eleven works suggested by the NFCI, and preparation of the research proposal. The number of heavy clay manufacturers not in the Federation is thought to be small.

During the pilot study visits at each works the processes, personnel records and any available dust measurements were inspected. On the basis of these inspections it was suggested that the works in this industry could be grouped into two classes on the basis of the major natural raw materials used. One group consisted of those using soft clays and marls (e.g. Oxford Clay, Keuper Marl, younger clays) while the other consisted of those using the harder shales, mudstones and fireclays (mostly of Carboniferous age). The main rock types have essentially similar mineralogy (e.g. quartz content) and grain size but they appeared to differ importantly in inherent moisture content and hardness. By eye, observations of pilot plants indicated that the wetter softer clays tend to produce lower airborne dust concentrations in the crushing and grinding parts of the preparation than the harder, drier shale types. It was therefore expected that the workers in these sections of the shale works would probably be exposed to higher airborne quartz concentrations than those in other sections of the industry.

Another particularly dusty process appeared (to the eye of an experienced occupational hygienist) to be the operation of Hoffman kilns in a large soft clay brick works. Other raw materials such as manganese, barium salts or grog (defective products or returned used products) were considered to be of lesser importance for workforce exposures, with the possible exception of the refractories industry, where the grog may contain large proportions of cristobalite.

The quartz content of the raw materials was considered to be the most important factor influencing the possible health hazards from inhalation of dust. While the most commonly used raw materials differed markedly in the types and proportions of the clay minerals, they generally had similar quartz contents in the range of 20–40% (bulk samples).

The older Carboniferous shales and fireclays contained higher proportions of illite and kaolinite respectively; the younger marls and soft clays contained higher proportions of smectite and chlorite with some vermiculite, sepiolite and polygorskite.

The use of sand as a surface coating in the brick industry is very widespread and not related to other factors. Its use may be important for the quartz exposure of some sections of the workforce but was not considered as a major factor in the selection of plants for the main study.

The type of product did not appear to be likely to influence the quality of exposure to dust or quartz, although there were obvious differences in the quantity of dust generated at particular parts of the process e.g. grinding, kiln loading, sand coating of bricks.

Records of past workers tended to be adequate or good in the case of several large works, poor or absent in the smaller works. It was generally reported that the workforce had contracted over the last decade, and that older men had left preferentially.

The processes inspected ranged from new to over 60 years old. For the purposes of the main study, it was advised that the target population be workers on processes which had not changed substantially for 20 or 30 years or more. These long standing processes were not confined to small works, and not confined to hand-made processes.

APPENDIX 2

Respiratory Symptoms and Smoking Questionnaire

site code						i.d. no.		
H	C	2						

Respiratory symptoms/smoking.

Preamble : I would like to ask you some questions, mainly about your chest. Your answers will be treated in the strictest confidence. I would like you to answer Yes or No whenever possible.

Cough

1. Do you usually cough first thing in the morning? [ ]

2. Do you usually cough during the day or at night? [ ]

if Yes to Q1 or Q2
3. Do you cough like this on most days for as much as three months each year? [ ]

Phlegm

4. Do you usually bring up any phlegm from your chest first thing in the morning? [ ]

5. Do you usually bring up any phlegm from your chest during the day or at night? [ ]

if Yes to Q4 or Q5
6. Do you bring up phlegm like this on most days for as much as three months each year? [ ]

Periods of cough and phlegm

7. In the past three years have you had a period of (increased) cough and phlegm lasting for three weeks or more? [ ]

if Yes to Q7
8. Have you had more than one such period? [ ]

Breathlessness

> If the subject is obviously disabled from walking by any condition other than heart or lung disease, omit questions 9 - 11 and enter 1 here. [ ]

9. Are you troubled by shortness of breath when hurrying on level ground or walking up a slight hill? [ ]

if Yes to Q9
10. Do you get short of breath walking with other people of your own age on level ground? [ ]

if Yes to Q9 & Q10
11. Do you get short of breath when walking at your own [ ]

Wheezing and shortness of breath

12. Have you had attacks of wheezing or whistling in your chest at any time in the last 12 months? [ ]

13. Have you ever had attacks of shortness of breath with wheezing? [ ]

if Yes to Q13

14. Is/was your breathing absolutely normal between attacks? [ ]

15. Have you at any time in the last 12 months had an attack of shortness of breath that came on during the day when you were not doing anything strenuous? [ ]

Chest illnesses

16. During the last three years have you had any chest illness which has kept you from your usual activities for as much as a week? [ ]

if Yes to Q16

17. Did you bring up more phlegm than usual in any of these illnesses? [ ]

if Yes to Q16 & Q17

18. Have you had more than one illness like this in the last three years? [ ]

Past illnesses

Have you ever had or been told that you have had:

19. An injury or operation affecting your chest [ ]

20. Heart trouble [ ]

21. Bronchitis [ ]

22. Pneumonia [ ]

23. Pleurisy [ ]

24. Pulmonary Tuberculosis [ ]

25. Bronchial asthma [ ]

26. Other chest trouble [ ]

27. Hay fever [ ]

Smoking history

Preamble : I would like to ask you some questions about your smoking habits. Please try to answer Yes or No whenever possible.

30. Do you smoke?

if No to Q30

31. Have you ever smoked as much as one cigarette a day (or one cigar a week or one ounce of tobacco a month) for as long as a year?

If subject answers NO to both questions 30 and 31 then omit the remaining questions on smoking.

---

32. How old were you when you first started smoking regularly?

33. Do/did you smoke manufactured cigarettes?

if Yes to Q33

34. How many do/did you smoke per day on weekdays?

35. How many do/did you smoke per day at weekends?

---

36. Do/did you smoke hand-rolled cigarettes?

if Yes to Q36

37. How much tobacco do/did you usually smoke per week in this way?

---

38. Do/did you smoke a pipe?

if Yes to Q38

39. How much pipe tobacco do/did you usually smoke per week?

---

40. Do/did you smoke small cigars?

if Yes to Q40

41. How many of these did you usually smoke per day?

---

42. Do/did you smoke other cigars?

if Yes to Q42

43. How many of these did you usually smoke per week?

For current smokers

44. Have You been cutting down your smoking over the past year?

For ex-smokers   month   year

APPENDIX 3

(a) DESCRIPTION OF ACTIVITIES CARRIED OUT IN BRICKWORKS

This section describes, in general terms, the standard methods used in the manufacture of bricks and tiles as observed at the 18 sites included in the study.

Approximately half of the sites visited also owned a quarry where a small number of men were involved in extracting the raw materials from the ground. Those sites without quarries had raw materials delivered directly to the site and held in storage. All quarry personnel were placed in the pre-production occupational group (OG3).

Material from the quarry or the stockpile is tipped into the box feeder which supplies the grinder and ultimately the pan mill. Operators working in these areas were also placed in the pre-production group. Oversize material rejected at the screens is returned to the grinder and material passing through the screens is conveyed to the silos for storage prior to feeding to the brick machine. The screen area is usually attended by general labourers (OG9), who ensure the area is kept clean.

Water is added at the mixer in order that the clay can be shaped and pressed or extruded. These mixer operations were classified as pre-production (OG3).

Shaped clay or formed bricks emerging from the mixer may be textured or have various colours or slurries/sands added to the surface. Operators involved in tasks using sand were allocated to a highly specific occupational group termed 'sand users' (OG10).

The unfired bricks are conveyed to a setting station where they are set out in the required patterns prior to drying. The setters were also allocated to the pre-production group (OG3). Depending upon the type of kiln in use the bricks may be dried in driers or in the kilns.

Persons employed to transfer the bricks from the setting station to the driers and/or kilns were placed in the fork lift truck group specific to kilns and driers (OG7).

After due consideration the kiln burners were placed in the supervisors occupational group (OG2) as the nature of the work and the degree of exposure to dust was similar. Persons associated with the kilns were placed in the general labourers group (OG9).

Once the bricks have been fired they are removed from the kiln either by fork lift truck (FLT) or by packers. Packers were placed in the post production group (OG6) regardless of whether the work was carried our manually or automatically. The packed bricks may be polythene wrapped or transferred directly to the storage yard by FLT.

At some sites display panels were prepared for marketing purposes. This usually involved the cutting of fired bricks and again these persons were allocated to a specialised group (OG4).

Further breakdown of the allocation of job titles to occupational groups is given in section 3.2.2.

APPENDIX 3

(b) RESPIRABLE DUST AND QUARTZ CONCENTRATIONS AND PERCENTAGE QUARTZ IN PERSONAL SAMPLES OBTAINED FROM OCCUPATIONAL GROUPS AT ALL SITES DURING OCCUPATIONAL HYGIENE SURVEYS

Owing to lack of space the following six tables have abbreviated headings for the 12 occupational groups. A key to the full titles of these groups is given below for reference. (See Table 3.4 and Section 3.2.2 for further details).

OG No.	Abbreviated Title	Full Title
1	No Dir	No direct exposure (to dust)
2	Superv	Supervisors
3	Pre Pr	Pre-production
4	Brk Cut	Brick cutters
5	Mixed	Mixed dust work
6	Post Pr	Post-production
7	Flt Kln	Forklift drivers/kilns
8	Pan Mil	Pan mill operators
9	Gen La	Labourers
10	Sand	Sand users
11	Cln Up	Clean up squad
12	Demol	Kiln demolition workers

Table A3.1 Average dust concentrations (milligrams per cubic metre) and number of samples at all sites, by occupational group

Occupational Group (number, short title, see key in Introduction of Appendix 3b)

site	1NoDir aver. conc.	1NoDir no	2Superv aver. conc.	2Superv no	3PrePr aver. conc.	3PrePr no	4BrkCut aver. conc.	4BrkCut no	5Mixed aver. conc.	5Mixed no	6PostPr aver. conc.	6PostPr no	7FltKln aver. conc.	7FltKln no	8PanMil aver. conc.	8PanMil no	9GenLa aver. conc.	9GenLa no	10Sand aver. conc.	10Sand no	11ClnUp aver. conc.	11ClnUp no	12Demol aver. conc.	12Demol no	All Groups aver. conc.	All Groups no
1	-	0	1.0	18	1.4	12	-	0	1.1	12	1.2	10	1.6	6	1.6	6	1.7	7	-	0	-	0	-	0	1.3	71
2	1.3	1	0.8	21	0.6	12	1.4	5	0.8	8	0.7	6	1.8	4	1.1	8	-	0	-	0	-	0	-	0	0.9	65
3	-	0	0.4	8	0.6	20	-	0	0.6	3	1.4	7	-	0	1.2	9	0.7	7	-	0	-	0	-	0	0.8	54
4	-	0	1.6	8	1.2	11	-	0	-	0	1.2	8	-	0	5.8	6	-	0	-	0	-	0	-	0	2.1	33
5	-	0	0.9	16	1.2	10	-	0	0.4	6	0.9	12	-	0	1.6	6	2.7	11	0.4	4	-	0	-	0	1.2	65
6	0.3	3	0.5	10	1.6	8	-	0	0.7	9	0.8	8	-	0	3.7	2	0.8	6	-	0	-	0	-	0	0.9	46
7	-	0	0.3	14	0.5	9	-	0	0.8	11	0.4	11	-	0	1.8	5	1.1	23	0.5	1	-	0	-	0	0.8	74
8	-	0	0.4	27	0.4	19	-	0	5.9	11	0.3	6	1.0	3	1.3	3	0.3	3	-	0	-	0	-	0	1.3	72
9	-	0	0.5	13	1.0	18	1.0	2	1.0	8	1.3	16	-	0	0.9	5	1.1	15	2.4	3	-	0	-	0	1.1	80
10	0.3	5	0.4	21	0.5	11	-	0	0.6	7	-	0	0.4	3	0.8	3	0.4	11	0.8	7	2.3	2	-	0	0.5	70
11	0.3	3	0.3	24	0.6	14	0.3	3	0.7	10	0.7	8	0.3	4	-	0	0.5	10	0.7	2	-	0	-	0	0.5	78
12	0.9	2	0.6	31	0.8	21	-	0	1.0	15	2.3	40	2.2	8	1.6	7	1.8	18	4.4	9	-	0	-	0	1.6	151
13	-	0	0.5	9	0.8	21	-	0	2.0	4	1.8	9	0.8	1	1.8	3	1.1	18	1.0	3	1.9	2	-	0	1.1	70
14	-	0	0.6	8	1.3	20	-	0	0.6	3	2.0	8	1.0	2	0.5	2	0.8	2	-	0	-	0	-	0	1.2	45
15	-	0	0.4	7	0.8	17	-	0	0.6	6	0.8	10	-	0	0.4	2	0.8	3	-	0	-	0	-	0	0.7	45
16	-	0	0.8	11	1.4	27	-	0	1.1	5	0.3	1	0.7	4	-	0	0.9	5	1.2	2	-	0	-	0	1.1	55
17	0.6	2	0.6	51	1.6	39	-	0	1.1	28	2.1	38	2.4	11	1.4	10	4.8	26	3.0	16	7.8	21	10.0	3	2.5	245
18	0.3	2	0.8	39	0.6	12	-	0	0.8	18	0.9	4	-	0	0.7	6	0.8	7	-	0	-	0	-	0	0.7	88
All Sites	0.4	18	0.6	336	1.0	301	1.0	10	1.2	164	1.5	202	1.6	46	1.7	83	1.7	172	2.3	47	6.9	25	10.0	3	1.3	1407

Table A3.2 Maximum dust concentrations (milligrams per cubic metre) at all sites, by occupational group

Occupational Group (number, short title, see key in Introduction of Appendix 3b)

Site	1NoDir	2Superv	3PrePr	4BrkCut	5Mixed	6PostPr	7FltKln	8PanMil	9GenLa	10Sand	11ClnUp	12Demol	All Groups
1	-	1.7	3.6	-	2.4	2.1	2.7	2.3	3.1	-	-	-	3.6
2	1.3	2.2	1.1	3.2	2.4	1.3	2.6	1.8	-	-	-	-	3.2
3	-	0.7	1.8	-	1.0	2.5	-	2.6	1.2	-	-	-	2.6
4	-	4.2	2.4	-	-	2.1	-	11.5	-	-	-	-	11.5
5	-	7.5	3.6	-	0.7	2.1	-	2.7	9.2	0.5	-	-	9.2
6	0.4	1.3	6.0	-	1.5	1.0	-	5.7	1.0	-	-	-	6.0
7	-	0.5	1.1	-	2.3	0.7	-	2.3	10.8	0.5	-	-	10.8
8	-	1.4	1.1	-	51.1	0.7	1.0	2.0	0.4	-	-	-	51.1
9	-	0.8	1.9	1.7	2.1	3.2	-	1.4	3.4	5.6	-	-	5.6
10	0.4	1.0	1.3	-	1.9	-	0.5	1.0	0.7	1.3	2.6	-	2.6
11	0.6	0.6	1.8	0.5	1.4	1.2	0.4	-	1.3	1.1	-	-	1.8
12	1.0	2.0	1.6	-	1.7	5.3	3.2	2.5	4.8	10.0	-	-	10.0
13	-	1.3	2.3	-	3.5	6.1	0.8	1.9	3.2	1.3	2.5	-	6.1
14	-	1.5	6.1	-	0.8	3.1	1.0	0.6	0.9	-	-	-	6.1
15	-	0.6	2.3	-	1.7	1.9	-	0.4	1.1	-	-	-	2.3
16	-	1.7	4.7	-	2.3	0.3	0.8	-	1.4	1.8	-	-	4.7
17	1.0	3.2	18.5	-	2.6	29.4	5.0	5.4	41.9	9.2	100.1	13.7	100.1
18	0.3	2.5	1.1	-	1.9	1.2	-	1.4	1.8	-	-	-	2.5
All Sites	1.3	7.5	18.5	3.2	51.1	29.4	5.0	11.5	41.9	10.0	100.1	13.7	100.1

Table A3.3 Average quartz concentrations (milligrams per cubic metre) and number of samples at all sites, by occupational group

Occupational Group (number, short title, see key in Introduction of Appendix 3b)

site	1NoDir aver. conc.	no	2Superv aver. conc.	no	3PrePr aver. conc.	no	4BrkCut aver. conc.	no	5Mixed aver. conc.	no	6PostPr aver. conc.	no	7FltKln aver. conc.	no	8PanMil aver. conc.	no	9GenLa aver. conc.	no	10Sand aver. conc.	no	11ClnUp aver. conc.	no	12Demol aver. conc.	no	All Groups aver. conc.	no
1	-	0	0.05	18	0.05	12	-	0	0.12	12	0.05	10	0.13	6	0.14	6	0.20	7	-	0	-	0	-	0	0.09	71
2	0.04	1	0.04	21	0.04	12	0.12	5	0.02	8	0.04	6	0.08	4	0.08	8	-	0	-	0	-	0	-	0	0.05	65
3	-	0	0.05	8	0.09	20	-	0	0.07	3	0.16	7	-	0	0.19	9	0.11	7	-	0	-	0	-	0	0.11	54
4	-	0	0.18	8	0.17	11	-	0	-	0	0.21	8	-	0	0.75	6	-	0	-	0	-	0	-	0	0.29	33
5	-	0	0.09	16	0.10	10	-	0	0.03	6	0.08	12	-	0	0.16	6	0.23	11	0.03	4	-	0	-	0	0.11	65
6	0.02	3	0.05	10	0.27	8	-	0	0.04	9	0.11	8	-	0	0.62	2	0.07	6	-	0	-	0	-	0	0.12	46
7	-	0	0.04	14	0.06	9	-	0	0.07	11	0.07	11	-	0	0.29	5	0.15	23	0.09	1	-	0	-	0	0.10	74
8	-	0	0.06	27	0.05	19	-	0	0.11	11	0.06	6	0.13	3	0.11	3	0.03	3	-	0	-	0	-	0	0.07	72
9	-	0	0.05	13	0.09	18	0.21	2	0.09	8	0.16	16	-	0	0.09	5	0.11	15	0.21	3	-	0	-	0	0.11	80
10	0.03	5	0.03	21	0.04	11	-	0	0.06	7	-	0	0.07	3	0.09	3	0.04	11	0.12	7	0.33	2	-	0	0.06	70
11	0.03	3	0.04	24	0.10	14	0.04	3	0.09	9	0.14	8	0.05	4	-	0	0.06	9	0.11	2	-	0	-	0	0.07	76
12	0.05	2	0.04	31	0.05	21	-	0	0.07	15	0.13	40	0.11	8	0.13	7	0.11	18	0.28	9	-	0	-	0	0.10	151
13	-	0	0.02	9	0.06	21	-	0	0.15	4	0.02	9	0.04	1	0.12	3	0.06	18	0.10	3	0.05	2	-	0	0.06	70
14	-	0	0.03	8	0.08	20	-	0	0.03	3	0.07	8	0.07	2	0.04	2	0.37	2	-	0	-	0	-	0	0.07	45
15	-	0	0.04	7	0.12	17	-	0	0.04	6	0.08	10	-	0	0.04	2	0.05	3	-	0	-	0	-	0	0.08	45
16	-	0	0.17	11	0.28	27	-	0	0.07	5	0.08	1	0.22	4	-	0	0.17	5	0.15	2	-	0	-	0	0.21	55
17	0.03	2	0.04	51	0.13	38	-	0	0.09	28	0.12	37	0.21	11	0.11	10	0.38	25	0.36	16	0.29	20	0.62	3	0.17	241
18	0.13	2	0.06	39	0.07	12	-	0	0.05	18	0.09	4	-	0	0.07	6	0.08	7	-	0	-	0	-	0	0.06	88
All Sites	0.04	18	0.05	336	0.11	300	0.12	10	0.07	163	0.11	201	0.13	46	0.18	83	0.15	170	0.23	47	0.27	24	0.62	3	0.11	1401

Table A3.4 Maximum quartz concentrations (milligrams per cubic metre) at all sites, by occupational group

	Occupational Group (number, short title, see key in Introduction of Appendix 3b)												
site	1NoDir	2Superv	3PrePr	4BrkCut	5Mixed	6PostPr	7FltKln	8PanMil	9GenLa	10Sand	11ClnUp	12Demol	All Groups
1	-	0.15	0.10	-	0.47	0.13	0.38	0.31	0.46	-	-	-	0.47 (3)*
2	0.04	0.14	0.08	0.34	0.06	0.10	0.11	0.16	-	-	-	-	0.34 (0)
3	-	0.14	0.31	-	0.16	0.21	-	0.39	0.21	-	-	-	0.39 (0)
4	-	0.41	0.31	-	-	0.49	-	1.48	-	-	-	-	1.48(18)
5	-	0.68	0.24	-	0.04	0.14	-	0.26	0.75	0.05	-	-	0.75 (5)
6	0.04	0.13	1.15	-	0.11	0.16	-	0.91	0.12	-	-	-	1.15 (4)
7	-	0.13	0.12	-	0.21	0.16	-	0.36	1.32	0.09	-	-	1.32 (1)
8	-	0.25	0.11	-	0.47	0.16	0.17	0.15	0.04	-	-	-	0.47 (3)
9	-	0.11	0.22	0.38	0.19	0.27	-	0.13	0.32	0.46	-	-	0.46 (1)
10	0.04	0.09	0.09	-	0.15	-	0.09	0.11	0.09	0.26	0.44	-	0.44 (1)
11	0.05	0.12	0.25	0.04	0.17	0.29	0.09	-	0.18	0.15	-	-	0.29 (0)
12	0.06	0.32	0.14	-	0.13	0.31	0.19	0.18	0.21	0.47	-	-	0.47 (1)
13	-	0.06	0.24	-	0.30	0.05	0.04	0.14	0.20	0.12	0.09	-	0.30 (0)
14	-	0.07	0.24	-	0.06	0.10	0.07	0.05	0.69	-	-	-	0.69 (2)
15	-	0.10	0.27	-	0.13	0.18	-	0.05	0.06	-	-	-	0.27 (0)
16	-	0.32	0.56	-	0.16	0.08	0.24	-	0.26	0.16	-	-	0.56 (9)
17	0.04	0.15	1.24	-	0.29	0.32	0.38	0.29	3.77	1.06	1.09	0.78	3.77 (7)
18	0.23	0.15	0.12	-	0.15	0.15	-	0.12	0.20	-	-	-	0.23 (0)
All Sites	0.23 (0)*	0.68 (1)	1.24 (3)	0.38 (0)	0.47 (2)	0.49 (0)	0.38 (0)	1.48 (6)	3.77 (4)	1.06(17)	1.09(17)	0.78(100)	3.77 (3)

* Percentage of samples in site or occupational group with quartz concentrations greater than 0.4 milligrams per cubic metre.

Table A3.5 Percentage of quartz concentrations greater than 0.1 milligrams per cubic metre at all sites, by occupational group

site	Occupational Group (number, short title, see key in Introduction of Appendix 3b)												
	1NoDir	2Superv	3PrePr	4BrkCut	5Mixed	6PostPr	7FltKln	8PanMil	9GenLa	10Sand	11ClnUp	12Demol	All Groups
1	-	11	8	-	33	20	17	50	57	-	-	-	24 (3)*
2	0	14	0	40	0	0	50	37	-	-	-	-	15 (0)
3	-	12	20	-	33	100	-	67	57	-	-	-	43 (0)
4	-	75	64	-	-	75	-	100	-	-	-	-	76(18)
5	-	12	20	-	0	17	-	83	64	0	-	-	28 (5)
6	0	10	75	-	11	87	-	100	33	-	-	-	41 (4)
7	-	7	33	-	18	27	-	100	30	0	-	-	28 (1)
8	-	11	5	-	18	17	67	33	0	-	-	-	14 (3)
9	-	8	39	50	37	94	-	40	40	67	-	-	46 (1)
10	0	0	0	-	14	-	0	67	0	43	100	-	11 (1)
11	0	4	29	0	33	87	0	-	22	50	-	-	24 (0)
12	0	10	10	-	13	65	75	100	50	89	-	-	42 (1)
13	-	0	24	-	50	0	0	67	22	33	0	-	20 (0)
14	-	0	20	-	0	0	0	0	50	-	-	-	11 (2)
15	-	0	47	-	17	30	-	0	0	-	-	-	27 (0)
16	-	73	93	-	20	0	100	-	80	100	-	-	80 (9)
17	0	8	26	-	32	57	100	50	52	62	90	100	43 (7)
18	50	10	17	-	11	50	-	17	29	-	-	-	16 (0)
All Sites	6 (0)*	12 (1)	30 (3)	30 (0)	21 (2)	51 (0)	57 (0)	60 (6)	38 (4)	57(17)	83(17)	100(100)	33 (3)

* Percentage of samples in site or occupational group with quartz concentrations greater than 0.4 milligrams per cubic metre.

Table A3.6 Average percentage quartz in the dust at all sites, by occupational group

site	Occupational Group (number, short title, see key in Introduction of Appendix 3b)												
	1NoDir	2Superv	3PrePr	4BrkCut	5Mixed	6PostPr	7FltKln	8PanMil	9GenLa	10Sand	11ClnUp	12Demol	All Groups
1	-	5	5	-	11	6	8	8	11	-	-	-	7
2	3	5	5	7	3	4	4	7	-	-	-	-	5
3	-	15	16	-	10	14	-	15	16	-	-	-	15
4	-	13	15	-	-	18	-	13	-	-	-	-	15
5	-	9	10	-	8	10	-	11	11	9	-	-	10
6	7	9	15	-	10	15	-	18	9	-	-	-	11
7	-	13	17	-	9	18	-	17	14	17	-	-	14
8	-	14	13	-	8	17	14	9	11	-	-	-	13
9	-	10	10	18	9	13	-	11	10	10	-	-	11
10	11	8	9	-	10	-	15	11	11	14	14	-	10
11	9	15	16	15	12	17	17	-	13	15	-	-	15
12	6	6	6	-	7	6	5	10	6	7	-	-	6
13	-	5	8	-	10	2	5	7	5	10	2	-	6
14	-	5	9	-	5	4	7	7	53	-	-	-	9
15	-	10	15	-	8	11	-	11	7	-	-	-	12
16	-	21	23	-	9	25	31	-	19	18	-	-	21
17	6	8	8	-	8	10	9	9	8	11	10	6	9
18	40	9	10	-	7	10	-	10	9	-	-	-	9
All Sites	12	9	12	12	8	10	11	11	11	11	9	6	10

APPENDIX 3

(c) QUARTZ GRAINS IN DUST SAMPLES FROM HEAVY CLAY SITES

The surface activity of quartz grains is partly governed by the nature of the surface: crystal growth face, fracture surface or weathered sedimentary surface. Two dust samples from plants 16 and 17 have been examined by scanning electron microscope with the aim of characterising the nature of the quartz grains.

The dust samples had been previously carbon-coated and mounted on transmission electron microscope (TEM) grids for sizing and compositional analysis. The quality of the image, although perfectly adequate, was slightly poorer than optimal because the samples were carbon rather than gold coated.

The quartz grains could be readily distinguished from other grains on the basis of their equant morphology and lack of cleavage. The dominant particle type on the filters are flakes of clay. Most of these flakes are very much less than 1 um in diameter. Weathered grains of feldspar and rare grains of pyrite (as cubes, dodecahedra and framboids) are also present. The quartz grains were divided into four main categories: fracture fragments; sedimentary with angular, subangular, subrounded, rounded and well rounded subdivisions; sedimentary with authigenic quartz overgrowths; and authigenic crystals (authigenic: precipitated within the sediment as opposed to a sedimented grain). The grains with authigenic overgrowths would have mixed surfaces comprising ideal crystal growth faces surrounded by unmodified sedimentary domains. The authigenic crystals would be dominated by ideal crystal growth faces. Authigenic quartz crystals in sedimentary rocks should have atomically smooth surfaces.

Quartz in the sample from plant 17 is dominated by well rounded sedimentary grains. Some of these grains are partially coated by thin authigenic overgrowths. A few of these overgrowths are virtually perfect little quartz crystals that are only loosely attached to the host grain. The remainder of the quartz comprises subangular sedimentary grains. The outline of these grains is similar to that of the grains with authigenic overgrowths, but in these subangular grains, the original crystal form of the overgrowths has been slightly rounded by erosion. The morphology of these grains suggests that they are redeposited quartz grains that have been eroded from an older quartz-cemented sediment.

Quartz in the sample from plant 16 is dominated by sedimentary grains enclosed by authigenic quartz overgrowths. The surfaces of most of these grains are dominated by ideal crystal faces. There are also some rounded and subrounded grains: these are slightly smaller in size than the grains with overgrowths. A few subangular sedimentary grains are present which appear to be reworked grains from an older quartz cemented sediment. There are a few tiny authigenic quartz crystals present and rare fractured grains. The fractured grains show conchoidal fracture which is typical of silica (ie. the fracture surfaces are concave).

APPENDIX 4

FACTORS AFFECTING ESTIMATES OF EXPOSURE TO DUST AND QUARTZ

(a) Use of Respiratory Protective Equipment

The use of respiratory protective equipment (RPE) within the 18 sites visited during the survey was, with some exceptions, minimal. Where RPE was available to the operators it ranged from simple unapproved nuisance masks to high efficiency respirators used for specific processes. The protection factor assigned to these devices ranged in practical terms from 2–100. The most commonly used forms of RPE in the plants visited were the 3M 8500 and 3M 8810, for which the manufacturers quote a protection factor of 10–12.

It was the policy at one plant that all operators working at the mill area should wear RPE (3M 8500) and certainly during the site survey this policy appeared to be complied with in a well-disciplined manner. At a second plant the wearing of RPE (8710) was compulsory at the sand mixing and pan mill areas. However, at this same plant no RPE was worn by the cleaners. The lack of use of RPE by general factory cleaners was common at all sites. In other plants the wearing of RPE was more haphazard and was at the individual's discretion.

A number of general labourers and pan mill operators wore RPE when involved in cleaning operations. RPE was worn readily by operators during specific tasks e.g. sand blasting and fuel cleaning which are recognised as potentially dusty jobs. In general the demolition/repair teams observed wore RPE, either 3M 8500 or airstream helmets.

RPE was available for use at all the sites visited: however, with a few exceptions, its use was voluntary. The effectiveness of RPE in providing protection relies upon correct choice, fit and use of equipment. This inevitably relies on good information, instruction and training being given to those who may wear RPE. It would appear that this training is not given and thus the effectiveness of any RPE will be reduced.

Because of very limited knowledge of the extent to which RPE was worn in the past, use of RPE was not taken into account when estimating dust and quartz exposures.

(b) Information from site histories of potential relevance to exposure assessment, by occupational group.

Group 1 – No direct exposure

For all sites it is assumed that the exposure of those persons assigned to this group will not have changed significantly with time. The general environmental conditions within and around the plant may have improved over the years. However, as most of the tasks carried out by persons in this group are conducted within the confines of an office or vehicle or away from the site the effects of such changes on exposure will be minimal.

Group 2 – Supervisors

This group includes kiln burners, general FLT drivers, workshop based fitters, supervisors and coal handlers. Although general conditions around the plant will probably have improved over the years, it is not possible to be specific about improvements and how they might have influenced exposure to dust.

Group 3 – Pre-production

Included in this group are quarry workers whose working practices, in this industry, appear to have changed little in the last 30–40 years. This group includes brick makers and moulders and setters. Of these personnel the setters' exposure may have altered over the years, mainly due to the location rather than the nature of the work. The exposure of men at sites where setting was carried out within the kiln would be expected to be higher than those sites where setting is carried out in areas away from the kilns. These changes were detailed for each site.

Group 4 – Brick Cutters

Brick cutters prepare bricks for use on display boards. This requires the bricks to be cut, normally by circular saw, with some hand finishing. Exposure to dust will vary depending upon the method of control applied to the task eg. dry cut, LEV in use, wet cut etc. Where this information was available relevant details were obtained.

Group 5 – Mixed dust work

Group 5 includes those potentially exposed to mixed dust (i.e. combination of pre- and post-production) within the plant, eg. factory fitters, and FLT drivers in general areas within the plant. Again the general dust concentrations to which these persons are exposed may have altered over the years. However, there is no specific information relating to time and extent of change which can be used to assess retrospective exposure.

Group 6 – Post-production

Of this group the packers' exposure to dust may have altered over the years. As with the setters, exposure will be dependent upon where the packing operation takes place and the degree of automation involved. Where possible details were obtained on a site by site basis.

Group 7 – FLT (Kilns, driers)

Their exposure will have been relatively constant as the job has remained the same over the years.

Group 8 – Pan mill operators

The pan mill area in many of the sites has remained unchanged for many years. At some sites this area has undergone some improvements, mainly to general and local exhaust ventilation. Details of such improvements and the effect on exposure were obtained.

Group 9 – Labourers

Kiln labourers who carry out general duties around the kiln as well as wicket men are likely to have similar exposures from year to year. Factory cleaners also carry out a number of duties which may bring them into direct contact with dust.

These duties are unlikely to have changed over the years.

Group 10 - Sand users

The exposure of operators who handle sand will be affected by the equipment in use and the application of LEV. Details of any relevant changes were obtained.

Group 11 - Clean-up squad

This group has direct exposure to relatively high dust concentrations which will not have altered greatly over the years. Flue cleaners' exposure may have changed with the introduction of improved equipment, although there are no records available.

Group 12 - Kiln demolition

The nature of demolition work means that the concentrations of dust experienced will not have altered with time. However, the actual exposure will have been reduced since the introduction of RPE. Records are available for some sites of the introduction and use of RPE but the actual use of the respirators and the protection afforded are notoriously difficult to assess. Therefore this information cannot be used in the estimation of retrospective exposures.

APPENDIX 5

Heavy Clay Leavers Feasibility Study

Introduction

In the original study proposal it was noted that the study would comprise approximately 2000 current workers and 500 workers who had left the industry. The leavers were to be included to help identify if the health status of such people was different from the current workforce, to provide a context in which the results of the current workforce could be evaluated.

Method

Initial contact with the study sites identified two sites (17 and 18) where records were believed to be adequate for the identification of ex-workers. The records for ex-workers at site 17 were held on computer from 1987. Prior to 1987 records were held on individual record cards which had been stored in alphabetical order. At this site all ex-workers (who had been employed for at least 1 year) from 1980 onwards were included in the group of leavers to be contacted. Information on each leaver was abstracted onto an IOM record card from either the computer record or the record card. The information obtained included forename, surname, date of birth, last known address, National Insurance Number, principal job, reason for leaving and dates of starting and finishing employment. Deceased individuals were identified from company records and excluded from the group. At site 18 records were held manually and did not extend as far back as 1980. A similar transcription of information was carried out.

The identified leavers were contacted by the IOM and asked to assist with the study by attending at the relevant site when the current workforce was being surveyed. Two letters were sent to individuals from the IOM. Subsequently, those who did not reply, indicating whether they would attend or not, were contacted via the DSS NI Contributions Branch, if the DSS had a current address for the individual.

Results and Discussion

At site 18 140 leavers were identified. Following the request to participate, 40 (28.6%) agreed to attend when the survey of current workers took place. Twenty-one (15%) ex-workers actually participated.

The chest Xrays of these 21 male ex-workers were assessed in random order by one experienced film reader using the ILO classification. His results indicated 13 subjects with category 0/0, 5 with category 0/1 and 3 with category 1/1 among the leavers. There were no large opacities. In addition this reader read a random selection of 29 other films from current workers at site 18. Two female current workers were inadvertently included in this group but have been excluded from statistical analyses). These readings were compared to the readings obtained from the panel of three film readers who had interpreted all the current workers' films.

Ex-workers (mean age 54, s.d. 18) were older than current workers (mean age 40, s.d. 12). The percentage of current smokers was similar (28% in ex-workers, 22% in current workers), but a greater proportion of the non-smoking ex-workers had smoked previously (11/15 compared to 7/21 current workers). However, ex–workers (smokers and ex–smokers) smoked or had smoked fewer cigarettes per day than current workers. Details are given in Table A5.1.

Eight (38%) of the 21 ex–workers showed some radiological abnormality (0/1+), compared to seven (26%) of the 27 current workers (Table A5.2). The difference in prevalence (12%) was not statistically significant; 95% confidence limits are -14% to 39%.

This film reader's classifications of radiographs of current workers were compared with those of the three readers used in the study reading panel (median reading). Results (Table A5.3) showed that he tended to read more abnormality: only three of the seven films classified abnormal by him were so classified by the Panel. His classifications of these three were 1/1 (two films) and 1/2; the Panel's were all 0/1. (However, individual readings by the panel for these films ranged from 0/0 to 2/2). Thus, the 26% level of abnormality found by this reader in 27 current male workers should not be regarded as an indication of prevalence of 0/1+ in the current workforce at Site 18, which was 4.8% according to the Reading Panel.

This comparison therefore indicated that the reader of the leavers' films found a higher frequency of radiological abnormality in the current workers than the other readers. The leavers were older than the current workers, which could also have accounted for the abnormalities noted as would differences in smoking histories. In any case the response rate was too low to permit a reliable estimate of frequency of abnormality among leavers.

At site 17 1500 leavers were identified. After two mailings from the IOM 470 replies were received. Three hundred and sixty five ex–workers agreed to participate. The intention was to contact the leavers who had not replied via the DSS. Prior to this the low attendance among leavers at site 18 became apparent. This led us to the conclusion that the leavers study was unlikely to lead to the numbers of subjects necessary for useful information to be obtained. It was decided to focus study resources on the inclusion of additional sites to make up the numbers of current workers required to replace a shortfall caused by site closures and redundancies and to include the soft mud works as requested by NFCI. Accordingly it was decided to cancel the leavers study at site 17 and concentrate efforts on obtaining an adequate sample size of current workers.

Table A5.1 Smoking habits of 27 current workers and 21 ex-workers at Site 18 (key: cigarettes smoked per day (s.d.) number of men).

Smoking Group	Current Men	Ex-workers
Never-smoker	0.0 (-) 14	0.0 (-) 4
Ex-smoker	28.0 (16.5) 7	17.1 (5.9) 11
Smoker	20.5 (9.0) 6	12.2 (10.6) 6

Table A5.2 Profusion of small opacities in 48 male current and ex-workers at Site 18

Profusion Category	Current Men	Ex-workers
0/0	20	13
0/1	3	5
1/0	0	0
1/1	3	3
1/2	1	0

Table A5.3 Median category of profusion of small opacities (derived from three readings carried out by the Study Reading Panel), and a single reading by an experienced chest physician for 27 current workers at Site 18.

	Median Reading		
Reader	**0/0**	**0/1**	**All categories**
0/0	20	0	20
0/1	3	0	3
1/0	0	0	0
1/1	1	2	3
1/2	0	1	1
All categories	24	3	27

APPENDIX 6

(a) The calculation of cumulative exposure to mixed dust and to quartz

1. **Dust Exposures**

1.1 Estimated dust concentrations

The calculations were based on a two-way table of estimated dust concentrations c_{ij}, indexed by site (i = 1, ..., 18) and occupational group (OG) (j = 1, ..., 12) (Table A6.1). These estimates were derived from an analysis of variance of the occupational hygiene survey data (section 3.2.3 of the main report). Cumulative exposures were obtained by multiplying these dust concentrations, appropriately weighted, by times worked in Occupational Groups, at both study and non-study heavy clay sites. The next two Sections describe the choice of weighting factors.

1.2 Time worked at study sites

Time worked at study sites included time worked at study sites other than the one at which the man was examined. It did not include time worked at sites 12 and 13 prior to 1969 and 1974 respectively, when these sites were completely rebuilt. Before these dates, sites 12 and 13 are regarded as non-study sites.

Two cases were distinguished in the calculations.

i) The site (say site i) operated tunnel kilns at time of survey.

For these sites, two dates, possibly coincident, were available, the earlier being the introduction of a tunnel kiln to the site, and the later, the final abandonment of Hoffman or Intermittent kilns. The time worked in occupational group j at these sites was thus partitioned into three components t_{ijk} (k = 1,2,3) by the two dates, where k = 1 corresponds to the earliest period when only Hoffman/Intermittent kilns were in use, k = 2 corresponds to a transitional period when both Hoffman/Intermittent) and tunnel kilns were operational, and k = 3 corresponds to the most recent period when the site operated only tunnel kilns. In the calculation of exposure, c_{ij} was assigned to t_{ij3}, 1.25 c_{ij} to t_{ij2}, and 1.5 c_{ij} to t_{ij1}. The choice of weighting factors was based on the analysis of variance of the dust concentrations, which had shown that dust levels were about 50% higher at sites operating Hoffman/Intermittent kilns compared to sites operating tunnel kilns.

ii) Site i operated Hoffman/Intermittent kilns at time of survey.

For these sites, there was no partitioning of time worked. In exposure calculations, c_{ij} was assigned to t_{ij}, i.e. there was no weighting applied to the dust concentration.

The dates of changes to the kiln type are given in Table A6.2.

Note that none of the 18 sites operated both tunnel kilns and Hoffman/Intermittent kilns at time of survey.

1.3 Time worked at non-study clay sites

i) For men who were examined at sites 12 or 13, the arithmetic mean of the predicted concentrations c_{ij} taken over study sites operating Hoffman/Intermittent kilns was applied to any time they had worked at non-study clay sites. These means are specific to occupational groups. This strategy was based on the supposition that men examined at sites 12 or 13, which used Hoffman kilns, were likely to have had their previous clay work experience at sites using similar methods.

ii) For all other men, the arithmetic mean of the predicted concentrations taken over sites operating tunnel kilns was used, in combination with a time weighting, as follows. For the period prior to 1/7/70, the tunnel kiln mean was multiplied by 1.5; for the period following 1/7/70, the mean was multiplied by 1.25. Again, these means are specific to OGs. The date 1/7/70 marks the assumed introduction of tunnel kilns.

1.4 Calculation of exposure indices

Each man has a sequence of time periods marked by dates $t_1, t_2, \ldots, t_n$ where t_1 denotes date of starting work in the heavy clay industry and t_n denotes date of survey. The dates t_m ($m = 2, \ldots, n - 1$) signal one of the following events:-

i) A move to a different occupational group at any site;

ii) A move to a different site;

iii) A change in kiln type at a study site;

iv) The (presumed) introduction of tunnel kilns at non-study sites (other than sites 12 and 13 prior to 1969 and 1974 respectively, which operated Hoffman/Intermittent kilns). Since men whose study site was 12 or 13 are assumed always to have worked with Hoffman/Intermittent kilns, this date applies only to men examined at the other 16 study sites. It was taken to be 1/7/70.

By the scheme described in Paragraphs 1.2 and 1.3 above, each of the periods $[t_1, t_{m+1}]$ had an estimated dust concentration d_m assigned to it. Three indices of exposure were calculated:

$$\sum_{m=1}^{n-1} d_m \,(t_{m+1} - t_m) \qquad (1)$$

$$\sum_{m=1}^{n-1} d_m \,(t_{m+1} - t_m)\left(t_n - \frac{t_m + t_{m+1}}{2}\right) \qquad (2)$$

$$\frac{2}{3}\sum_{m=1}^{n-1} d_m \left[(t_n - t_m)^{\frac{3}{2}} - (t_n - t_{m+1})^{\frac{3}{2}}\right] \qquad (3)$$

Index (1) gave the ordinary cumulative exposure. The other two indices required that each component of exposure be multiplied by the time elapsed since its acquisition, before accumulating over the Occupational History. Untransformed elapsed time was used for Index (2), the square root of elapsed time for Index (3).

2. <u>Quartz Exposures</u>

These were calculated using a table of estimated percentages of quartz in dust, q_{ij}, indexed by site and occupational group (Table A6.3).

As outlined above, the calculation of dust exposures required identifying a sequence of time periods, to which estimated dust concentrations d_m were assigned. Three indices of quartz exposure were calculated by substituting $q \times d_m$ for d_m in equations (1), (2), and (3), where q is the estimated percent quartz appropriate to the period $[t_m, t_{m+1}]$. The 'q' to be used depends on the site and the occupational group in which the man was working during $[t_m, t_{m+1}]$. If he was working in study site i and OG_j, then $q = q_{ij}$. If he was working at a non-study site, in OG_j, then

$$q = \overline{q}_{\cdot j} = \frac{1}{18}\sum_{i=1}^{18} q_{ij}$$

the unweighted mean of the estimated percentages, over sites.

3. <u>Time Spent Outside the Heavy Clay Industry</u>

This was accumulated (as years spent) in eight classes:

No.	Class
1	Quarries
2	Underground mining
3	Other mining
4	Asbestos
5	Other noxious or dusty
6	Agriculture, forestry, farming
	overseas employment
7	Construction
	Other industrial
	Fishing
	Armed Services
8	Education
	Other non-industrial
	Unemployed
	Invalidity
	Returned from abroad

(b) Additional approaches to logistic regression analysis of the prevalence of radiological abnormality

Three different weightings were used to calculate three different versions of cumulative exposure to respirable dust, and to quartz, i.e. (i) an unweighted exposure, equivalent to ordinary cumulative exposure (ii) a linear weighting, and (iii) a "square root" weighting. Furthermore, each version of exposure to dust and to quartz was transformed to the natural log scale, so that, finally, six different versions of dust exposure, and six different versions of quartz exposure were available for analysis in relation to radiology, as follows:

Ordinary, untransformed
" logarithmically transformed
Linear weighting, untransformed
" " logarithmically transformed
Square root weighting, untransformed
" " " logarithmically transformed.

Each of these 12 exposures was considered in relation to two radiological response variables: category 0/1+ and 1/0+. For each of these responses, two regression models were fitted:

AGE + SMOKING + EXPOSURE

AGE + SMOKING + EXPOSURE + SITE

Table A6.4 shows regression coefficients of the exposure variables, corresponding 't' statistics, and the so-called residual deviance of the fitted statistical model (a measure of goodness-of-fit of the model to the data).

Note that for each of the two response variables 0/1+ and 1/0+, and for both transformed and untransformed exposures, 't' statistics are largest for ordinary cumulative exposures, smallest for linearly weighted exposures, and take intermediate values for the square root weighting. Note too that residual deviances are smallest for ordinary cumulative exposures, largest for linearly weighted exposures, and take intermediate values for the square root weighting. These results suggested that the most appropriate measure of exposure was the ordinary cumulative exposure.

In the comparison of transformed with untransformed exposure, only the ordinary cumulative exposure was considered. With 0/1+ as response, for each of the two types of exposure (dust or quartz), and each of the two statistical models (with and without site terms), 't' statistics were substantially higher for the transformed exposure. Residual deviances were lower, suggesting that transformed exposures were better predictors of radiological abnormality than the untransformed. In contrast, with 1/0+ as response, 't' statistics were in fact slightly HIGHER for the untransformed exposure, except in the case of quartz adjusted for site, where the 't' statistic for the transformed exposure was higher. However, as in the case of 0/1+, residual deviances were without exception slightly lower.

It was decided that the logarithmic transformation should be used, since (i) it gave a better fit to the data (as measured by the residual deviance), and (ii) gave a substantially greater measure of statistical significance to the relationship with the more prevalent abnormality (0/1+). Although for the 1/0+ response, 't' statistics were slightly higher for the untransformed exposure, it was felt that the differences in 't' were not so great as to make the use of the transform inappropriate in this case also.

Table A6.1. Estimated mean dust concentrations (mgm^{-3}) by site and Occupational Group*.

SITE	OCCUPATIONAL GROUP											
	NO CON	SUPERV	PREPRO	BRKCUT	MIXED	POSTPR	FRKLFT	PANMIL	LABROR	SAND	CLEANR	KLNDEM
1	0.793	0.932	1.322	1.446	1.358	1.873	2.068	2.261	1.806	2.540	4.513	15.454
2	0.576	0.677	0.960	1.050	0.986	1.360	1.502	1.642	1.311	1.845	3.277	11.222
3	0.434	0.510	0.723	0.791	0.743	1.025	1.132	1.237	0.988	1.390	2.469	8.455
4	0.913	1.073	1.523	1.666	1.564	2.158	2.382	2.604	2.080	2.926	5.198	17.802
5	0.516	0.606	0.860	0.941	0.883	1.218	1.345	1.470	1.174	1.652	2.934	10.050
6	0.504	0.592	0.840	0.920	0.863	1.191	1.315	1.437	1.148	1.615	2.869	9.825
7	0.345	0.406	0.576	0.630	0.592	0.816	0.901	0.985	0.787	1.106	1.966	6.732
8	0.319	0.375	0.532	0.582	0.547	0.754	0.833	0.910	0.727	1.023	1.817	6.222
9	0.577	0.678	0.962	1.053	0.988	1.363	1.505	1.645	1.314	1.849	3.284	11.248
10	0.315	0.370	0.525	0.575	0.540	0.744	0.822	0.898	0.718	1.009	1.793	6.142
11	0.298	0.350	0.497	0.544	0.511	0.705	0.778	0.850	0.679	0.955	1.697	5.812
12	0.759	0.892	1.266	1.385	1.300	1.794	1.980	2.164	1.729	2.432	4.321	14.797
13	0.511	0.600	0.852	0.932	0.875	1.207	1.333	1.457	1.164	1.637	2.908	9.961
14	0.610	0.717	1.018	1.114	1.046	1.442	1.593	1.741	1.391	1.956	3.475	11.901
15	0.399	0.469	0.666	0.729	0.684	0.943	1.042	1.138	0.909	1.279	2.273	7.783
16	0.682	0.801	1.137	1.244	1.168	1.611	1.778	1.944	1.553	2.184	3.880	13.289
17	0.632	0.743	1.054	1.154	1.083	1.494	1.650	1.803	1.440	2.026	3.599	12.326
18	0.533	0.627	0.889	0.973	0.914	1.260	1.392	1.521	1.215	1.709	3.036	10.398

* Key to abbreviated names:

NO CON = No direct contact with dust
SUPERV = Supervisors
PREPRO = Pre-production
BRKCUT = Brick cutters
MIXED = Mixed dust work
POSTPR = Post-production
FRKLFT = Forklift drivers working in and out of kilns
PANMIL = Pan mill operators
LABROR = Labourers
SAND = Sand users
CLEANR = Cleaning squad
KLNDEM = Kiln demolition squad

Table A6.2. Dates of changes in kiln types at 18 study sites. (Changes are assumed to occur at mid-year).

Site	Kiln type		
	Hoffmann/ Intermittent	Both*	Tunnel
1	No changes - i.e. always Hoffmann/Intermittent		
2	" " " " "		
3	" " " " "		
4	" " " " "		
5	-1965	1965-68	1968-
6	-1969	Zero transition+	1969-
7	-1972	" "	1972-
8	-1974	" "	1974-
9	-1978	" "	1978-
10	-1965	" "	1965-
11	-1966	" "	1966-
12	No changes - i.e. always Hoffmann/Intermittent		
13	" " " " "		
14	" " " " "		
15	" " " " "		
16	" " " " "		
17	" " " " "		
18	-1965	1965-80	1980-

* At sites 5 and 18, there were transitional periods when both Hoffmann/Intermittent and Tunnel kilns were operating.

\+ The introduction of tunnel kilns coincided with the abandonment of Hoffmann/Intermittent kilns.

Table A6.3. Estimated mean percentage quartz in dust (%) by site and Occupational Group*.

SITE	OCCUPATIONAL GROUP											
	NO CON	SUPERV	PREPRO	BRKCUT	MIXED	POSTPR	FRKLFT	PANMIL	LABROR	SAND	CLEANR	KLNDEM
1	5.981	6.574	7.944	10.209	5.602	7.943	8.777	8.216	7.291	9.317	7.947	5.182
2	3.538	4.131	5.502	7.766	3.160	5.501	6.335	5.773	4.848	6.874	5.504	2.740
3	13.108	13.701	15.072	17.336	12.730	15.071	15.905	15.343	14.418	16.444	15.074	12.310
4	13.190	13.783	15.153	17.418	12.811	15.152	15.986	15.425	14.499	16.526	15.156	12.391
5	8.239	8.832	10.202	12.467	7.860	10.201	11.036	10.474	9.549	11.575	10.205	7.440
6	10.115	10.709	12.079	14.343	9.737	12.078	12.912	12.351	11.425	13.451	12.081	9.317
7	12.636	13.229	14.600	16.864	12.258	14.599	15.433	14.871	13.946	15.972	14.602	11.838
8	11.617	12.211	13.581	15.845	11.239	13.580	14.414	13.852	12.927	14.953	13.583	10.819
9	9.326	9.919	11.290	13.554	8.948	11.289	12.123	11.561	10.636	12.662	11.292	8.528
10	8.942	9.536	10.906	13.170	8.564	10.905	11.739	11.178	10.252	12.278	10.908	8.144
11	13.238	13.831	15.202	17.466	12.860	15.201	16.035	15.473	14.548	16.574	15.204	12.439
12	4.871	5.464	6.834	9.098	4.492	6.833	7.667	7.106	6.180	8.207	6.837	4.072
13	4.396	4.990	6.360	8.624	4.018	6.359	7.193	6.632	5.706	7.732	6.362	3.598
14	5.282	5.876	7.246	9.510	4.904	7.245	8.079	7.518	6.592	8.618	7.248	4.484
15	10.332	10.925	12.296	14.560	9.954	12.295	13.129	12.567	11.642	13.668	12.298	9.534
16	19.795	20.388	21.759	24.023	19.417	21.758	22.592	22.030	21.105	23.131	21.761	18.996
17	7.098	7.691	9.062	11.326	6.720	9.061	9.895	9.333	8.408	10.434	9.064	6.300
18	8.102	8.695	10.066	12.330	7.724	10.065	10.899	10.337	9.412	11.438	10.068	7.303

* Key to abbreviated names:

NO CON = No direct contact with dust
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BRKCUT = Brick cutters
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Table A6.4: Regression coefficients of six versions of cumulative dust exposure and of cumulative quartz exposure, taken from logistic regression equations relating exposure, age, smoking and site, to the probability of radiological abnormality (0/1+ and 1/0+). Key: regression coefficient ('t') residual deviance. 't' values of about 2 or greater indicator that the coefficient was statistically significant at the 5% level.

Weighting of exposure	Transformation			
	Untransformed		Logged	
	0/1+	1/0+	0/1+	1/0+
(a) Dust exposure, allowing for age and smoking				
I (Unweighted)	0.00933 (2.31) 512.7	0.01138 (2.29) 223.1	0.460 (3.06) 506.2	0.526 (2.11) 221.7
II (Linear)	0.000393 (1.21) 515.8	0.000553 (1.27) 225.5	0.2142 (2.42) 510.4	0.229 (1.59) 224.0
III (Square root)	0.00219 (1.77) 514.5	0.00288 (1.82) 224.3	0.303 (2.68) 508.8	0.333 (1.79) 223.2
(b) Dust exposure, allowing for age, smoking and site				
I (Unweighted)	0.00561 (1.30) 443.1	0.00845 (1.62) 191.1	0.369 (2.12) 439.6	0.452 (1.58) 190.4
II (Linear)	0.000162 (0.46) 444.3	0.000400 (0.87) 192.5	0.163 (1.59) 441.8	0.199 (1.16) 191.7
III (Square root)	0.00117 (0.87) 443.9	0.00212 (1.27) 191.8	0.237 (1.81) 440.9	0.290 (1.33) 191.2
(c) Quartz exposure, allowing for age and smoking				
I (Unweighted)	0.1436 (2.62) 511.2	0.1803 (2.52) 221.9	0.493 (3.26) 504.7	0.609 (2.40) 220.2
II (Linear)	0.00403 (1.11) 516.0	0.00499 (0.98) 225.9	0.2251 (2.51) 510.0	0.261 (1.75) 223.4
III (Square root)	0.0282 (1.81) 514.2	0.0362 (1.68) 224.4	0.322 (2.80) 508.1	0.383 (2.00) 222.2
(d) Quartz exposure, allowing for age, smoking and site				
I (Unweighted)	0.0989 (1.66) 442.0	0.1258 (1.64) 190.9	0.407 (2.37) 438.2	0.469 (1.68) 190.0
II (Linear)	0.00272 (0.68) 444.1	0.00333 (0.60) 192.8	0.185 (1.79) 441.0	0.216 (1.28) 191.4
III (Square root)	0.0193 (1.14) 443.3	0.0249 (1.08) 192.1	0.266 (2.03) 440.0	0.308 (1.44) 190.9

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