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AN EPIDEMIOLOGICAL STUDY OF RESPIRATORY DISEASE IN WORKERS EXPOSED TO POLYVINYLCHLORIDE DUST

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INSTITUTE OF OCCUPATIONAL MEDICINE

REPORT OF A SURVEY CARRIED OUT AT THE
HILLHOUSE WORKS
OF
IMPERIAL CHEMICAL INDUSTRIES LIMITED

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AN EPIDEMIOLOGICAL STUDY OF RESPIRATORY DISEASE IN WORKERS EXPOSED TO POLYVINYLCHLORIDE DUST

by

C.A. Soutar, L.H. Copland, P.E. Thornley, J.F. Hurley, J. Ottery

SUMMARY

Polyvinylchloride PVC) is produced in industry in the form of a powder. A proportion of these particles of PVC is sufficiently small to be inhaled into the smaller airways of the lungs (respirable dust), and recent reports in the medical literature have suggested that this dust may cause lung disease.

A study of a sample of the present and past workforce of the Hillhouse Works of Imperial Chemical Industries Limited, which manufactures PVC, has assessed the prevalence of respiratory symptoms, chest radiographic and lung function abnormalities, and has related them to estimates of exposure to respirable PVC dust based on measurement of current dust levels and detailed occupational histories.

1. Environmental Survey

In an environmental survey of the plants manufacturing or further processing PVC, personal sampling of respirable dust was carried out on 130 men engaged in occupations within the PVC plants. Selection of men to wear the dust samplers was based on subjective estimates of dustiness made during a preliminary visit to the Works and measurement of particle sizes of typical PVC dusts. The major sampling effort was directed towards the occupations thought to be dustiest.

Results of the environmental survey indicated that respirable dust levels were highest for the drying and packing operations in an older plant making PVC by the emulsion method and the mixing process in a PVC processing plant. The highest mean average respirable dust exposure for any occupation over a shift was 2.88 mg/m^3 (SD $\pm$ 1.84). Dust levels in other plants were generally lower.

2. Methods of Medical Survey

On the basis of factory personnel records, a preliminary inspection of the factory and estimates of the particle sizes of typical PVC dusts, all current and many ex-employees were allocated to four broad categories corresponding to different probable exposures to PVC dust. The study sample was drawn in such a way that all those in the two higher exposure categories were included, and lower proportions of men in the other categories.

Men were seen by appointment: a detailed occupational history was taken; a questionnaire of respiratory symptoms administered; chest radiograph and lung function measurements taken. The

appearances of the chest radiographs were read by three medically qualified readers highly experienced in the interpretation of the radiographic appearances of occupational lung disease.

3. Results of Medical Survey

Results for 818 men were analysed, 663 men currently employed at the factory, 98 pensioners and 57 men who had left for reasons other than retirement.

(a) Respiratory Symptoms

Exposure to PVC dust was not associated with chronic cough or sputum production (chronic bronchitis), acute chest illnesses, acute bronchitis, pneumonia, pleurisy or asthma.

There was a relationship between exposure to PVC dust and the complaint of breathlessness when hurrying on level ground or walking up a slight hill, but this relationship was found only in cigarette smokers and not in non- or ex-smokers.

(b) Lung Function

A measurement of the breathing capacity, the forced expired volume in one second (FEV_1) was statistically significantly lower among men with higher PVC dust exposure. This effect was seen principally in current cigarette smokers, and not confirmed among non-smokers when considered separately. The pattern of results suggested that there were real differences in the response to PVC dust related to smoking habit. The magnitude of this reduction in all men in relation to the mean dust exposure was approximately one-seventh of that caused by ageing, and of a similar magnitude to the loss caused by smoking 20 cigarettes a day. (The FEV_1 measures the rate at which air can be blown out of the lungs through the air passages, and reductions of the FEV_1 are usually caused by narrowing of the air passages in the lung.)

Another measure of breathing capacity is the forced vital capacity (FVC), the volume of air expired in a full breath, and this was also statistically significantly reduced at higher PVC dust exposure. The magnitude of this reduction was less than that of the FEV_1.

(c) Chest Radiographs

One of the three expert readers who examined the chest radiographs detected small rounded opacities more commonly in the radiographs of men with higher exposures to PVC dust than in those with lower or no exposure. The other two readers did not detect an effect of PVC dust, though they saw small rounded opacities in a few cases. The opacities seen by these readers were not more common in those with higher exposures to dust than in those with lower or no exposure. Nevertheless, men with small rounded opacities also had reduced lung function, compared to those without.

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(d) Autoclave Workers

The observed effects could not be related to past exposure to vinylchloride monomer. Men working on the autoclaves may have been exposed to significant amounts of vinylchloride monomer in the past. However, the observed effects of PVC dust exposure could not be explained by an effect of working on the autoclaves, and thus were unlikely to be due to exposure to the monomer.

(e) Factors other than PVC Dust Effects

The associations with PVC dust exposure were detected against a background of other non-occupationally-induced effects. Cough, sputum and other respiratory symptoms were strongly related to smoking habits. So also were abnormalities of lung function; both deterioration in lung function and small opacities in the chest radiograph were strongly associated with age. The statistical analyses of the results have taken these factors into account.

4. Conclusion

Exposure to respirable PVC dust is associated in a proportion of exposed workers with the presence of small rounded opacities on the chest radiograph and a decline in mean ventilatory capacity. This suggests that PVC dust causes a small but detectable effect on the respiratory health of the workforce.

1. INTRODUCTION

Polyvinylchloride is produced in industry by the polymerisation of vinylchloride monomer. The monomer is gaseous at normal temperature and pressure, and hazards of occupational exposure to it are now well known, notably acro-osteolysis (CORDIER et al., 1966), Raynaud's syndrom (SUCIU et al., 1967), angiosarcoma of the liver (CREECH and JOHNSON, 1974) and hepatitis (SUCIU et al., 1967; LANGE et al., 1973). Hazards of exposure to the monomer are not the subject of this report, and will not be reviewed here.

In the manufacture of PVC, pressurised liquid vinylchloride monomer in the form of an emulsion or suspension in water is polymerised by heating under pressure. Particles of PVC are formed, and during the drying and bagging operations PVC dust may be released.

Though the manufacturing process is not necessarily universally identical, the PVC dust produced has been reported by Italian workers to include a large proportion by number of small particles of respirable size (CASULA et al., 1977; HAPP et al., 1978). The proportion of small particles is greater for the emulsion method than the suspension method (CASULA et al., 1977). Such small particles are likely to be inhaled and deposited in the lung, and there have been suggestions in the medical literature that inhalation of PVC dust may be harmful.

1.1 Animal and In Vitro Studies on Toxicity of PVC

In animal studies intratracheal administration of PVC dust has been reported to cause peribronchitis and thickening of alveolar septa (BOITSOV, 1963) and in rats single large intratracheal inoculations of PVC dust have caused vascular and inflammatory changes in the terminal and respiratory bronchioles and alveoli, and a proliferation of histiocytes and reticulin fibres (AGARWAL et al., 1978). Multinucleated giant cells and granulomatous lesions developed, and serial measurements of enzymes from lung tissue showed increases in energy-linked and lysosomal enzymes. Small mammals kept in the bagging area of a PVC plant developed a histiocytic and giant multinucleate cell alveolar reaction (FRONGIA et al., 1974).

PVC has also been reported to have a cytotoxic effect when prevalence of respiratory disease have given conflicting results.

1.3 Surveys of PVC Workers

1.3.1 Chest Radiology

A report by VERTKIN *et al*. (1970) suggested diffuse pulmonary radiographic shadowing in 83% of 96 PVC workers in the USSR, though no details of radiographic film reading methods are given. LILIS *et al*. (1975; 1976; 1977) reported a high prevalence of radiographic abnormality in workers at two of three PVC plants in North America. Prevalence of abnormality was related to years of work at the plants, but was common (13 - 16%) even among workers exposed to PVC dust for less than two y ars. No dust measurements were reported, and although the radi graphic appearances were recorded using the ILO U/C pneumoconiosis classification by five physicians experienced in this method, no information is given of reader agreement, nor are the criteria for 'abnormality' given.

MAPP *et al*. (1978) found a low prevalence of chest radiographic abnormality among 258 PVC workers in a plant in Italy; only one radiograph showed ILO U/C small irregular opacities category 1/0, while 29 showed category 0/1.

1.3.2 Lung Function

MILLER *et al*. (1975) and LILIS *et al*. (1976; 1977) reported a high prevalence of abnormal lung function, obstructive in typ , in the two PVC plants in North America mentioned above. The predicted normal values, based on regressions for age and height derived from other populations, and the criteria for abnormality may not have been appropriate to the regions, which were reported to have been highly industrialised. Adequate control groups were not included in the studies, and it was not possible to take account of the effect of smoking.

GAMBLE *et al*. (1976) and WAXWEILER *et al*. (1977) compared the lung function of workers in a PVC plant with vinylchloride monomer workers and rubber workers, and after carefully taking into account age and smoking effects, concluded that there was no evidence that PVC workers had reduced lung function, even when the same criteria for abnormality used by MILLER et al. (1975) and LILIS et al. (1976; 1977) were applied. However, dust levels were not measured, and the control subjects were also exposed to other chemicals which may have influenced their lung function.

MAPP et al. (1978) found that the prevalence of airways obstruction was related to duration of exposure to PVC dust, though it was not possible to allow for the effects of age and smoking.

LANGE et al. (1973) reported a restrictive abnormality of lung function in 8 of 13 PVC workers, though numerical details are not given. VERTKIN et al. (1975) found lung function to be normal in the 96 workers mentioned above, the majority f whom had abnormal chest radiographs.

1.3.3 Respiratory Symptoms

LILIS et al. (1976) and MAPP et al. (1978) reported relatively high prevalences of chronic cough and sputum am ng PVC workers, using standard questionnaires (20% and 34% respectively), but it was not clear to what extent this was due to smoking and local atmospheric pollution. VERTKIN et al. (1970) found a lower prevalence of cough (7%), but the method of questioning was not described.

1.4 Hazards of PVC Pyrolysis Products

Respiratory symptoms have been reported in workers using hot wires to cut PVC film for food-wrapping, and this has b n attributed to pyrolysis products of PVC (SOKOL et al., 1973). These symptoms appear more common in food wrappers who are cigarette smokers, and it has been suggested that the effects of PVC pyrolysis products are more pronounced in smokers (FALK and PORTNOY, 1976). This syndrome has been studi d by other workers (ANDRASCH et al., 1975; POLAKOFF et al., 1975; JOHNSON and ANDERSON, 1976; BROOKS and VANDERVORT, 1977) and will not be further reviewed here.

In the PVC manufacturing process, the PVC is not heated sufficiently to release fumes, and smoking is not permitted within th plants, though PVC dust may be carried out of the plants on skin and clothing.

1.5 The Present Study

In view of the published reports summarised above, ICI Ltd. commissioned a study by the Institute of Occupational Medicine (IOM) of the health of workers in a PVC production and processing works. The study was planned to investigate the prevalence of respiratory symptoms, radiographic changes and pulmonary function abnormalities in a sample of the present and past workforce of the factory, and to relate any abnormalities found to estimates of exposure to respirable PVC dust.

Men were selected for medical studies from the present workforce of a factory manufacturing PVC, and from men who had retired from the factory, and men who had left for other reasons, in such a way as to include a high proportion of those workers likely to have been exposed to higher concentrations of respirable PVC dust for prolonged periods, together with samples of those men likely to have been exposed to less or no dust. An environmental survey of the factory was carried out to measure current PVC dust levels to obtain an estimate of relative dust exposure between different jobs, and a detailed occupational history obtained from the men selected for study. On the basis of current respirable dust measurements and occupational history, an index of PVC dust exposure was derived, and compared with the measurements of respiratory health made in the medical survey. In the medical survey, information about respiratory symptoms was obtained by questionnaire, lung function measurements made and chest radiographs obtained.

The study was agreed beforehand by representatives of management and the unions after detailed discussions with the senior staff of the IOM.

2. THE FACTORY PLANTS AND PROCESSES

Plants C2 to C6 produce PVC from vinylchloride monomer. Plant C1, now closed, was similarly employed. In these processes liquid vinylchloride monomer is admitted to autoclaves under pressure, and mixed with water to form either an emulsion or a suspension. The droplets of monomer and particles of PVC finally produced are smaller in the emulsion than the suspension method. Small quantities of surface active agents and catalysts are used in both methods.

The mixture is heated under pressure, the polymerisation reaction being complete in about eight hours. The remaining gaseous monomer is vented back to the gasholder. However, further monomer remains within the polymer, and this is stripped from the polymer by heating the slurry under reduced pressure. This is done within the autoclave in the older plants, and in a separate lower chamber in the newer plants. When the slurry of water and polymer has been discharged the autoclave is cleaned with jets of water. After cleaning the autoclaves in the older plants are entered for inspection. Before the hazards of vinylchloride monomer were known, significant exposure to the monomer occurred during autoclave cleaning, but now the stripping procedure and flushing of the chamber with air ensure monomer concentrations well below strict regulatory control levels in the autoclave section.

The PVC slurry passes through pipes to closed stock tanks over which air is circulated and vented to atmosphere to reduce further residual contamination with monomer. Up to this point in the process the PVC particles are wet, and little dust is apparent to the casual observer.

The slurry then passes to the drying and packing areas, which are physically separate from the autoclave areas. In the plants producing emulsion polymers drying is in several large spray driers, each of which requires opening and cleaning every seven days, this being an obviously dusty operation. In the plants producing other grades of PVC, the slurry is centrifuged and dried by standard solids drying operations, which are less dusty. The dry powder is conveyed by air to bulk storage silos or to sack packing machines. Packing can also be a dusty operation in the older plants, particularly in emulsion polymer plants.

Information from the manufacturer indicated that the approximate size ranges of PVC particles from the emulsion process were 3 to 100 μm and from the suspension process 50 to 300 μm. The emulsion particles may be milled further to paste polymer, range 1 to 50 μm. Some simple spot checks by the IOM using the Coulter counter technique were consist nt with this information.

Part of the PVC produced in these operations is processed further in separate compounding plants (Plants W1, W2, D) in which the PVC powder is mixed with various additives, fillers, and pigments. These plants appear to the casual observer to be generally less dusty than the PVC polymerisation plants, although some dust is generated in the mixers and in the bagging operation.

Other plants in the Works operate in adjacent areas, to produce various chemicals. These plants were not obviously dusty, and PVC dust levels within them were assumed to be negligible.

3. METHODS

3.1 Population to be Studied

Men were selected for study on the basis of information from factory personnel records. Records of place of work and occupation were reasonably complete except for a six-year peri d between 1966 and 1972.

Records of men retiring from work and receiving pensions from the manufacturers were also available, and records of men leaving the factory for reasons other than retirement w re adequate for those leaving between 1966 until the present.

The sample to be studied was therefore selected from 1,501 currently employed men, 339 pensioners who had retired since 1st January 1967, and 468 men leaving for other reasons sinc 1st January 1967. No women had been employed in dusty occupati ns, and none was included in the study.

For the purpose of selection of men for medical studi s, occupations and place of work were allotted to categories of dustiness derived from the preliminary inspection of th plant and measurements of the particle size ranges of typical PVC dusts. There were four such categories of dustiness, A to D, where A included the most dusty occupations and D negligibly dusty occupations. The process, maintenance and distribution work in plants C1 (an emulsion plant shut down in 1974) and C4 was allocated to category A; process, maintenance and distribution work in plants C2 and C3 (old suspension polymer plants), and process and maintenance work in plant W (an old compounding plant) were allocated to category B; work in plant C5, C6 and plant D, and all occupations in which exposure was slight or occasional, such as laboratory, quality control and work study jobs were allocated to category C. Occupations listed without sufficient detail for accurate categorisation were included in this group. In category D were all other jobs, mostly office work. This categorisation naturally involved some generalisations, and it is emphasised that these categories were for selection of men for medical studies, and were not used in the analysis. Detailed employment histories were obtained from the men themselves during the study, and actual dust measurements were made subsequently.

On the basis of these categories of job, the men were allocated to dust/job groups I to V. Men who had worked 10 years or more in category A jobs or 15 years or more in category B jobs were defined as group I. Men not in group I who had worked five years or more, but less than ten, in category A jobs, or who had worked ten years or more, but less than 15, in category B jobs were defined as group II. M n not in groups I and II, who had worked one or more years, but less than five, in category A jobs or one or more, but less than ten, years in category B jobs were defined as group III. Men no in groups I, II or III who had worked one or more years in category C jobs were defined as group IV. The remainder, men who had spent no time, or less than a year, in job categories A, B or C were defined as group V. The numbers of men in each group are set out in TABLE 1.

3.2 <u>The Sample</u>

For sampling, the currently employed men, pensioners and other leavers, were all considered separately. The sample (TABLE 2) consisted of all those in groups I (332 men) and II (196 men), randomly divided into two samples, a and b, and c and d, respectively; two random equal samples (e and f) from group III, the sum of the two groups totalling 98 of 501 men (20%); two random samples (h and i) from group IV, totalling 50 of 953 men (5%); two random samples (f and k) from group V, totalling 74 of 326 men (31%).

Additional random samples (g and l) were drawn from groups III and V respectively, and used as reserves. If any man in groups a to f was unable or unwilling to take part, a r serve from group g was included; similarly group l acted as reserves for groups h to k.

This intended total sample consisted of 750 men, the most heavily exposed men being highly represented in the sample. A clerical error resulted in an additional 92 men being fully studied, and a further 158 had chest radiographs taken and spirometry performed. The results for this latter group are recorded separately; the results for the additional men who were fully studied are included in the analysis. Th se additional men were in low dust/job groups. One-hundred and three reserves from the 'current' men, 31 pensioners and 22 leavers were drawn from sample g to replace men from groups I, II and III who did not attend the survey. In view of the 92 additional men studied as a result of the error mentioned above, no reserves were drawn to replace men from groups IV and V. Thus, finally, 841 men were fully studied.

Single breath gas transfer factor for carbon monoxide (see Methods) was measured in men in groups b, d, f, i, k. A further 22 men had gas transfer measurements as a result of the error mentioned above (total 322 men).

3.3 Environmental Survey

Current personal exposures to respirable PVC dust were measured by occupation in each plant in which PVC was manufactured or processed. The sampling device used (HARRIS and MAGUIRE, 1976) samples a 'respirable' fraction of total airborne dust in accordance with the Johannesburg Convention (ORENSTEIN, 1960), including 50% of all particles with an aerodynamic diameter of 5 µm and a density of 1.0 gm/cm^3, and excluding 100% of the particles above 7.1 µm.

Personal dust sampling was planned to include 180 men, with emphasis on those in the dustier occupations. Preliminary estimates of dustiness were based on subjective observation during a previous visit to the works and on particle size measurements of typical suspension and emulsion PVC dusts. Thus the major sampling effort was directed towards occupations in the drying and packing areas in plants C2 to C6 and mixing areas in plants W1 and W2 (plant C1 is now closed). Plants making emulsion and paste polymer received more study than thos making suspension polymer.

In the event only 130 reliable personal samples were obtained; the dust tended to cause failure of the sampling pumps, which required frequent servicing. The numbers of men sampled in each occupation and plant are set out in TABLES 3 to 12 in the Results section. Numbers of men in each shift and numbers of samples taken are also indicated. Office staff were not included in the survey. Plant A, which processed polyethyl ne, was the only non-PVC plant included in the surv y.

Three shifts were worked daily at each plant, one six-hour shift and two nine-hour shifts. Samples were taken on the afternoon shift (1 pm to 10 pm) except for one occasion when a morning shift (7 am to 1 pm) was monitored. Plants C2 to C6 and W1 and W2 were monitored on more than one day to reduce errors due to daily variations in dust concentrations.

All personal samples were taken for full shift periods on Sartorius cellulose ester membrane filters (type 11301), diameter 37 mm, pore size 8.0 µm. Each filter was inserted into a Casella Simpeds 70 cyclone (MAGUIRE *et al.*, 1970) which was fixed to the workman's lapel in a vertical position. A Casella personal sampling pump (an 'intrinsically safe' mod 1 in appropriate factory areas) was used to draw air through the filters at a flow rate of 1.9 l/m.

Sampling rates and revolution counter readings were recorded at the beginning and end of the shift, and the volume of air sampled calculated. A check was made during the shift to ensure that the instruments were functioning correctly.

A small number of static samples were taken in plants C2 to C6 and W1 and W2. The sampling instruments were placed in selected work areas to measure dust concentrations in the general atmosphere.

Filters were weighed twice before and after sampling. Prior to each weighing, the filters were allowed to reach equilibrium with the balance room atmosphere for 24 hours so that their weights were stable. Every tenth filter was retained as a control and not used for sampling, to calculate correction factors for changes in filter weights arising from changes in atmospheric humidity.

The airborne dust concentrations for each sample were calculated from the dust weight and the volume of air sampled.

3.4 Medical Survey

A medical survey team visited the factory and the men were seen by appointment. A full occupational history was recorded by a trained clerk who was familiar with the topography and operation of the factory and types of job within each plant. Details of type of work and plant within the plastics factories were recorded with dates. Dates and type of work outside the

The Medical Research Council Questionnaire of Respiratory Symptoms (MRC, 1976) was administered by a trained clerk. The clerk was instructed not to prompt; if a man had difficulty answering yes or no, encouragement was given in the form of a standard sentence and the question was repeated. If the answer was again equivocal, 'NO' was recorded.

Forced expiratory volume in one second (FEV_1) and forced vital capacity (FVC) were measured using a modified Gaensler spirometer (GAENSLER, 1951; McKERROW, 1960). After a practice expiration, three technically satisfactory forced expirations were recorded. The largest values of FEV_1 and FVC, not necessarily in the same breath, were used for the analysis, and the FEV_1/FVC ratio derived from these figures.

Single breath gas transfer factor for carbon monoxide (TL_{CO} was measured by the breathholding method of MEADE et al. (1965) based on the modified Krogh technique. Duplicate estimations were made at least ten minutes apart on an automated spirometer gas sampling system (Transfer test B, P.K. Morgan Ltd., Chatham Kent). Effective alveolar volume ($V_A eff$) was measured by h l dilution in the same single breath, and used in the calculatio of TL_{CO} and K_{CO} ($K_{CO} = \frac{TL_{CO}}{V_A eff}$). Technically unsatisfactory te were rejected and repeated (i.e. if the inspired volumes of t two tests differed by more than 10%, if the spirograms of the manoeuvres were of different shape or if the rates of inspir and expiration were too slow). The mean of the results of two satisfactory manoeuvres was used in the analysis. In men only one satisfactory test was performed, and the value from this test were used in the analysis.

The men were weighed fully clothed, and their standin heights measured.

A full-size postero-anterior chest radiograph was tal a standard technique (95 - 120 kV).

The chest radiographs were read independently using ILO U/C International Classification of Radiographs of Pneumoconiosis (International Labour Office, 1972) by th medically qualified National Coal Board readers highly experienced in this work. The readers were chosen to represent a range of interpretations of the presence of small radiographic opacities, on the basis of systematic inter-reader differences recorded in previous work.

The radiographs were also read by a chest physician for clinical purposes. When an abnormality was found the man and his general practitioner were informed by letter. If a man's lung function tests were abnormal he was informed of this and advised not to smoke.

3.5 Methods of Analysis

Data were checked, coded, punched on cards, recorded on magnetic tape, re-checked and edited.

Every occupation within the plastics division site at Hillhouse Works was allotted a PVC dust concentration on the basis of the measured current dust levels, the results of which are described in the next section. Sixty-six such job/dust categories were derived from the 130 measurements made and from knowledge of the factory conditions. Details of this allocation are described in Appendix 1.

A 'dust index' was derived from the current dust measurements and the occupational history such that the current dust levels in each of a man's occupations in the plastics factory was multiplied by the years he had spent in that occupation, and this figure added to the figures derived from his other occupations in the factory, i.e.

$$\text{'Dust index'} = \sum_{i=1}^{n} (\text{number of years in occupation}_i \times \text{mean dust concentration in occupation}_i)$$

where n is the number of occupations an individual has worked in the plastics factory. This index does not represent the man's actual dust exposure, for only present dust levels have b en measured, and subjective impressions of airborne dust over the years suggest that dust levels have been higher in the past than those presently experienced. This index can be considered an approximate estimate of relative dust exposure. It is expressed in years, weighted by present dust levels. For instance a man who had worked for 30 years in an office in the factory had a dust index of zero; a man who had worked over 30 years in the dustiest occupati ns had a dust index of 90.

Criteria for respiratory symptoms, based on the questionnaire were as follows:-

Chronic cough; yes to questions 1 or 2 plus yes to question 3

Sputum; yes to question 4 or 5 plus yes to question 6

Period of increased cough and phlegm lasting 3 weeks or more in the last 3 years; yes to question 7a

Chest illness during last 3 years which has kept subject from normal activities for as much as a week; yes to question 11a

Dyspnoea; shortness of breath when hurrying on lev l ground or walking up a slight hill; yes to question 8a

Asthma; attacks of shortness of breath with wheezing; yes to question 10a and/or history of asthma; yes t question 12g.

Men were grouped by smoking category; lifelong non-smokers, current cigarette smokers (including men smoking cigars or a pipe as well as cigarettes), ex-smokers and 'other' smokers, including present pipe and/or cigar smokers, excluding cigarette smokers. Lifetime cigarette consumption in packs (mean daily cigarette consumption x years smoked x $\frac{365}{20}$;) was calculated for cigarette smokers and ex-smokers on the basis of the answers to the detailed smoking history included in the questionnaire. If a man smoked cigars or a pipe, this was not considered in the figure for lifetime cigarette consumption.

Data were examined by standard methods including multiple linear regression and subsequent examination of residuals, and logistic analysis.

4. RESULTS

4.1 Environmental Survey

The mean airborne respirable dust concentrations to which 130 workers in various occupational groups were exposed during the survey are shown, by plant, in TABLES 3 - 12. The occupations are listed in TABLE 13 in order of dust concentration.

Respirable dust levels were generally low except for the C4 drying and packing operations and mixing process in plant W1. The highest mean average respirable dust exposure over any occupation over a shift was 2.83 mg/m^3.

The distribution of calculated dust indices (years x mg/m^3) for the 818 men studied in the medical survey are shown in FIGURE 1.

The concentrations measured by the static samplers were low compared with those from the personal samplers (TABLE 14), and have not been used in the analysis.

4.2 Medical Survey - Summary of Results

Measures of respiratory symptoms, lung function and chest radiographs are typically affected by many factors at once. The effect attributable to any one of these factors (age, dust index, smoking status, ...) depends to some extent on what other factors are also considered to contribute to the response. Correspondingly, in deriving the levels of significance quoted here for any one variable allowance was made at the same time for the effect of other variables of interest.

4.2.1 PVC Dust Effects

4.2.1.1 Respiratory Symptoms

There was an association of complaints of mild breathlessness on exertion with PVC dust exposure index among cigarette smokers ($P < 0.02$). Chronic cough or sputum, recent acute chest illness or history of asthma were not related to PVC dust exposure index.

4.2.1.2 Lung Function

Index of PVC dust exposure was significantly related to reduction of forced expired volume in one second (FEV_1) ($P < 0.025$).

4.3 Medical Survey - Detailed Results

4.3.1 Features of Population Studied

Eight hundred and forty-one men were seen, of whom 23 men were excluded from the analysis because of incomplete records of age, occupational history or spirometry.

The results for the remaining 818 men have therefore been analysed. Six hundred and sixty-three men were currently employed at the factory ('current men'); 98 were pensioners, and 57 men had left for reasons other than retirement ('leavers') (TABLE 15). Current men and leavers were of similar mean age (44.2 and 43.2 years respectively); pensioners were older (63.4 years). Mean dust indices were similar in current men and pensioners (13.4 and 14.2 units * respectively) and less in leavers (4.9 units *). The current men and pensioners had spent mean periods of 14.3 and 16.6 years respectively at the factory, the leavers only 5.5 years. The FEV_1, FVC and FEV_1/FVC ratio were similar in the current men and leavers, and lower in the (older) pensioners (TABLE 15).

Numbers of current men, pensioners and leavers are set out by age group and smoking category in TABLE 16. In TABLE 17, all men are shown by these categories, with mean dust indices for the groups. One hundred and forty-eight (18%) of the whole population were lifelong non-smokers; 378 (46%) were current cigarette smokers or smoked cigarettes as well as cigars or a pipe; 58 (7%) smoked cigars or a pipe without cigarettes (other smokers); 234 (29%) were ex-smokers.

4.3.2 Preliminary Analysis

Multiple linear regression was used to screen possible explanatory variables in relation to response. There was no evidence that years worked at the PVC plant or work in an outside industry in which noxious materials were used were related to prevalence of symptoms, lung function or radiographic abnormality,

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* Dust index units are years x mg/m^3, but this does not represent actual dust exposure, as only current dust levels are known.

after age, index of dust exposure, smoking habits, and (in the case of lung function) height and weight were taken into account.

4.3.3 Respiratory Symptoms

Analysis of respiratory symptoms was based on the answers to the questionnaire.

The only respiratory symptom showing a relationship with index of PVC dust exposure was dyspnoea.

4.3.3.1 Chronic Cough or Sputum

One hundred and fifty-two men (18.6%) reported chronic cough for as much as three months in each year. One hundred and thirty-four men (16.4%) reported sputum for as much as three months in the year. Ninety-four of these men (11.5%) reported both cough and sputum. Chronic cough was positively associated with sputum ($P \ll 0.001$), and prevalence of chronic cough (irrespective of sputum) and prevalence of sputum (irrespective of cough) each showed highly significant differences between smoking categories (TABLE 18). The association of cough and sputum was similar in the different smoking categories when the different prevalences were allowed for.

Chronic cough alone, sputum alone and cough and sputum have been considered together in the subsequent analysis (called 'cough or sputum'). One hundred and ninety-two men (23.5%) reported chronic cough or sputum.

There were marked differences in prevalence of cough or sputum between smoking categories (X^2 test, $P < .001$), and smoking category influenced the apparent relationship of cough or sputum with other variables including age, lifetime cigarette consumption and dust index. For this reason men in the four smoking categories were considered separately by logistic analysis.

Non-smokers

Only five of 148 men (3.4%) reported cough or sputum, and there were no evident relationships with dust index or age.

Cigarette Smokers

There was a higher prevalence of cough or sputum among cigarette smokers (34.4%) than among non-smok rs, and this effect was related to lifetime cigarette consumption.

Logistic analysis showed a strong positive relationship between cough or sputum and cigarette consumption ($P < .001$).

Using the log of lifetime cigarette consumption in the logistic function gave a better fit with cough or sputum, and, for these data, a simpler mathematical expression for the relationship*. Using this form of relationship between cough or sputum and cigarette consumption, the age effect was no longer apparent and there was still no effect of index of dust exposure.

Other Smokers

In pipe and cigar smokers there was a greater prevalence of cough or sputum (31%) than in non-smokers, similar to that in cigarette smokers. No relationship with years smoked, dust or age could be demonstrated.

Ex-Smokers

Logistic modelling taking account of age, lifetime cigarette consumption and dust simultaneously, showed a relationship with age ($P < 0.05$), a relationship with cigarette consumption which did not reach significance ($P = 0.11$), and no dust effect. (Lifetime cigarette consumption was taken as zero in cigar and pipe smokers.)

4.3.3.2 Asthma

No relationship was demonstrated between a history of asthma and index of PVC dust exposure.

Ninety-two men (11.2%) reported suffering from asthma or

* Fitting the logistic function:

$$P(x) = \frac{\exp(a + b \log x)}{1 + \exp(a + b \log x)}$$

gives b = 1.008, very close to 1.

Taking b as 1, the expression becomes

$$P(x) = \frac{C x}{1 + C x} \qquad x > 0, \quad C = e^{a}$$

C is estimated as 0.06.

This fit is illustrated in FIGURE 2.

Where $P(x)$ is the probability of cough or sputum as x varies
x = lifetime cigarette consumption (units = 1,000 packs), a, b being unknown constants estimated by the curve-fitting procedure (using maximum likelihood methods).

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attacks of shortness of breath with wheezing. More men in the smoking groups (cigarette smokers (12.7%), other smokers (13.8%), ex-smokers (12.8%)) reported these symptoms than in the non-smoking group (4%). The differences between the four categories are significant (X^2 test, $P < 0.04$).

Logistic likelihood analysis confirmed the differences between smoking groups at a sharper level of significance ($P < 0.01$), but no effect of age or dust was apparent. There was no discernible interaction between smoking and PVC dust.

4.3.3.3 Dyspnoea

There was a significant slight association of breathlessness on exertion with index of dust exposure.

Two hundred and fifteen men (26.3%) admitted to dyspnoea on exertion grade I ('shortness of breath when hurrying on level ground or walking up a slight hill'). Prevalence was approximately three times higher in the smoking groups (32% in cigarette smokers) than in the non-smokers (10%). Linear logistic analysis confirmed this ($P < 0.0001$), and showed a strong age effect ($P < 0.00001$). A dust effect approached significance ($P = 0.054$) after adjustment for age and smoking, and this effect was pronounced in current cigarette smokers ($P < 0.02$) after allowing for age and lifetime cigarette consumption, but not present in the other smoking categories.

Prevalence of more severe grades of dyspnoea showed a strong relationship with age and a weak relationship with smoking, but no dust effect.

4.3.3.4 Acute Chest Illnesses

No relationships were demonstrated between acute chest illness and index of dust exposure.

A history of recent periods of increased cough and phlegm was more common in cigarette smokers and other smokers than non-smokers or ex-smokers, though this difference only approached significance (X^2 test, $P = 0.063$; likelihood test, $P < 0.03$), and no effect of index of dust exposure or age was apparent after smoking differences had been taken into account.

Prevalence of a history of recent chest illness was not significantly related to smoking, age or index of dust exposure. Combination of these two features of chest illness showed no significant relationships with smoking, age or index of dust exposure, nor did the inclusion of positive histories of pneumonia, pleurisy or (acute) bronchitis.

4.3.4 Lung Function

FEV_1 and FVC were significantly inversely related to the index of PVC dust exposure.

4.3.4.1 Forced Expired Volume in One Second (FEV_1)

Preliminary analysis indicated the anticipated relationship between FEV_1 and age and smoking category (FIGURE 3), cigarette smokers having the greatest loss of FEV_1 with age, non-smokers the least.

Dust effect was studied after standardisation for age, height and weight by multiple regression. Pensioners were found to have significantly lower mean FEV_1 after age, height, weight and dust index had been taken into account than current men or leavers (FIGURE 4), though the slope of the regression for dust index was similar in all three groups.

For subsequent analysis the slopes of the regression for FEV_1 with dust index were constrained to be the same for current men, pensioners and leavers: the intercepts for current men and leavers were constrained to be the same, but the intercept for pensioners was allowed to vary independently. Introducing different intercepts for smoking categories and additional regression for lifetime cigarette consumption into the model did not seriously alter the overall regression with dust index, though there was a significant inverse relationship of FEV_1 with cigarette consumption ($P < 0.0001$) (TABLE 19).

There was a significant negative effect on FEV_1 of increasing dust index ($P < 0.025$) after adjustment for age, height, weight and smoking.

Further expansion of this model by allowing different slopes of regression of FEV_1 with dust index for the different smoking categories (TABLE 20) showed that the dust effect was most marked in cigarette smokers, and not apparent in non-smokers, though the magnitude of difference in slopes between these two groups is just significant at the 10% level. The intermediate values of the slopes for ex-smokers and other smokers provide slight additional evidence that the dust effect varied according to smoking status. The effect was significant among smokers ($P < 0.005$), and was not demonstrated in non-smokers, but this may partly be the result of their lower mean dust exposures (TABLE 17), and small number of men (148). More detailed modelling allowing different regression of FEV_1 with age for each smoking group confirmed a dust effect in cigarette smokers. and also indicated a slight but statistically non-significant effect of dust in the non-smokers. In conclusion an ov rall effect of PVC dust was demonstrated, and suggestive evidence of differences between smoking categories was identified.

Addition of chronic cough or sputum, and recent chest illness to the model (with a single regression for dust effect) indicated that each of these was associated with a lower level of FEV_1 ($P < .001$, $P < 0.002$ respectively). Association of radiological abnormality with FEV_1 is reported in the section on chest radiographs.

Magnitude of FEV_1 Loss

After taking into account the effects of age, height and weight, the overall regression of FEV_1 with dust index was -0.0040 litres per dust index unit (years x mg/m^3). This was equivalent to a loss of 52 ml of FEV_1 for the mean dust index. As an illustration this would be equivalent to a loss for all men of 5.2 ml of FEV_1 per year during exposure to the mean dust index over a period of ten years. In cigarette smokers considered separately this loss was 8.9 ml of FEV_1 per year for similar exposure, additional to the loss caused by smoking and age. It is emphasised that dust index does not represent actual dust exposure for it is based on current dust levels only.

This may be compared with the mean losses due to age (35 ml per year) or smoking one pack of cigarettes a day (6.2 ml per year).

4.3.4.2 Forced Vital Capacity (FVC)

FVC was significantly inversely related to index of PVC dust exposure among currently employed men.

Preliminary analysis indicated the anticipated adverse effects of age and smoking category on FVC (FIGURE 5). Multiple regression techniques, allowing different intercepts and different slopes of regression with dust index for current men, pensioners and leavers showed a negative association between dust index and FVC among the current men ($P < 0.05$) (TABLE 21). Pensioners had a lower mean level of FVC after adjustment for age, height and weight for any dust index, and no dust effect was apparent. Leavers had a similar mean level of FVC to the current men but no dust effect (FIGURE 6).

The pattern of dust effects among smoking groups was similar to that for FEV_1, though the differences did not approach significance at conventional levels.

4.3.4.3 Ratio of Forced Expired Volume in One Second to Forced Vital Capacity (FEV_1/FVC ratio)

The FEV_1/FVC ratio was not significantly related to index of PVC dust exposure.

Preliminary analysis of FEV_1/FVC ratios demonstrated age and smoking effects (FIGURE 7). Multiple regression for log(FEV_1/FVC) in the same manner as for FEV_1 and FVC confirmed age, height and weight effects, but dust effects did not reach significance. Pensioners did not have significantly lower FEV_1/FVC ratios. The introduction of chronic cough or sputum and recent chest illness into the model indicated a significant association of chronic cough or sputum with lower FEV_1/FVC ratio ($P < 0.001$) (TABLE 22).

4.3.4.4 Gas Transfer for Carbon Monoxide (TL_{CO})

TL_{CO}, K_{CO} and $V_A$eff were not significantly related to index of PVC dust exposure.

Multiple regression for TL_{CO} in 322 men showed significant age, weight and smoking effects but no dust effect.

Pensioners had lower TL_{CO} adjusted for age, height, weight and smoking than other groups but no dust effect (TABLE 23).

Diffusion constant, K_{CO}, showed significant inverse relationships with age and height for all men, significant smoking effects but no dust effect. Alveolar volume, $V_A$eff, showed age and height effects but no dust effect. Pensioners had lower $V_A$eff adjusted for age, height and smoking.

4.3.5 Chest Radiographs

A significant relationship of the prevalence of small rounded opacities with index of PVC dust exposure was found by one reader only.

Results for the three expert readers are described separately. The anticipated differences between readers in interpretation of small opacities were apparent (TABLE 24).

4.3.5.1 Prevalences of Small Opacities

The prevalences of small rounded and small irregular opacities of U/C category 0/1 or greater, and 1/0 or greater, are set out in TABLE 25. Reader 17 found the greatest prevalence of small rounded opacities; 50 radiographs (6.1%) with category 0/1 or more, ten (1.2%) with category 1/0 or more. (These ten consisted of six radiographs with category 1/0 and four with category 1/1.).

Reader 15 found more small irregular opacities than the other readers; 53 radiographs (6.5%) with category 0/1 or more, most of whom were classified as 1/0 or more (46, 5.6% of the entire sample) (TABLE 24). Of these 46 radiographs, 16 were 1/0, 20 were 1/1, 1 was 1/2, 6 were 2/1 and 3 were 2/2.

For two readers (03 and 17) there was a slight tendency for films classified as showing one type of small opacity to be classified as showing the other type as well. Agreement between readers in classifying type of small opacities is set out in TABLES 25 and 26.

4.3.5.2 Small Rounded Opacities - Category 0/1 or Greater

Reader 17 found a significant relationship between prevalence of small rounded opacities category 0/1 or greater and index of PVC dust exposure.

Preliminary analysis of the data for readers 03 and 17 showed a relationship between the prevalence of small rounded opacities and age (FIGURE 8). The results for reader 03 were dominated by a relatively high prevalence (7.9%) in the oldest age group. The results for reader 17 showed a progressive increase in prevalence of small rounded opacities with increasing age, the highest prevalence being 11.4% in the oldest age group.

Results for reader 03 showed no relationship with dust index (FIGURE 9), but reader 17 found an additional relationship of prevalence of small rounded opacities with dust index, even when age was taken into account (FIGURE 10). The zero prevalence of small rounded opacities category 0/1 or more in the lowest dust index category (TABLE 27) does not necessarily indicate that dust exposure is required for the development of these opacities. The subsequent logistic analysis indicated a strong age effect independent of dust effect (for two readers).

Reader 15 classified only four radiographs as rounded opacities 0/1 or more. These showed no striking relationships with dust or age, and have not been analysed further.

Results for readers 03 and 17 were examined by logistic analysis. Reader 03 found a clear relationship of the prevalence of small rounded opacities category 0/1 or more with age ($P < 0.002$), and no relationship with dust when age was taken into account ($P = 0.83$). The fitted model indicated a prevalence of 1.5% for men aged 45 years, subsequently increasing approximately twofold for each additional ten years of age. Smoking category did not influence these results.

Reader 17 found highly significant relationships of small rounded opacities category 0/1 or more with both age and dust index. Age and dust index were independently related to prevalence of opacities. The relationship with dust index after allowing for age was significant at $P < 0.001$ (FIGURE 10). The relationship with age after allowing for dust index was significant at $P < 0.001$.

The fitted model estimates a prevalence of small rounded opacities category 0/1 or more of 4% among 45-year-old men with ten dust index units. This estimate increases by a factor of approximately 5/3 for each additional ten years of age, and (separately) by a factor of approximately 4/3 for each additional ten dust index units. An alternative representation of the fitted model is illustrat in FIGURE 11. Predicted prevalence of rounded opacities category 0/1 or more is plotted against dust index for differe age groups. Reader 17's actual readings for all ages are al shown. This model predicts a 7.6% prevalence of small round opacities category 0/1 or more for 65-year-old men never expo to PVC dust. Twenty PVC dust index units increases this prevalence at age 65 to 13.5%.

Age and dust effects for reader 17 were no. the same fo smoking categories. The dust effect was seen in the ex-smo and 'other' smokers, among whom no age effect was se n. Am non-smokers, who were younger, and of whom only thre of 148 had small rounded opacities category 0/1 or more, an age effect was indicated but notconfirmed, and the dust effect w doubtful. Amongst cigarette smokers there was a clear relationship with age, and no dust effect. The reasons fo these differences were not apparent, and the results presen are those for all smoking categories combined.

Age for age the pensioners had a lower prevalence of s rounded opacities when age and dust had been taken into acc

Relationship of Respiratory Symptoms to Prevalence of Small Rounded Opacities

There was no evidence that the presence of chronic co sputum, or recent acute chest illness was related to the p of small rounded opacities when age and dust had been take account.

4.3.5.3 Small Rounded Opacities - Category 1/0 or Greater

Reader 17 found ten radiographs showing small rounde opacities category 1/0 or greater, and in spite of this sm number, a significant relationship with both age ($P < 0.0$ dust index ($P < 0.02$) (after adjusting for the other) was

The estimated prevalence of small rounded opacities 1/0 or more for men aged 45 with ten dust index units wa the prevalence increasing by a factor of approximately each ten years of life and approximately 1½ for each fur dust index units.

4.3.5.4 Small Irregular Opacities - Category 0/1 or Greater

No significant relationships were found between prevalence of small irregular opacities and index of PVC dust exposure.

Preliminary analysis showed a clear relationship betw en prevalence of small irregular opacities category 0/1 or greater and age for all three readers (FIGURE 12). There appeared to be no or little relationship with dust index (FIGURE 13).

Logistic analysis confirmed the age effect for all three readers (reader 03, $P < 0.001$; reader 15, $P < 0.00001$; reader 17, $P < 0.001$). In the case of reader 15, for example, the estimated prevalence among men aged 45 years was 2.8%. This increased by a factor of three (approximately) for each additional ten years of age. There was no relationship of prevalence of small irregular opacities with dust index for any of the three readers.

For reader 15 the relationship of small irregular opacities with age could in small part be explained by a positive history of chronic cough or sputum ($P < 0.03$), and by history of chest illness. The criteria of chest illness, in this instance only, included a history of pneumonia, pleurisy or (acute) bronchitis, or a period of increased cough and phlegm lasting three weeks or more in the last three years, or a chest illness during the last three years which had kept the subject from his normal activities for as much as a week. Prevalence of small opacities was related to chest illness by these criteria ($P < 0.03$). Men with chronic cough or sputum, or men with a history of chest illness were each approximately twic as likely to have small irregular opacities as those without thes features. Chronic cough or sputum and history of chest illness were to some extent alternatives to each other: the inclusion of each in the model reduced the significance of the other, while a positive history of both was more strongly associated with small irregular opacities.

Reader 17 also found a relationship between small irregular opacities and chronic cough or sputum ($P = 0.061$), but no relationship with history of chest illness. For both readers, the age effect remained extremely strong even when these symptoms were taken into account.

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Peader 03 found differences between smoking categories. Prevalence o. ~~all irregular opacities was lowest in non-smokers (0.7%) and highest am... ... ...okers (12.1%). Ex-smokers (3.8%) were similar to cigarette smokers ... Th... differences were formally significant ($P = 0.021$) after allowing for differences in age distribution between the smoking groups. There was no dust effect.

Neither of the other two readers identified smoking differences.

4.3.5.5 Small Irregular Opacities - Category 1/0 or Greater

Analysis of readings of small irregular opacities category 1/0 or more (TABLE 24 shows prevalence) confirmed the age effects and did not show any dust effect. Results for reader 15 confirmed the relationship of small irregular opacities with history of chronic cough and sputum and/or acute chest illness ($P < 0.02$). Reader 17's results indicated a relationship with chronic cough and sputum ($P = 0.054$).

4.3.5.6 Relationship of Lung Function to the Presence of Small Rounded Opacities

Men with small rounded opacities had significant reductions of FEV_1, FVC and $V_A$eff.

Reader 17 found small rounded opacities category 0/1 or greater in 50 radiographs. The lung function of these men was significantly reduced. The FEV_1 was reduced by a mean of 219 ml ($P < 0.01$) after age, height, weight, smoking, cigarette consumption and dust index had been taken into account. The FVC was reduced by a mean of 264 ml ($P < 0.01$), using the same model, and FEV_1/FVC ratio not significantly different. TL_{CO} and K_{CO} were measured in 21 of these men, and were not found to b significantly reduced. $V_A$eff was reduced in these 21 men by a mean of 328 ml ($P < 0.05$).

The same reader found small rounded opacities category 1/0 or more in ten radiographs. In these ten subjects the mean FEV_1 was reduced by 293 ml but this difference failed to reach significance ($P < 0.2$) because of the small numbers of men. Similarly the FVC was 323 ml lower but this difference also fail d to reach significance ($P < 0.2$). The TL_{CO} was m asured in only one of these men.

These results suggest that the men with small rounded opacities had an associated impairment of lung function, predominantly of obstructive pattern.

4.3.5.7 Relationship of Lung Function to the Presence of Small Irregular Opacities

Men with small irregular opacities in the chest radiograph had significantly reduced FEV_1, FVC and FEV_1/FVC ratio.

Radiographs of 90 men were thought by one or more readers to show small irregular opacities category 0/1 or greater. The lung function of these men was significantly reduced. Their mean FEV_1 was reduced by 210 ml after adjusting for age, height, weight, smoking category, lifetime cigarette consumption and dust index ($P < 0.01$). The mean FVC was reduced by 147 ml, using a similar model ($P < 0.05$). The log of the ratio FEV_1/FVC was also significantly reduced ($P < 0.01$). TL_{CO} was measured in 34 of these men, and was reduced by a mean of 1.59 ml/min. mm Hg ($P < 0.05$). V_A and K_{CO} were not significantly different.

Radiographs of 52 men were thought by one or more readers to show small irregular opacities category 1/0 or greater. The mean FEV_1 of these men was reduced by 325 ml ($P < 0.001$) using a similar model to that used above. The mean FVC was reduced by 276 ml ($P < 0.01$). The $\log(FEV_1/FVC)$ ratio also was significantly reduced ($P < 0.01$). TL_{CO} was measured in 25 of these men, and was reduced by a mean of 1.97 ml/min. mm Hg ($P < 0.05$).

These findings suggested that the presence of small irregular opacities was associated with an obstructive lung defect, and that greater profusion of opacities was associated with more severe airflow obstruction.

4.3.6 Autoclave Workers

Autoclave workers may have been exposed to significant concentrations of vinylchloride monomer in the past. The effect of a history of being an autoclave worker was examined in the respiratory symptoms, lung function and chest radiographic abnormality models. With one exception, a history of having been an autoclave worker had no influence on symptoms, lung function or chest radiographic abnormalities. The exception was in the presence of small rounded opacities category 0/1 or more found by reader 03; men who had worked at some time on the autoclaves had a significantly lower prevalence of small rounded opacities category 0/1 or more, after age and PVC dust effects ($P < 0.04$). This was not the result of differences in smoking habit. Thus apparent PVC dust effects were not the result of exposure to vinylchloride monomer during autoclave working.

4.3.7 Chest Radiographs of Men not included in the Analysis

The readings of the chest radiographs of 181 men not included in the analysis are given in TABLE 28. These comprise the radiographs of 23 men excluded from the analysis because of inadequate data, together with 158 men whose chest radiographs were taken but who were not intended to be part of the selected study population. The prevalences of small opacities were similar to those of the study population.

4.3.8 Clinical Readings of Chest Radiographs

As a result of the readings of chest radiographs by two chest physicians for clinical purposes, 84 men were referred to their general practitioners.

Most of these referrals were for minor abnormalities of the chest radiographs, particularly pleural shadows consistent with past infections, apical shadows consistent with inactive or healed tuberculosis, probable nipple shadows, and slight diffuse shadowing in the lungs. Cardiomegaly was also observed. In six men the appearances were thought to require clinical investigation to exclude or confirm malignant disease. At th present time, serious disease has been excluded in four men, one has refused further investigation and one is still undergoing investigation.

The chest radiograph of one man showed advanced diffuse pulmonary fibrosis. This man had a chest radiograph taken though he was not in the intended study sample. He had worked in plants C1 and C4 for 32 years, though not in employment close t the process. H was asympt matic, though on examination he had clubbing of the fingers and many crepitations were audible over the lower parts of his lungs. He was referred to his general practitioner for investigation, and it is hoped that further information will be available later.

5. DISCUSSION

A survey of the literature has shown that there is some evidence that inhalation of PVC dust might be associated with the development of respiratory disease, expressed as radiographic changes, respiratory symptoms or functional abnormalities (VERTKIN et al., 1970; MILLER et al., 1975; LILIS et al., 1976; ARNAUD et al., 1978; MAPP et al., 1978). However, one epidemiological study failed to demonstrate any functional abnormality related to PVC dust (GAMBLE et al., 1976). The results of this and the previous studies were equivocal, and this has generally been because such symptoms, dysfunction and radiological changes have multiple potential causes, of which inhalation of PVC dust is only one. It is necessary therefore in studying the effect of inhalation of PVC dust to take into account other factors known to cause respiratory symptoms, radiological changes and reduced lung function. Moreover, in studying any working population it is desirable to include those workers who have left the labour force either to move to other jobs or on retirement, as such men may include disproportionate numbers of less healthy men (FOX and COLLIER, 1976).

This study was planned to sample the present workforce and thos who had previously worked in the factory. It was not possible to study th entire population and so a random sample was selected, weighted to include a relatively high proportion of those who had the highest lifetime exposure to PVC dust. The initial selection was based on rough estimates of past exposure, but analysis of the effects of exposure to PVC dust was based on more accurate estimates calculated from a careful occupational history and on measurements of current exposure to respirable PVC dust. Nevertheless, these estimates remain inexact, as it was not possible to obtain measurements of past dust exposures in the factory. Insofar as it is probable that earlier levels were higher than those obtaining at present, our exposure estimates are probably rather lower than the actual historical values especially for those men with the longest working history, and this should be borne in mind when drawing conclusions about dust/disease relationships. The assumption was also made, and is likely to have been valid, that the ratios of exposure between difference jobs had remained approximately constant.

In the selected sample of the population, the study was planned to measure the prevalence of respiratory symptoms, the levels of lung function (both of the airways and of the peripheral, gas-exchanging parts of the lung) and the amount of radiological abnormality, and to relate these findings to the estimates of exposure to respirable PVC dust. In so doing it was necessary to allow for the effects of other factors that were known to affect, or were suspected of affecting, these measurements. In the case of symptoms and respiratory function, age and cigarette smoking (and size with regard to lung function) are known to have important effects, while in the case of radiological changes it was thought probable that observer differences and effects due to age and smoking might be observed. The analysis was therefore planned to take these factors into account as well as the possible effects of PVC dust exposure.

In the case of this epidemiological study, a clinical reading of the chest radiograph was carried out, as in any such study a proportion of men are found with serious and usually coincidental disease that requires medical attention. Among those found to have abnormalities was one with pulmonary fibrosis. There is no way of knowing at present whether this man's disease was related to his work, but he is being investigated further clinically and it is hoped to acquire further information later. No excess of other disease, such as lung cancer, was apparent in this study.

We found a relationship between estimates of exposure to PVC dust and symptoms, lung function and radiological abnormalities. In the cas of symptoms, the relationship was between exposure to dust in cigarette smokers and grade I (or slight) dyspnoea. This relationship was n t present in non- or ex-smokers or in other smokers. The effects of age and cigarette smoking on this symptom were, as anticipated, much stronger and it seems unlikely that the effect of PVC dust on symptoms alone is of clinical significance.

However, the relationship between PVC exposure estimates and respiratory function showed that inhalation of the dust has an effect on the FEV_1 that is comparable to that of smoking, though not as pronounced as that of age.

The effect of PVC dust exposure on the FEV_1 was seen strongly in cigarette smokers, and not confirmed among non-smokers considered separately, and the pattern of the regressions for dust effect in the different smoking categories suggested that there were real differences in PVC dust effect according to smoking habit. This suggested interaction between PVC dust and smoking might be caused by a combined effect of dust and smoking acting separately on the airways, or possibly to PVC pyrolysis products released from cigarettes contaminated with PVC dust. Smoking was not permitted within the factory plants, but the dust could be carried out on skin and clothing. Respiratory symptoms are known to occur in workers cutting PVC film with hot wire (SOKOL et al., 1973), and it has been suggested that these effects are more pronounced in smokers (FALK and PORTNOY, 1976). While this suggested interaction between smoking and effect of PVC dust on lung function could be caused by either of these mechanisms, the effect of PVC dust on the chest radiographs was not clearly related to smoking, and therefore presumably not related to PVC pyrolysis products.

We only measured respirable dust, but an effect on the airways could also have been due to dust of larger particle size, also present in th air, and which would be deposited less peripherally in the lung than the respirable fraction. Measures to reduce respirable dust will of c urse reduce dust of larger particle size as well. This effect on FEV_1 is important. Although the mean decline with exposure is small, within the range there are likely to be workers whose decline, by analogy with the known response to cigarette smoking, is of clinical significance.

The effect of dust exposure on FEV_1 was mirrored by a similar small effect on FVC. However, no effect on transfer factor or alveolar volume was found. This suggests that dust exposure has a predominant effect on airways and that there is no evidence of an effect, such as lung fibrosis, on the gas-exchanging parts of the lung from this study. This is in keeping with what has so far been reported from human and animal pathological studies, where pulmonary fibrosis has not been a prominant finding. The effect of dust exposure on airways may be a non-specific effect, related to the mass and number of dust particles, or it may be a specific effect due to a particular property of the dust. Which of these is correct must await further pathological and experimental studies, but some evidence may be adduced from the radiological findings.

Interpretation of chest radiographs is a largely subjective exercise, large variations occurring between differ nt readers. We have chosen to use those readers trained specifically in the assessment of radiographs according to the ILO U/C classification (International Labour Office, 1976), and known to show little intra-reader variability. They did, however, show some variability between themselves, which had been apparent in previous studies and was seen in this work. All readers detected small shadows, both rounded and irregular, in a small proportion of films. Almost all were of a low category and there was no evidence of advanced pulmonary fibrosis in the survey population. The small irregular opacities were clearly related to age by all three readers, and two readers found them to be related to cough and sputum. This, taken with the finding of a reduced FEV_1 in these men, suggests that age and bronchitis are important factors in the development of these opacities.

Small rounded opacities were found to be related to age by two readers, but one of these also found a relationship to dust exposure. Again, men with small rounded opacities showed a reduction in their FEV_1 and FVC and $V_A$eff. The transfer factor was not significantly reduced. This suggests that the reduced ventilatory capacity was due primarily to obstructive (bronchial) lesions, but with an additional restrictive component (small airways or alveoli).

6. CONCLUSIONS AND RECOMMENDATIONS

We have thus found the clearest evidence yet obtained that inhalation of PVC dust is associated with respiratory dysfunction and radiographic changes. We have not found evidence of a serious progressive form of pulmonary fibrosis, but we have shown that radiographic abnormalities occur in a proportion of exposed men and that they are associated with measurable abnormalities of airway function. This suggests that the effect is a specific one on airways associated with structural changes. We have also shown that the effect of PVC dust inhalation on lung function is of the same order of that of cigarettes and approximately 1/7 of that of ageing. While these results are not unduly alarming, they do indicate that further measures to reduce individual dust exposure would be prudent. Moreover, consideration should be given to monitoring the ventilatory function and radiographs of those men in the highest exposure categories. Clinical follow-up of these men with radiographic abnormalities is desirable in order to determine whether the condition is progressive or indeed if it regresses.

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	Currently employed men	Pensioners	Leavers	Total
Group I: 10 years or more in category A jobs	124	15	6	145
or 15 " " " " " B "	156	29	2	187
	280	44	8	332
Group II: Not in group I 5 years or more, but less than 10 years in category A jobs	44	9	18	71
or 10 years or more, but less than 15 years in category B jobs	94	25	6	125
	138	34	24	196
Group III: Not in groups I or II 1 year or more, but less than 5 years in category A jobs	95	2	53	150
or 1 year or more, but less than 10 years in category B jobs	187	51	113	351
	282	53	166	501
Group IV: Not in groups I, II or III 1 or more years in category C jobs	601	148	204	953
Group V: No time in A, B or C (= remainder)	200	60	66	326
Totals (population)	1,501	339	468	2,308

TABLE 1 Sampling Frame: groups of men by dust/job category.

		Currently employed men	Pensioners	Leavers	Total
Group I (all):	Sample a	168	26	5	
	" b	112	18	3	
		280	44	8	332
Group II (all):	Sample c	84	20	14	
	" d	54	14	10	
		138	34	24	196
Group III (38% sample):	Sample e	33	6	20	
Reserves g were drawn from this group.	" f	22	4	13	
		55	10	33	98
Group IV (5% sample):	Sample h	19	5	6	
	" i	13	3	4	
		32	8	10	50
Group V (33% sample):	Sample j	27	8	9	
Reserves l were drawn from this group.	" k	19	5	6	
		46	13	15	74
Total (10 samples, excluding reserve samples)		551	109	90	750

TABLE 2 Sampling from total population of 2,308 men.

Occupational Group	Number of Men per Shift	Number of Men Sampled	Mean Respirable Dust Concentration ± Standard Deviation (mg/m^3)
Autoclaves	13	4	0.46 ± 0.18
Driers	6	7	2.59 ± 1.56
Packers	9	14	2.88 ± 1.84
Recovery operator	1	1	0.65
Fork truck driver	2	2	0.89
Drier foreman	1	1	0.94
Cleaner	1	1	1.19
Maintenance	9	3	0.84 ± 0.48

TABLE 3 Dust concentrations in occupational groups in Plant C4.

Occupational Group	Number of Men per Shift	Number of Men Sampled	Mean Respirable Dust Concentration ± Standard Deviation (mg/m^3)
Autoclaves	8	2	0.17
Driers	3	5	0.54 ± 0.31
Packers	5	7	0.60 ± 0.33
Fork truck driver	1	1	0.70
Maintenance	10	3	0.21 ± 0.13

TABLE 4 Dust concentrations in occupational groups in Plant C2 and C3.

Occupational Group	Number of Men per Shift	Number of Men Sampled	Mean Respirable Dust Concentration ± Standard Deviation (mg/m^3)
Autoclaves	19	0	-
Driers	6	4	0.50 ± 0.28
Packers (including polymer recovery)	9	7	0.38 ± 0.12
Fork truck driver	1	1	0.29
Foreman	1	1	0.35

TABLE 5 Dust concentrations in occupational groups in Plant C5

Occupational Group	Number of Men per Shift	Number of Men Sampled	Mean Respirable Dust Concentration ± Standard Deviation (mg/m^3)
Premix team	7	4	1.41 ± 0.74
Mixing unit operators	9	17	1.86 ± 1.27
Foreman	1	1	0.49
Fork truck driver	2	1	0.86
Cleaner	1	1	0.72

TABLE 6 Dust concentrations in occupational groups in Plant W1.

Occupational Group	Number of Men per Shift	Number of Men Sampled	Mean Respirable Dust Concentration ± Standard Deviation (mg/m^3)
Premix team	6	4	1.04 ± 0.48
Dry blend units	6	5	0.86 ± 0.84
Unit controller	2	2	0.57
Ground floor team	4	6	0.37 ± 0.20
Fork truck driver	1	0	-
Cleaners	2	2	0.23
Supervisor	1	1	0.61

TABLE 7 Dust concentrations in occupational groups in Plant W2.

Occupational Group	Number of Men per Shift	Number of Men Sampled	Mean Respirable Dust Concentration (mg/m^3)
Assembly	4	1	0.13
Press operator	2	1	0.38
Polishing	1	1	0.49
Fork truck driver	1	1	0.22
Trimmer	1	1	0.14
Mill cutter	1	1	0.37
Premix operator	1	1	0.10

TABLE 8 Dust concentrations in occupational groups in Plant D.

Occupational Group	Number of Men per Shift	Number of Men Sampled	Mean Respirable Dust Concentration ± Standard Deviation (mg/m^3)
Testers	6	3	0.34 ± 0.11

TABLE 9 Dust concentrations in occupational groups in laboratory (Plant W1).

Occupational Group	Number of Men per Shift	Number of Men Sampled	Mean Respirable Dust Concentration ± Standard Deviation (mg/m^3)
Chemists	3	2	0.19
Testers	3	3	0.23 ± 0.17

TABLE 10 Dust concentrations in occupational groups in laboratories (Plants C2/C3, C5/C6).

Occupational Group	Number of Men per Shift	Number of Men Sampled	Mean Respirable Dust Concentration ± Standard Deviation (mg/m^3)
Fitters and instrument technicians	12	3	0.52 ± 0.30

TABLE 11 Dust concentrations in the occupational group at the central workshops.

Occupational Group	Number of Men per Shift	Number of Men Sampled	Mean Respirable Dust Concentration ± Standard Deviation (mg/m^3)
Mixer operators	3	3	0.35 ± 0.05
Packers	2	1	0.47

TABLE 12 Dust concentrations in occupational groups in Plant A (not PVC)

Occupational Group	Mean Dust Concentration (mg/m^3)
C4 packers	2.88
C4 driers	2.59
W1 mixing operators	1.86
W1 premix team	1.41
C4 cleaner	1.19
W2 premix team	1.04
C4 drier foreman	0.94
C4 fork truck driver	0.94
W2 dry blend units	0.86
C4 maintenance	0.84
C2/C3 fork truck driver	0.70
W1 foreman, cleaner	0.69
C4 recovery operator	0.65
W2 supervisor	0.61
C2/C3 packers	0.60
C2/C3 driers	0.54
Central workshops	0.52
C4 autoclaves	0.46
C5/C6 driers	0.50
Plant A (non-PVC) packers	0.47
C5/C6 packers	0.38
W2 ground floor teams	0.37
Plant A mixer operators (non-PVC)	0.35
Semi-technical laboratory	0.34
Plant D (all groups)	0.27
W2 cleaner	0.28
C5/C6 fork truck driver	0.29
All C plants shift laboratory (testers)	0.23
All C plants shift laboratory (chemists)	0.19
C2/C3 autoclaves	0.23

TABLE 13 Occupational groups in order of dust concentrations.

Plant	Location	Dust Concentration (mg/m^3)
C4	Driers	0.19
	Packing	0.22
	Packing	0.15
C2/C3	Packing	0.15
	Packing	0.11
C5/C6	Packing	0.13
	Packing	0.16
W1	Premix Unit	0.29
	Mixer Unit	0.06

TABLE 14 Mean dust concentrations measured using static samplers in selected areas in Plants C1 to 6 and W1.

	Current Men	Pensioners	Leavers
Number	663	98	57
Mean age (years)	44.2	63.4	43.2
Mean height (cm)	173.0	170.2	171.2
Mean weight (Kg)	77.7	75.6	77.4
Mean dust index*	13.39	14.23	4.86
Years at the plant	14.34	16.63	5.46
Mean FEV_1 (litres)	3.54	2.43	3.53
Mean FVC (litres)	4.62	3.41	4.54
Mean FEV_1/FVC	0.76	0.70	0.78

TABLE 15 Features of 818 men studied, according to currently employed, pensioner or other leaver status.

*Dust index is expressed in years x mg/m^3, but does not represent actual dust exposure, since only current dust levels are known.

	Age Groups (yrs)						
	< 35	35-44	45-49	50-54	55-59	60 +	Total
Current men							
Non-smokers	48	35	11	14	5	6	119
Cigarette smokers	59	88	54	55	44	12	312
'Other' smokers	3	10	12	7	11	4	47
Ex-smokers	32	42	34	37	25	15	185
Total	142	175	111	113	85	37	663
Pensioners							
Non-smokers	0	0	0	0	0	13	13
Cigarette smokers	1	0	2	3	7	28	41
'Other' smokers	0	0	0	1	0	7	8
Ex-smokers	0	1	0	3	5	27	36
Total	1	1	2	7	12	75	98
Leavers							
Non-smokers	2	6	5	2	0	1	16
Cigarette smokers	5	9	4	2	4	1	25
'Other' smokers	0	1	0	1	1	0	3
Ex-smokers	5	5	1	1	1	0	13
Total	12	21	10	6	6	2	57

TABLE 16 Numbers of current men, pensioners and leavers by age group and smoking category.

	Age groups (yrs)						
	< 35	35-44	45-49	50-54	55-59	60 +	All
Non-smokers	50 (4.07)	41 (6.71)	16 (8.19)	16 (12.3)	5 (15.[illegible])	20 (15.2)	148 (8.02)
Cigarette smokers	65 (5.23)	97 (12.0)	60 (16.4)	60 (16.6)	55 (18.[illegible])	41 (16.9)	378 (13.7)
Other smokers	3 (3.05)	11 (14.7)	12 (13.8)	9 (19.4)	12 (19.[illegible])	11 (11.7)	58 (15.0)
Ex-smokers	37 (6.63)	48 (12.9)	35 (14.5)	41 (16.5)	31 (16.[illegible])	42 (18.1)	234 (14.2)
All	155 (5.15)	197 (11.3)	123 (14.5)	126 (16.2)	103 (17.[illegible])	114 (16.5)	818 (12.9)

TABLE 17 Numbers of men and (mean dust indices) of 818 men grouped by age and smoking category. (Units of dust indices are years x mg/m^3).

	All men	Non-smokers	Cigarette Smokers	Other Smokers	Ex-smokers	χ^2 3 d.f.	P value*
No. of men	818	148	378	58	234		
Chronic cough (disregarding sputum)	152 (18.6%)	5 (3.4%)	111 (29.4%)	16 (27.6%)	20 (8.5%)	57.27	<< .001
Sputum (disregarding cough)	134 (16.4%)	7 (4.7%)	88 (23.3%)	15 (25.9%)	24 (10.2%)	31.80	<< .001
Chronic cough and/or sputum	192 (23.5%)	10 (6.8%)	134 (34.4%)	18 (31.0%)	30 (12.1%)	53.46	<< .001

TABLE 18 Number of men (prevalence) with chronic cough and/or sputum among 818 men grouped by smoking category.

* Significance of difference between smoking categories.

Variables	Units	Mean	Regression Coefficient	t	P
Age	Years	46.4	- 0.0350	- 15.31	< 0.001
Height	cm	172.5	0.0424	11.04	< 0.001
Weight	kg	77.4	- 0.0022	- 0.99	N.S.
Dust index	Years x mg/m^3	12.9	- 0.0040	- 2.27	< 0.05
Lifetime cigarette consumption	1,000 packs	7.42	- 0.0169	- 5.28	< 0.001
			Constants (Intercepts)		
Constant for current men and leavers (non-smokers)			- 1.8845		
Constant for pensioners (non-smokers)			- 2.1527		
Effect on intercept of:					
Cigarette smoking			- 0.0757	- 1.16	N.S.
Other smoking			- 0.0949	- 1.02	N.S.
Ex-smoking			0.0973	1.44	N.S.

TABLE 19 Multiple regression of FEV_1 with age, height, weight, dust index and lifetime cigarette consumption. Different intercepts allowed for smoking categories and pensioners.

All smoking categories	Regression with dust index - 0.0040	t value - 2.27	P < 0.025
Cigarette smokers	- 0.0069	- 2.82	< 0.005
Other smokers	- 0.0033	- 0.62	NS
Ex-smokers	- 0.0016	- 0.53	NS
Non-smokers	0.0025	0.48	NS

TABLE 20 Further expansion of the model for regression of FEV_1 shown in Table 19. Different slopes for the regression with dust index have been allowed in the model, which still includes age, height, weight and lifetime cigarette consumption, and different intercepts for pensioners and smoking categories.

Variables	Units	Regression Coefficient	t	P
Age	Years	- 0.0324	- 13.14	< 0.001
Height	cm	0.0634	15.35	< 0.001
Weight	kg	- 0.0089	- 3.70	< 0.001
Dust index (current men)	years x mg/m^3	- 0.0047	- 2.27	< 0.05
Dust index (pensioners)	" "	0.0011	0.20	N.S.
Dust index (leavers)	" "	0.0085	0.68	N.S.
Iifetime cigarette consumption	1,000 packs	- 0.0136	- 3.97	< 0.001
		Constants (Intercepts)		
Constant for current men (non-smokers)		- 4.0818		
Constant for pensioners (non-smokers)		- 4.5541		
Constant for leavers (non-smokers)		- 4.2108		
Effect on intercept of:				
Cigarette smoking		- 0.0017	- 0.02	N.S.
Other smoking		0.0176	0.18	N.S.
Ex-smoking		0.1036	1.43	N.S.

TABLE 21 Multiple regression of FVC allowing for different intercepts and slopes for employment categories.

Variables	Units	Mean	Regression Coefficient	t	P
Age	Years	46.4	- 0.0032	- 7.68	< 0.001
Height	cm	172.5	- 0.0022	- 3.07	< 0.01
Weight	kg	77.4	0.0019	4.62	< 0.001
Dust index	Years x mg/m^3	12.9	- 0.0003	- 0.83	N.S.
Lifetime cigarette consumption	1,000 packs	7.42	- 0.0017	- 2.83	< 0.01
			Constants (Intercepts)		
Constant for current men and leavers (non-smokers)			0.1323		
Constant for pensioners (non-smokers)			0.1220		
Effect on intercept of:					
Cigarette smoking			- 0.0121	- 1.00	N.S.
Other smoking			- 0.0277	- 1.61	N.S.
Ex-smoking			- 0.0001	- 0.00	N.S.
Chronic cough or sputum			- 0.0607	- 6.08	< 0.001
Recent exacerbation of cough and phlegm			- 0.0030	- 0.29	N.S.
Recent chest illness			- 0.0169	- 1.83	< 0.1

TABLE 22 Regression of $\log\left\{\frac{FEV_1}{FVC}\right\}$ with explanatory and associated variables.

Variables	Units	Mean	Regression Coefficient	t	P
Age	Years	46.4	- 0.2146	- 8.00	< 0.001
Height	cm	172.5	0.0831	1.84	< 0.1
Weight	kg	77.4	0.1485	5.35	< 0.001
Dust index	Years x mg/m^3	12.9	0.0121	0.61	N.S.
Lifetime cigarette consumption	1,000 packs	7.42	- 0.0717	- 2.21	< 0.05
			Constants (Intercepts)		
Constant for current men and leavers (non-smokers)			15.4156		
Constant for pensioners (non-smokers)			12.5996		
Effect on intercept of:					
Cigarette smoking			- 3.7445	- 4.97	< 0.001
Other smoking			- 2.9082	- 2.58	< 0.01
Ex-smoking			- 1.1565	- 1.16	N.S.

TABLE 23 Regression for TL_{CO} (ml/min. mm Hg) allowing different intercepts for employment and smoking categories.

Reader	Small rounded opacities		Small irregular opacities		Both rounded and irregular opacities
	Category 0/1 or more	Category 1/0 or more	Category 0/1 or more	Category 1/0 or more	Category 0/1 or more
03	18 (2.20%)	2 (0.24%)	32 (3.91%)	7 (0.86%)	4 (0.49%)
15	4 (0.49%)	2 (0.24%)	53 (6.48%)	46 (5.62%)	0 (0.00%)
17	50 (6.11%)	10 (1.22%)	29 (3.55%)	8 (0.98%)	4 (0.49%)

TABLE 24 Prevalences of categories of small opacities found by three readers in 818 chest radiographs.

(Radiographs in which both rounded and irregular opacities were found are also represented here in the rounded and irregular categories.)

		Reader 15 Absent	Reader 15 Present	Total
Reader 03	Absent	796	4	800
	Present	18	0	18
	Total	814	4	818

		Reader 17 Absent	Reader 17 Present	Total
Reader 03	Absent	759	41	800
	Present	9	9	18
	Total	768	50	818

		Reader 17 Absent	Reader 17 Present	Total
Reader 15	Absent	766	48	814
	Present	2	2	4
	Total	768	50	818

TABLE 25 Agreement between readers for presence of small rounded opacities category 0/1 or more.

		Reader 15 Absent	Reader 15 Present	Total
Reader 03	Absent	748	38	786
	Present	17	15	32
	Total	765	53	818

		Reader 17 Absent	Reader 17 Present	Total
Reader 03	Absent	763	23	786
	Present	26	6	32
	Total	789	29	818

		Reader 17 Absent	Reader 17 Present	Total
Reader 15	Absent	745	20	765
	Present	44	9	53
	Total	789	29	818

TABLE 26 Agreement between readers for presence of small irregular opacities category 0/1 or more.

		DUST INDEX RANGES (years x mg/m³)							All Men
		0.0 - 1.5	1.5 - 4.5	4.5 - 7.5	7.5 - 12.0	12.0 - 18.0	18.0 - 30.0	30.0 +	
Age (yrs) < 44	% with 0/1+	0.00	1.45	2.94	5.66	0.00	2.56	20.00	2.56
	(number)	(0)	(1)	(2)	(3)	(0)	(1)	(2)	(9)
	Total	73	69	68	53	41	39	10	352
45 - 49	% with 0/1+	0.00	7.69	0.00	10.34	0.00	12.50	15.79	7.32
	(number)	(0)	(1)	(0)	(3)	(0)	(2)	(3)	(9)
	Total	12	13	18	29	16	16	19	123
50 - 54	% with 0/1+	0.00	7.14	7.41	9.09	0.00	4.17	10.00	6.35
	(number)	(0)	(1)	(2)	(2)	(0)	(1)	(2)	(8)
	Total	4	14	27	22	15	24	20	126
55 - 59	% with 0/1+	0.00	10.00	18.18	10.53	7.14	10.34	14.29	10.68
	(number)	(0)	(1)	(2)	(2)	(1)	(3)	(2)	(11)
	Total	6	10	11	19	14	29	14	103
60+	% with 0/1+	0.00	9.09	12.50	10.53	10.7[illegible]	11.11	23.53	11.40
	(number)	(0)	(1)	(1)	(2)	(3)	(2)	(4)	(13)
	Total	13	11	8	19	28	18	17	114
All Men	% with 0/1+	0.00	4.27	5.30	8.45	3.51	7.14	16.25	6.11
	(number)	(0)	(5)	(7)	(12)	(4)	(9)	(13)	(50)
	Total	107	117	132	142	114	126	80	818

TABLE 27 Reader 17: prevalence of small rounded opacities category 0/1 or more by age and dust index ranges.

Reader	Small rounded opacities		Small irregular opacities		Both rounded and irregular opacities
	Category 0/1 or more	Category 1/0 or more	Category 0/1 or more	Category 1/0 or more	Category 0/1 or more
03	6 (3.3%)	2 (1.1%)	11 (6.1%)	4 (2.2%)	2 (1.1%)
15	2 (1.1%)	1 (0.6%)	10 (5.5%)	8 (4.4%)	1 (0.6%)
17	9 (5.0%)	2 (1.1%)	5 (2.8%)	3 (1.7%)	0 (0.0%)

TABLE 28 Prevalence of categories of small opacities found by 3 readers in chest radiographs of 181 men not included in the analysis.

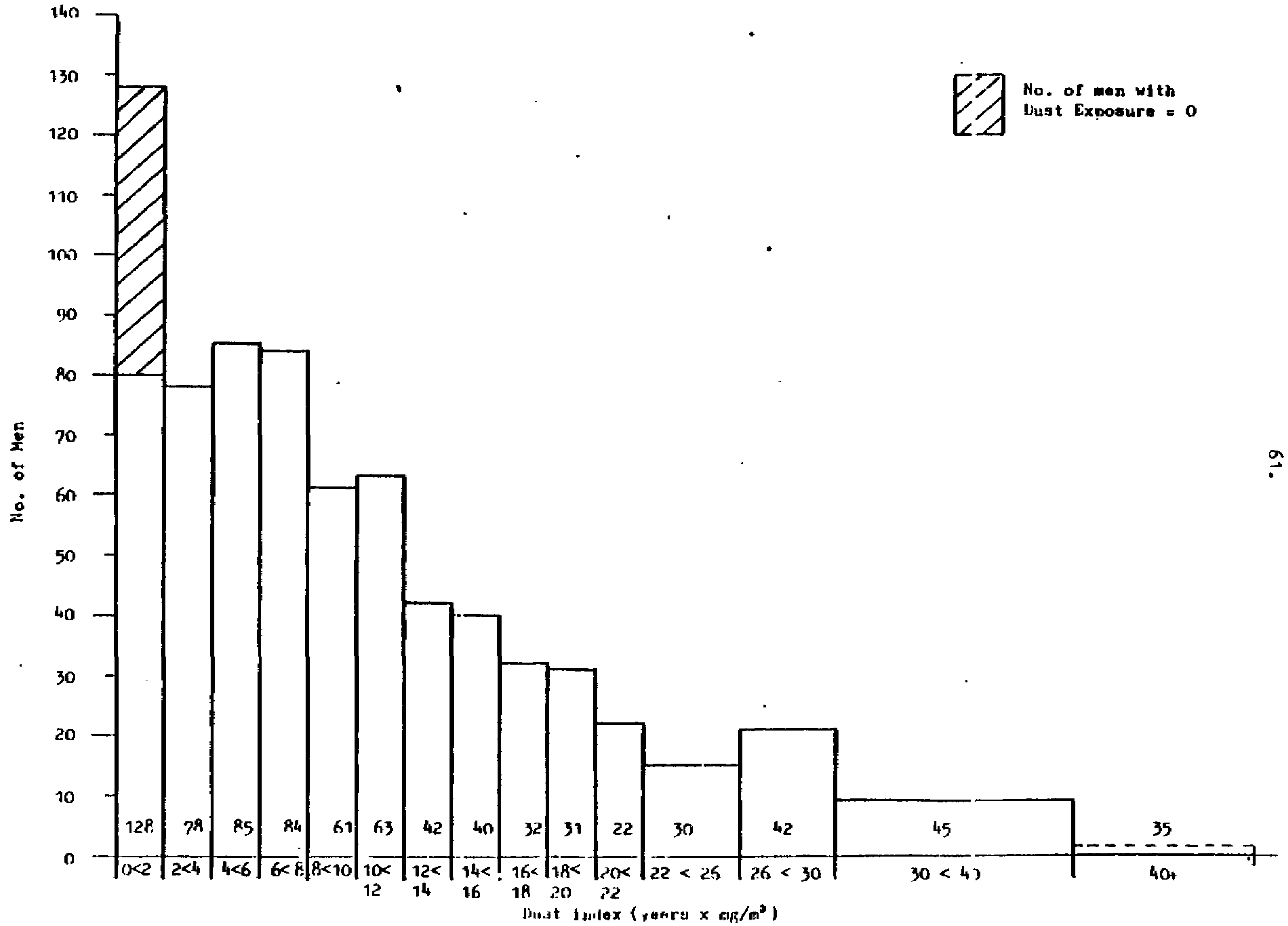

FIGURE 1 Frequency of dust indices.

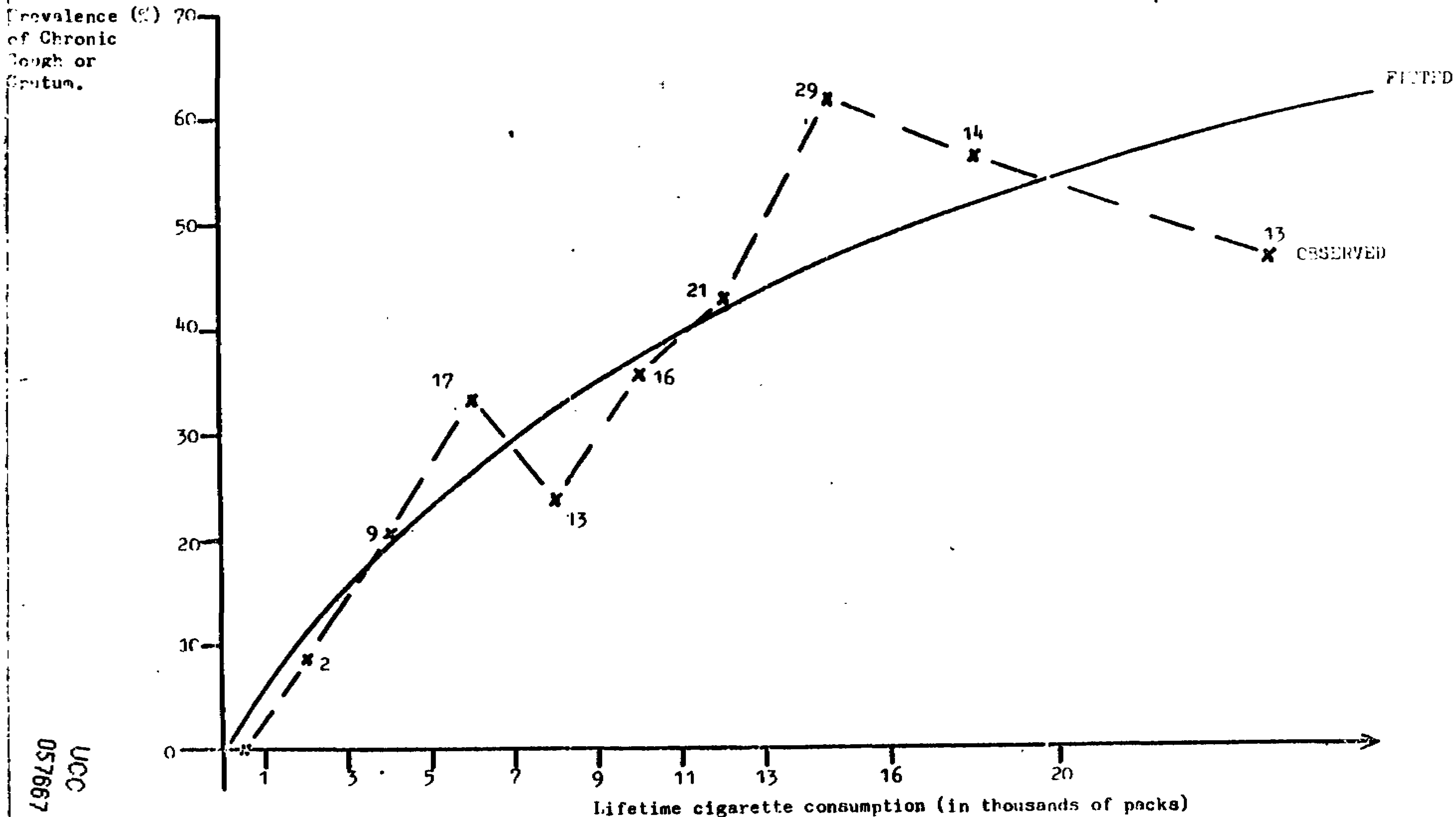

FIGURE 2 Observed and fitted prevalence of chronic cough or sputum among 378 cigarette smokers, related to lif time cigarette consumption.

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Age ranges	< 35	35 - 44	45 - 49	50 - 54	55 - 59	60+	No. of Men
	50	41	16	16	5	20	Non-smokers
	65	97	60	60	55	41	Cigarette smokers
	3	11	12	9	12	11	Other smokers
	37	48	35	41	31	42	Ex-smokers

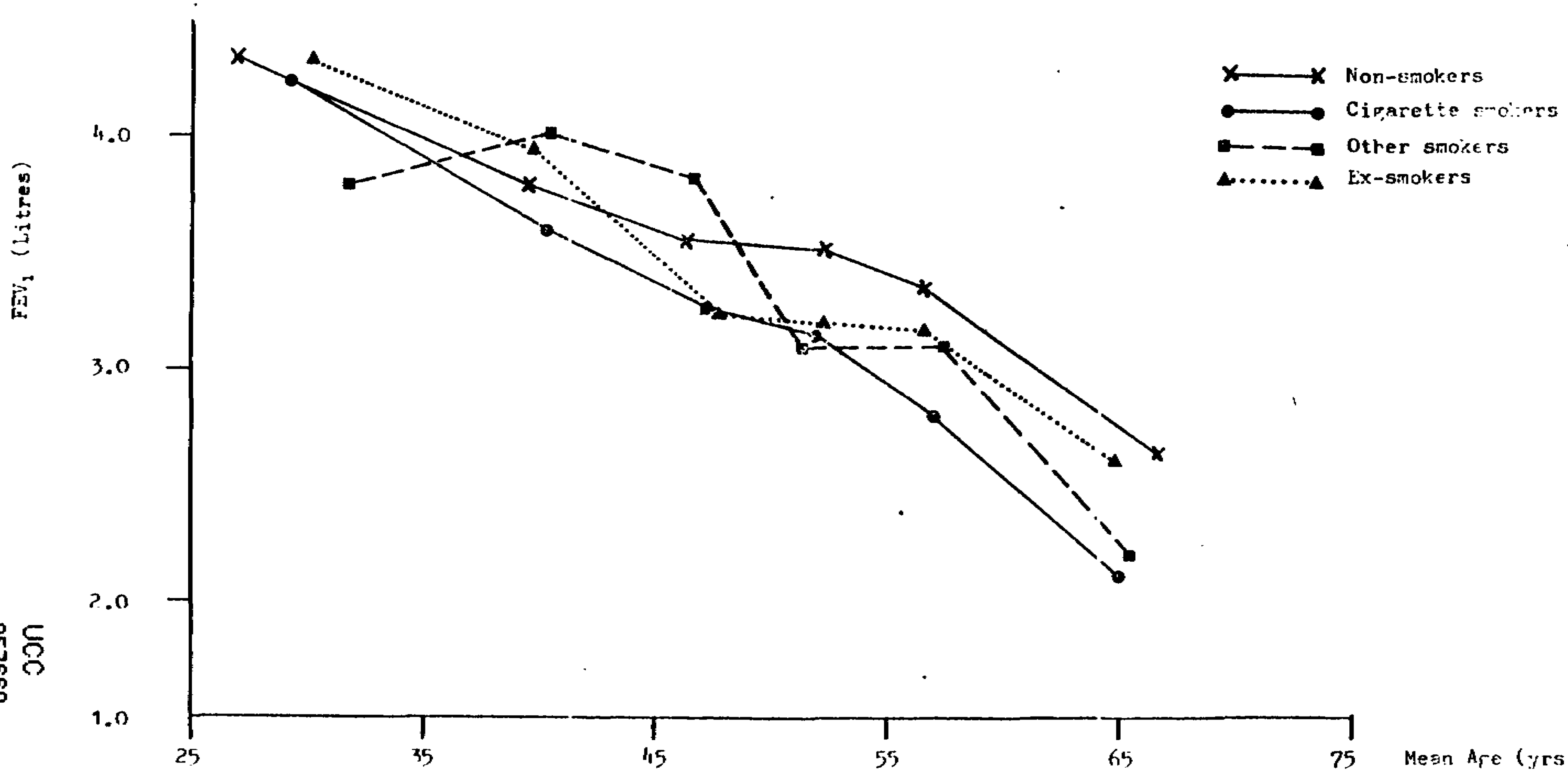

FIGURE 3 Relationship of FEV_1 with age - crude data.

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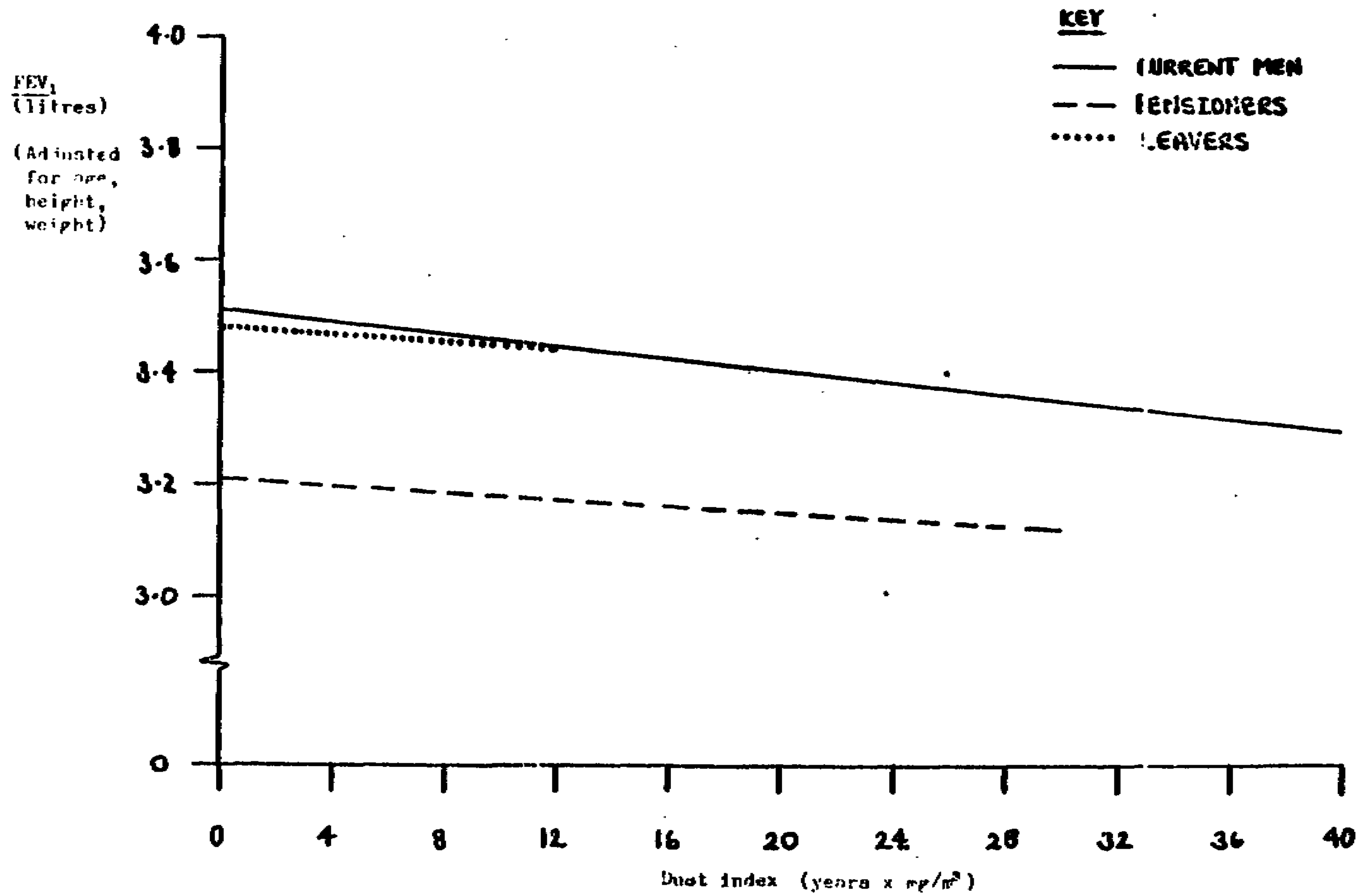

FIGURE 4 Regression of FEV_1 with dust index (FEV_1 adjusted for age, height and weight).

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No. of Men							
Age ranges	< 35	35 - 44	45 - 49	50 - 54	55 - 59	60+	
	50	41	16	16	5	20	Non-smokers
	65	97	60	60	55	41	Cigarette smokers
	3	11	12	9	12	11	Other smokers
	37	48	35	41	31	42	Ex-smokers

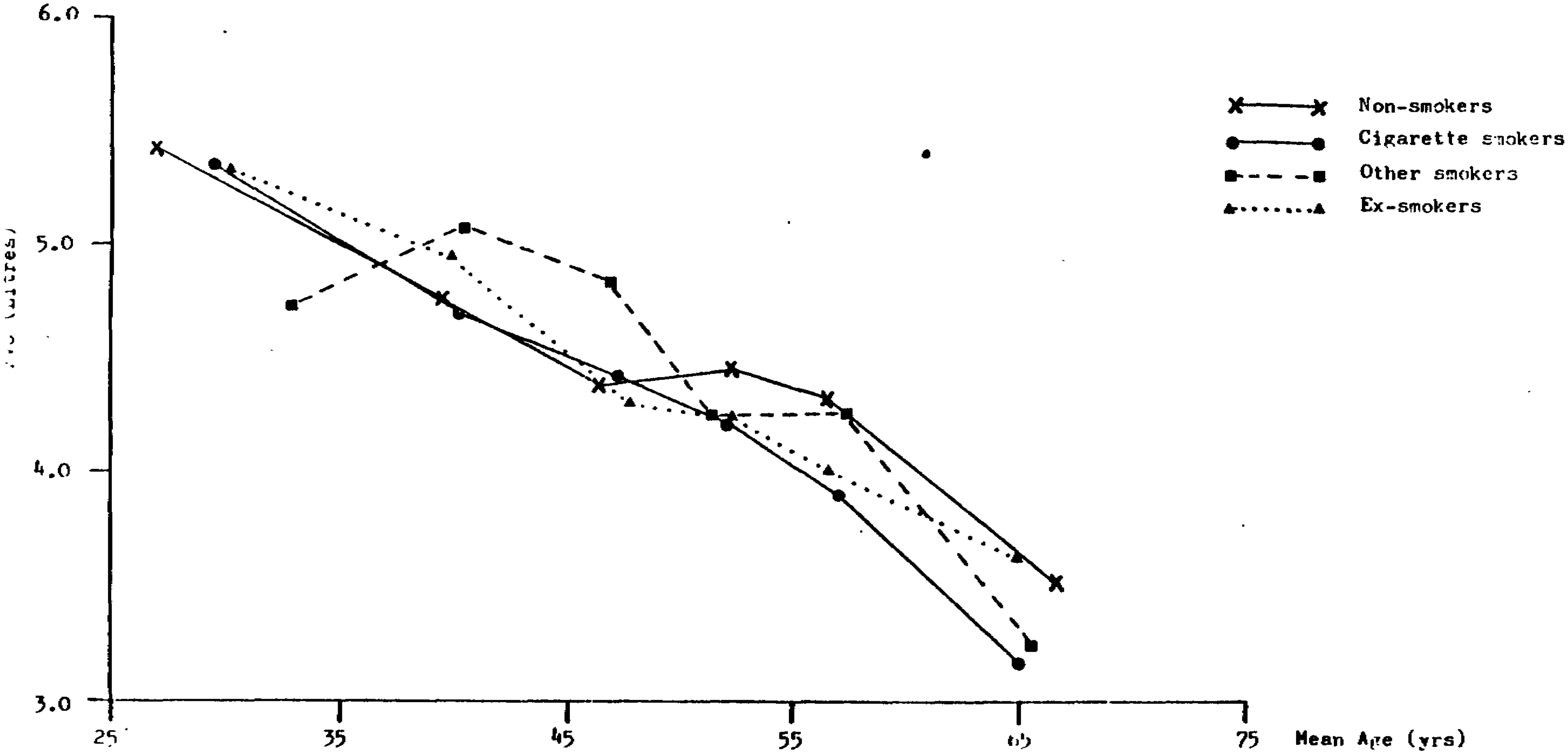


FIGURE 5 Relationship of FVC with age - crude data.

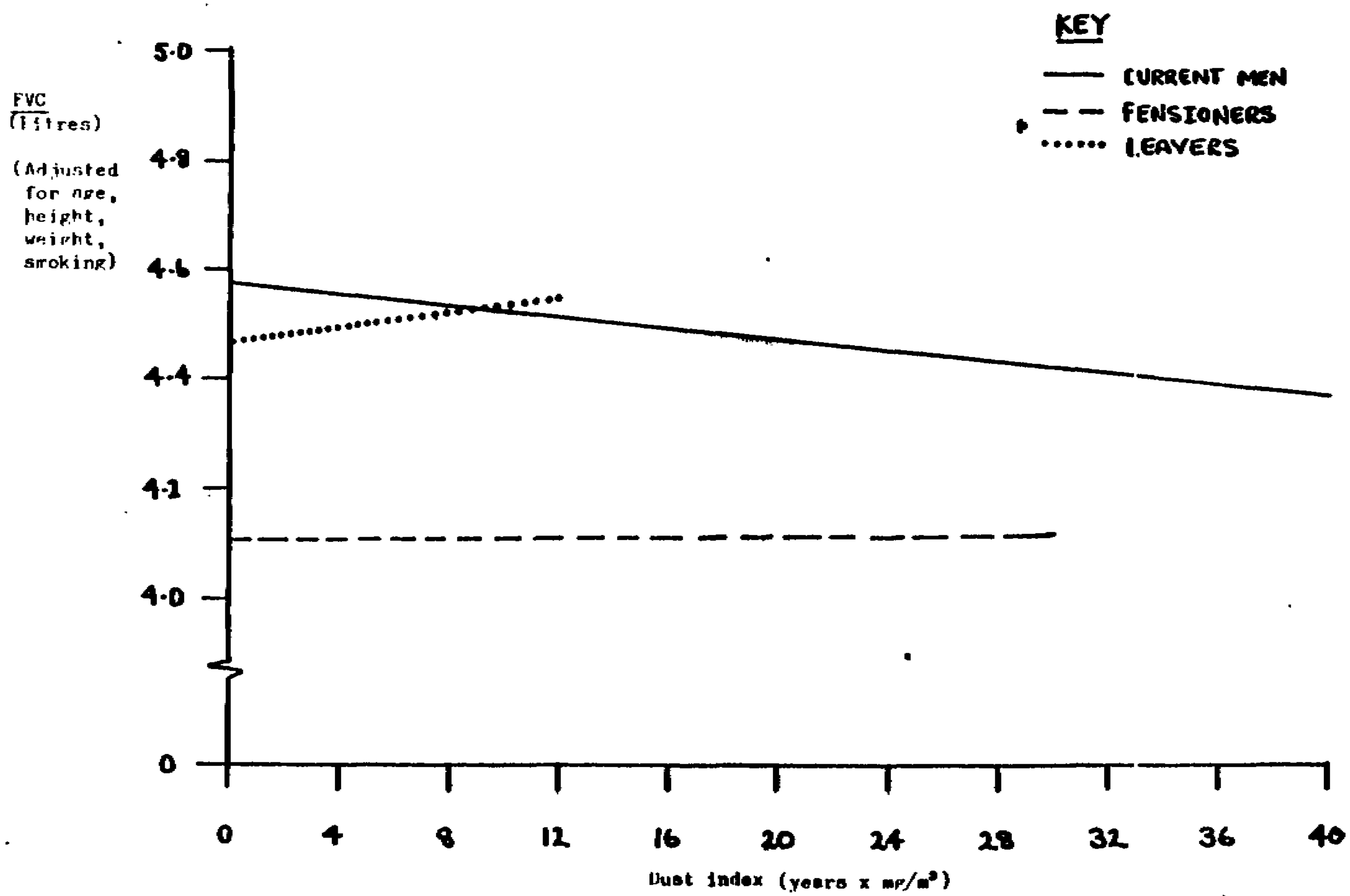
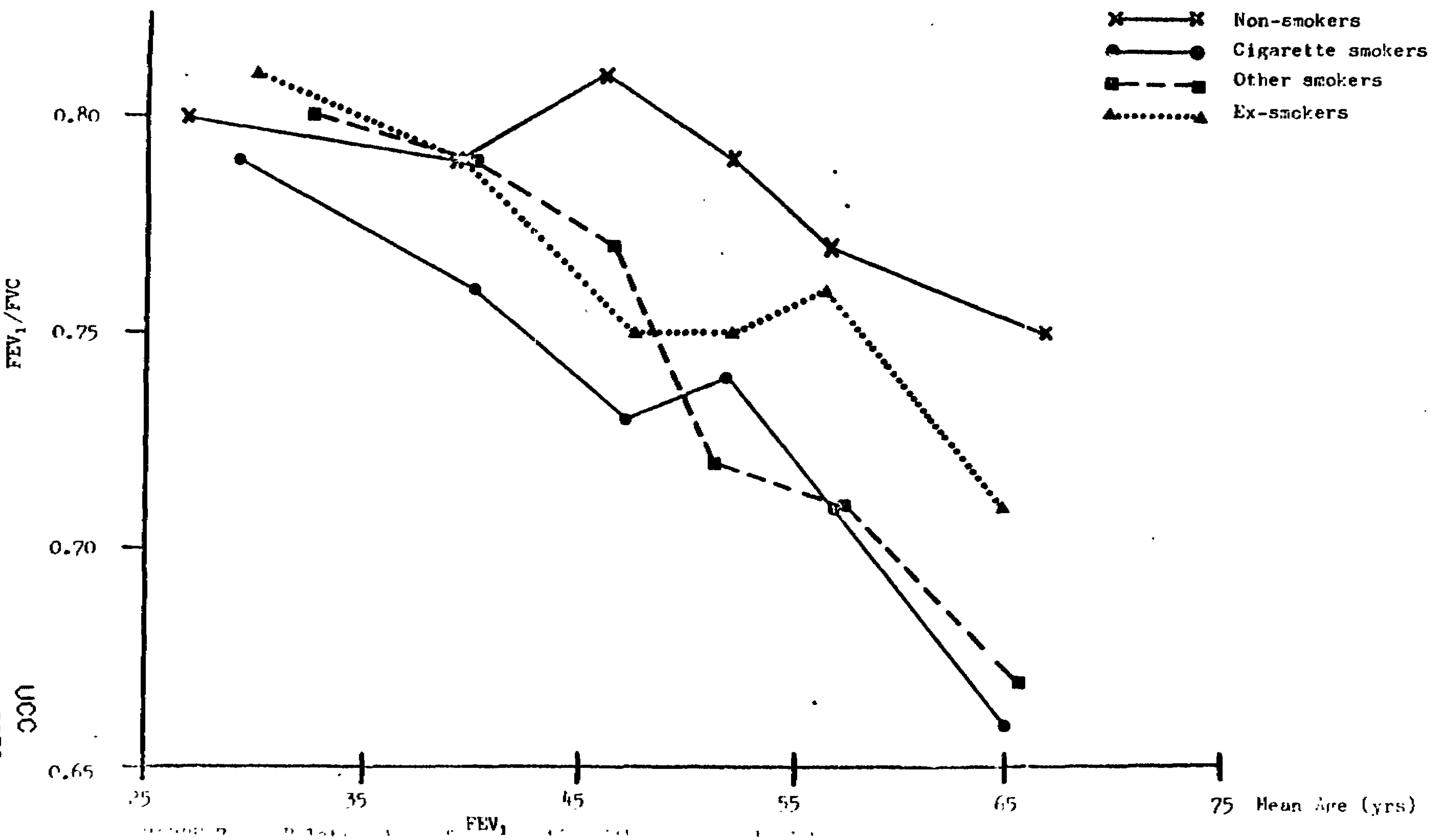


FIGURE 6 Regression of FVC with dust index (FVC adjusted for age, height and weight).

	< 35	35 - 44	45 - 49	50 - 54	55 - 59	60+	
No. of Men	50	41	16	16	5	20	Non-smokers
	65	97	60	60	55	41	Cigarette smokers
	3	11	12	9	12	11	Other smokers
	37	48	35	41	31	42	Ex-smokers

Age ranges



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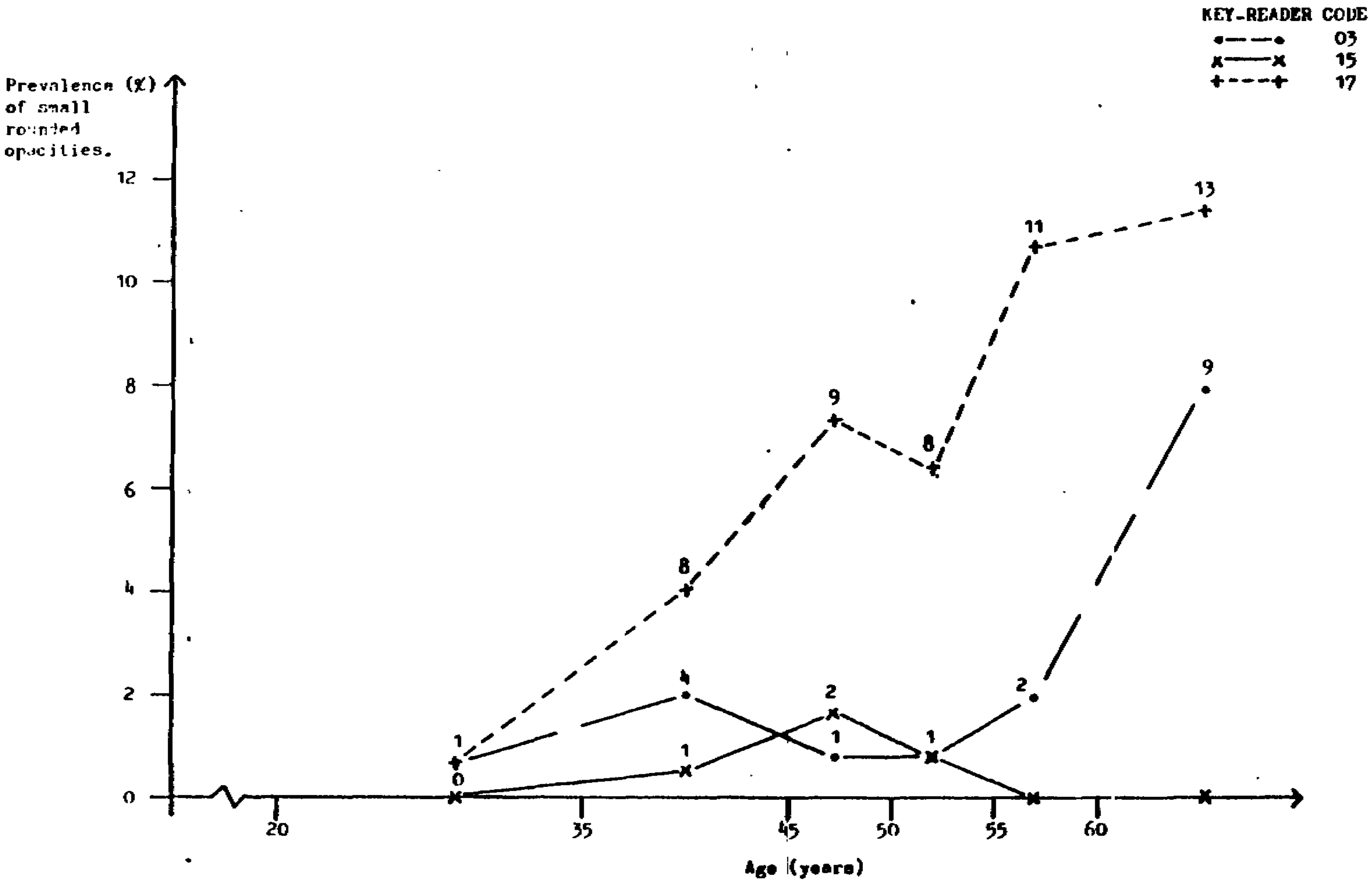

FIGURE 8 Prevalence of small rounded opacities category 0/1 or more, found by three readers, related to age group. Numbers of men are given on the graphs.

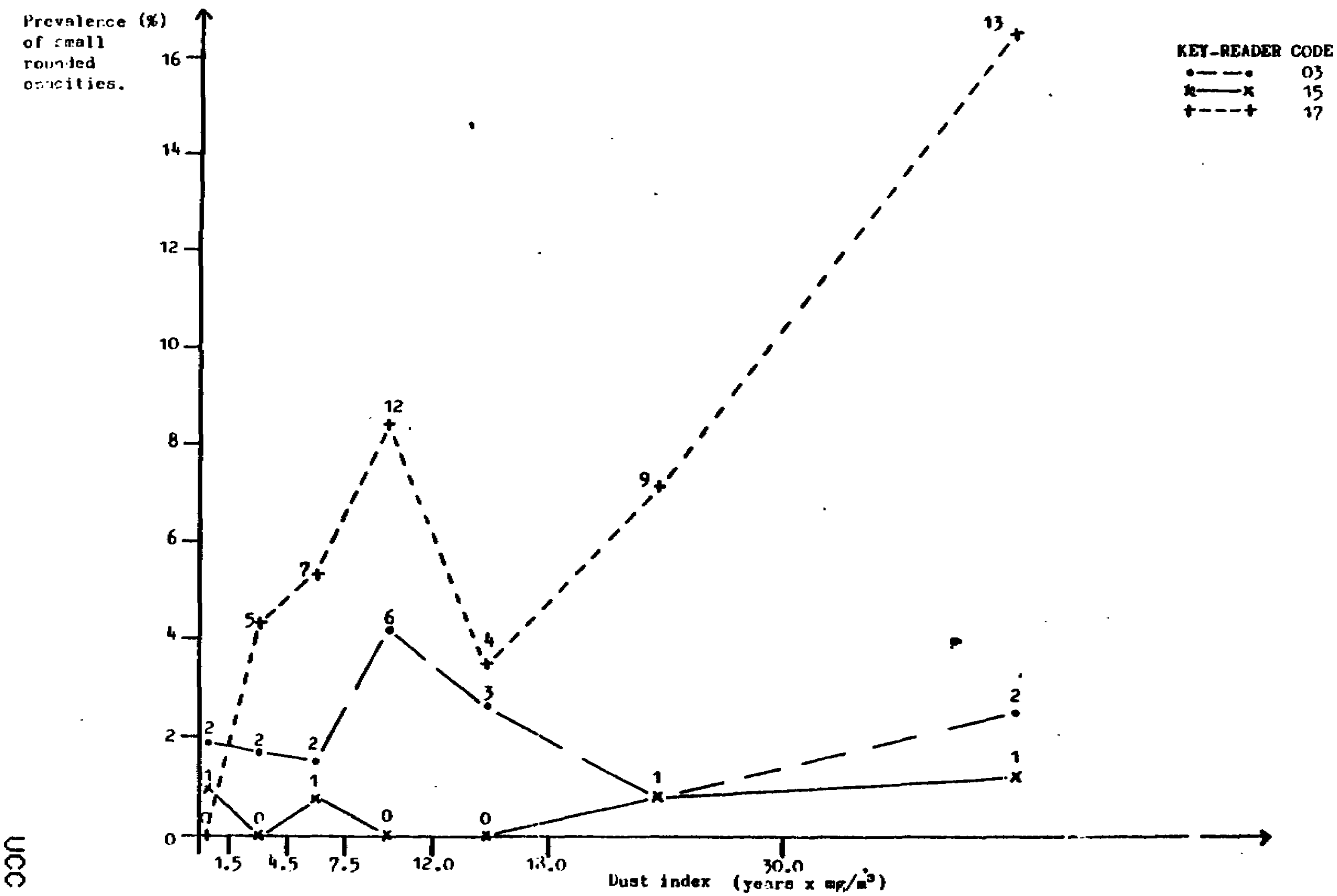

FIGURE 9 Prevalence of small rounded opacities category 0/1 or more, found by three readers, related to dust index.

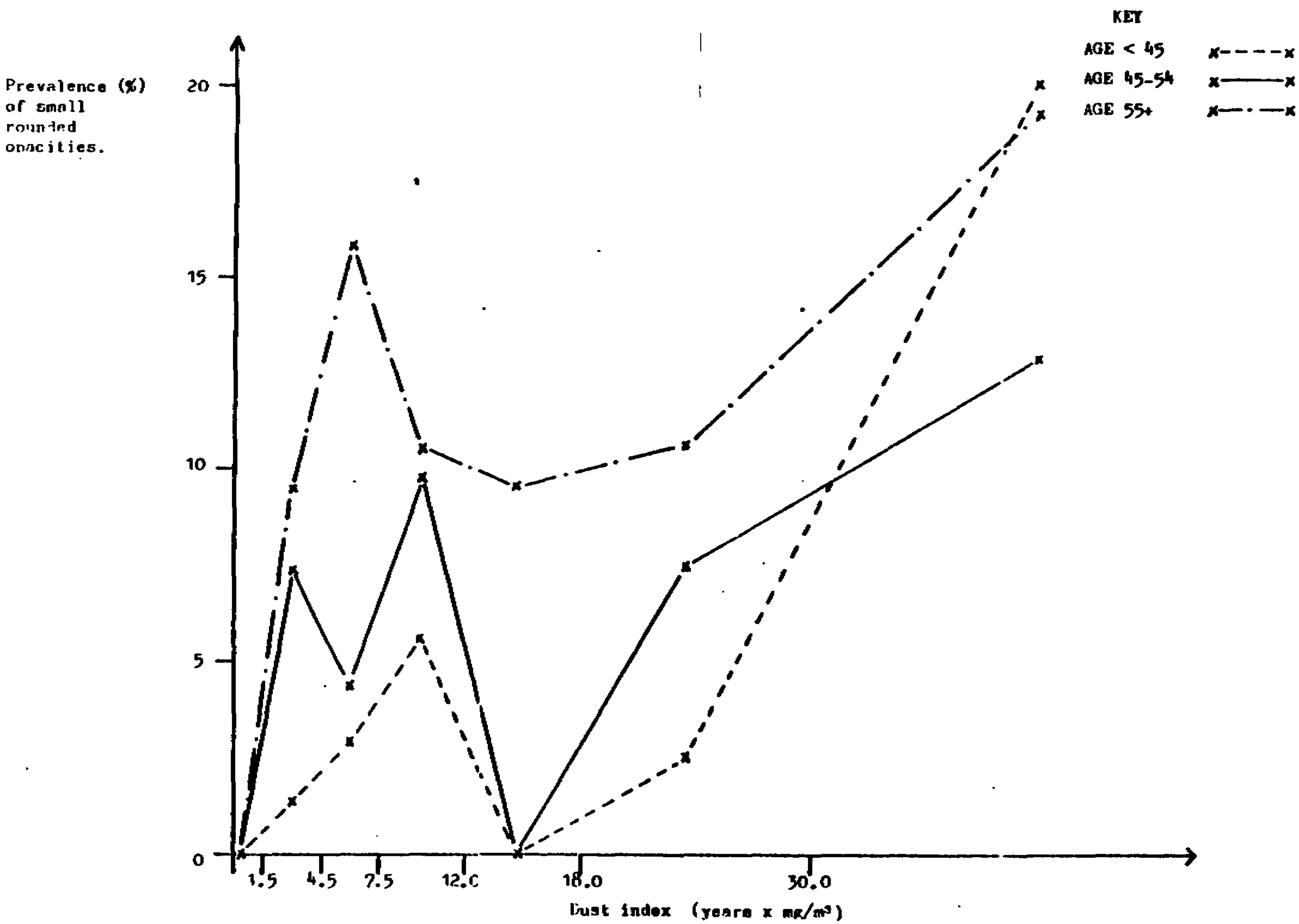

FIGURE 10 Prevalence of small rounded opacities category 0/1 or more, by age group, reader 17, related to PVC dust index. (See Table 26 for numbers of men.)

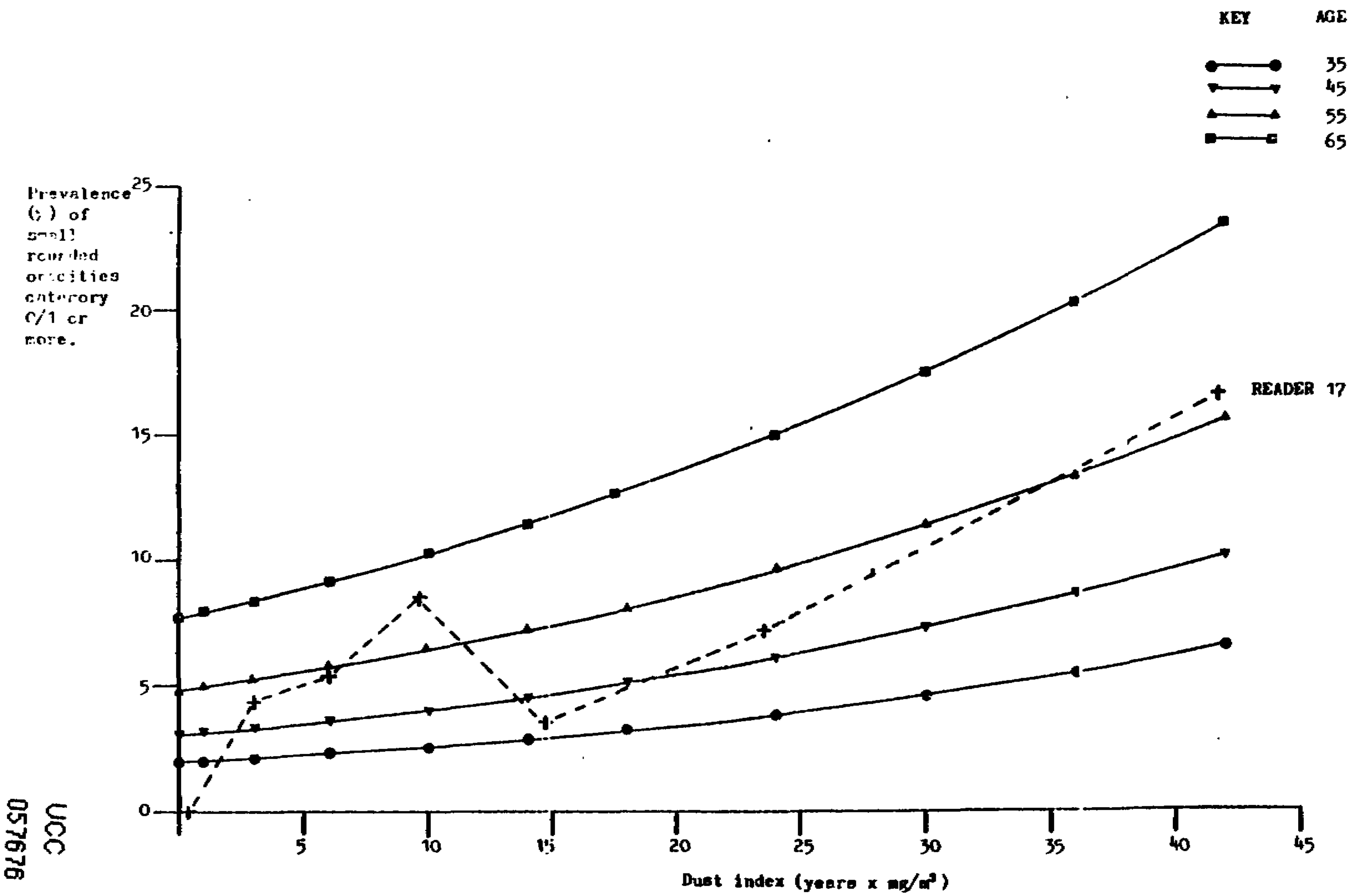

FIGURE 11 Reader 17: observed prevalence of small rounded opacities, category 0/· or more; and, for each of four age groups, predicted prevalence; related to index of dus exposure.

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71.

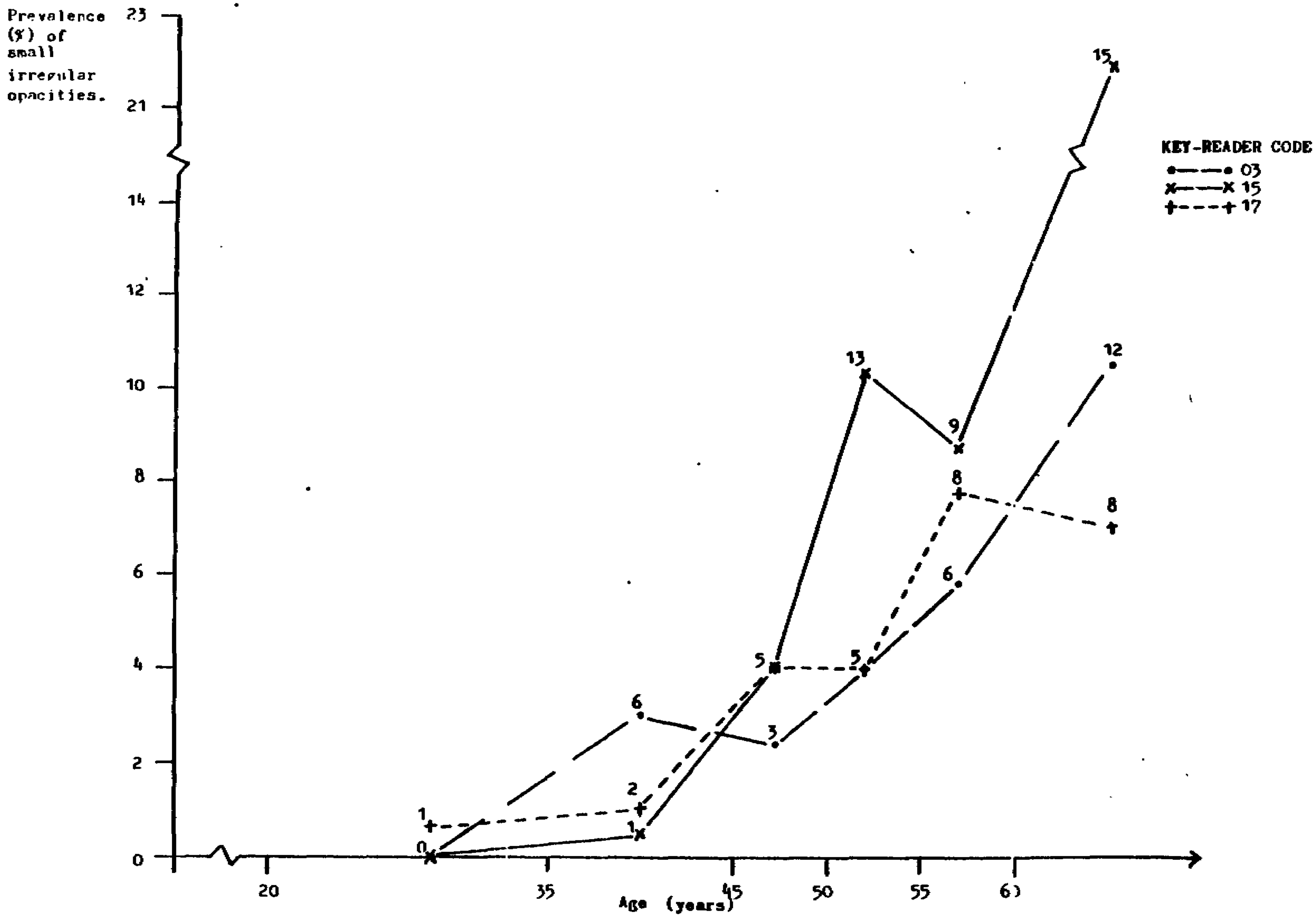

FIGURE 12 Prevalence of small irregular opacities category 0/1 or more, found by three readers, related to age.

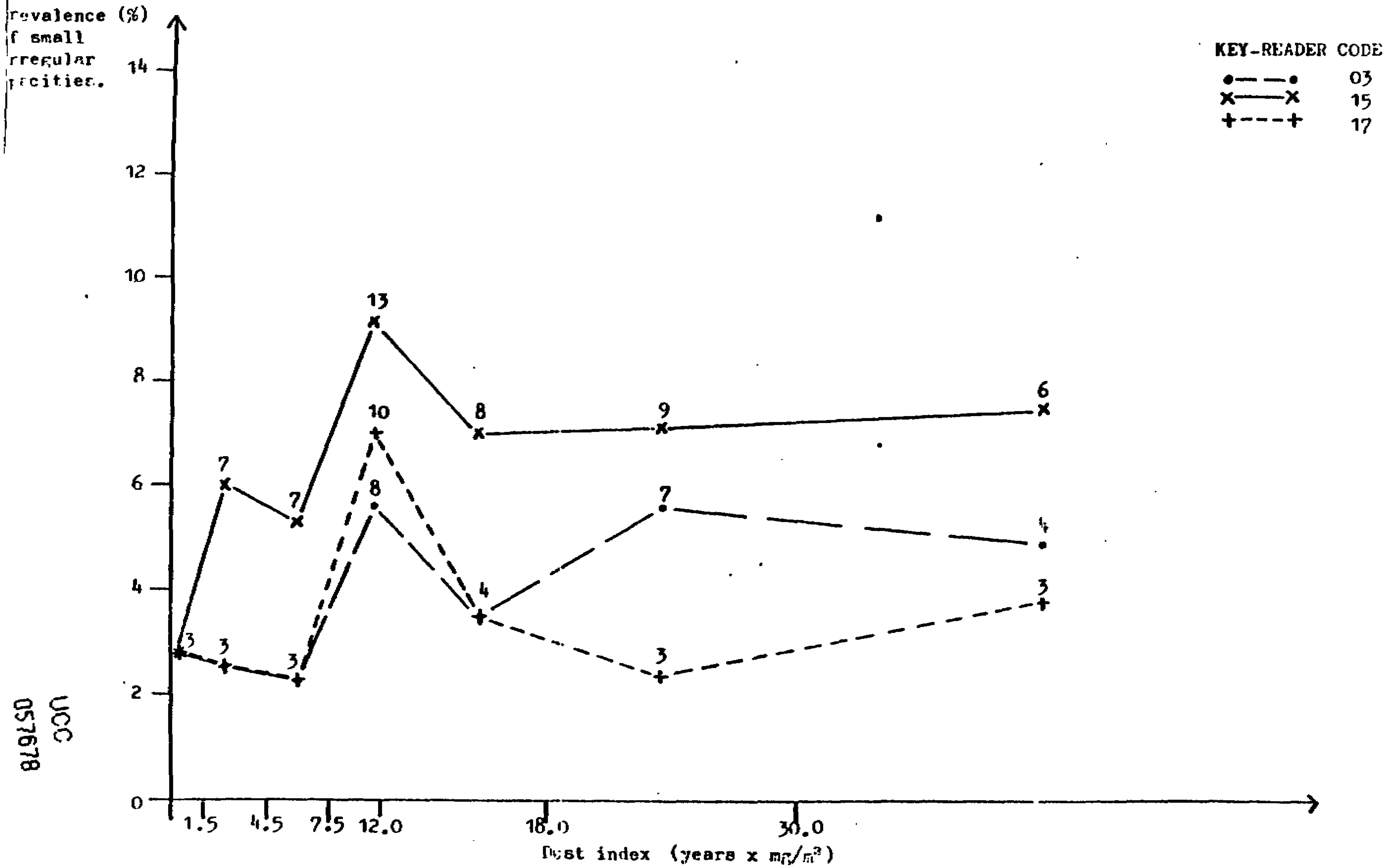

FIGURE 13 Prevalence of small irregular opacities category 0/1 or more, by three readers, related to dust index.

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PVC dust concentrations allotted to occupations on the basis of measured dust concentrations for 130 men.

Plant	Occupation	Concentration
C1/4, C1, C4	Laboratory	0.21
C2/3, C2, C3	"	"
C5/6, C5, C6	"	"
C1/4, C1, C4	Work Study/Quality Control	"
C2/3, C2, C3	"	"
C5/6, C5, C6	"	"
C2/3, C2, C3	Tester	"
C unspecified	"	"
C1/4, C1, C4	"	"
C5/6, C5, C6, C	Instrument Technician	"
C unspecified	Process - Work Study/Quality Control	1.41
C1/4, C1, C4	General	0.98
C1/4, C1, C4	Process - Mixing	"
C1/4, C1, C4	Process - Milling	"
C1/4, C1, C4	Investigation	"
C1/4, C1, C4	Estimator	"
C1/4, C1, C4	Foreman	0.94
C1/4, C1, C4	Superintendent	"
C1/4, C1, C4	Chargehand	"
C1/4, C1, C4	Fork Lift, Driver, Distribution	0.89
C1/4, C1, C4	Maintenance/Engineers	0.84
C unspecified	Trainee, Investigation	0.82
C2/3, C2, C3	Fork Lift, Driver, Loader	0.70
C unspecified	Fork Lift, Driver, Distribution	0.69
C2/3, C2, C3	Process - Packing	0.60
C2/3, C2, C3	Foreman	0.58
C2/3, C2, C3	Superintendent	0.58
C2/3, C2, C3	Chargehand	0.58
C2/3, C2, C3	General	0.58
C2/3, C2, C3	Process - Washing	0.58
C2/3, C2, C3	Process - Drying	0.54
C unspecified	Foreman	0.51
C1/4, C1, C4	Process - Autoclaving	0.50
C1/4, C1, C4	Process - Recovery	0.50
C1/4, C1, C4	Process - Reaction	0.50

Plant	Occupation	Concentration
All Plants	All Workers	0.24
All Plants (PVC)	"	"
Distribution	"	"
Research	"	"
Yard	"	"
Stores	"	"
Construction	"	"
South Support Group	"	"
Alkathene	Process - Packer, Bagger	0.47
Alkathene	Process - Mixer, Gardner Operator	0.35
Alkathene	Engineer, Inspector, Investigation, Distribution	0.38
Alkathene	Process - Milling, Machine Operator	0.38
Alkathene	Process - Filming, Tubing, Extrusion, Pigments	0.38
Alkathene	Process - Filtering, Steeping Charcoal	0.38
Alkathene	Process - Lead Weighing, Washing	0.38
Alkathene	General, Work Study, Management/ Office	0.24
Alkathene	Fork Lift, Foreman, Chargehand, Supervisor	0.24
W1/2, W	Process - Washing, Lead Weighing, Others	0.59
W1/2, W	Process - General, Relief Operator, Press	0.59
W1/2	Tester, Investigation, Work Study/ Quality Control	0.59
W	Investigation, Storekeeper, Superintendent	0.59
Fluon	All	0.0
Nylon	"	"
Terylene	"	"
Fluon Lab	"	"
Squiresgate	"	"
Welvic 3	"	"
PES	"	"
Polythene	"	"

Plant	Occupation	Concentration
Perspex	All	0.0
LPT	"	"
CL7	"	"
PI (1)	"	"
P2	"	"
Office Staff (outwith plants or at 0.0 plants).	"	"
Restaurant	"	"
Training	"	"