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by

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J Addison, LST Davies, A Robertson, RJ Willey*

SUMMARY

Both natural and industrial asbestos contamination in soil on sites required for development can present health hazards if the soil is to be disturbed. Very little information is available about likely airborne asbestos fibre concentrations which might be encountered in working such a site or on the possible suppressant effects of water spraying during work. This study is aimed at providing some basic relevant information to these problems.

Artificial mixtures were prepared using three different soil types (clay, sand and intermediate) with each of three asbestos types (chrysotile, amosite and crocidolite) in concentrations of 1%, 0.1%, 0.01% and 0.001%, by weight.

Airborne dust clouds were generated over periods of four hours from each mixture using a dust dispenser discharging into a 1.3 m^3 test chamber. Airborne dust concentrations were measured for the full duration of the test using gravimetric dust sampling instruments and a sequence of membrane filter samples were collected for fibre counting by phase contrast optical microscopy. Airborne fibre concentrations were determined for each test as time weighted averages and these were compared to the average respirable dust concentration in the normalised fibre concentration (f ml^{-1}/mg m^{-3}) which allows the airborne fibre concentration to be related to common occupational exposure limits such as that for nuisance dust at 5 mg m^{-3}. Parallel tests were carried out using transient dust clouds generated from each mixture with progressive controlled addition of water. Airborne fibre concentrations measured over fixed time periods after initial dust cloud generation were used to compare the effects of the addition of water to the soils.

The results showed that airborne fibre concentrations could be very high (> 20 f ml^{-1}) and even 0.001% of asbestos in a dry loose mixture was capable of producing airborne respirable asbestos concentrations in excess of the 0.01 f ml^{-1} clearance limit while at the same time the respirable dust concentration remained below the nuisance dust OEL of 5 mg m^{-3}. The major controlling factor on airborne fibre levels was the amount of asbestos in the mixtures, although the nature of the soil and the asbestos type had some influence. For example, loose sandy soils and soils containing amphibole asbestos tended to produce higher fibre concentrations (when disturbed) than clay soils or soils with chrysotile. The addition of water to the soils greatly reduced the airborne fibre concentrations.

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It is recommended that soils containing more than 0.001% asbestos are regarded as being capable of generating airborne fibre concentrations in excess of 0.1 f ml^{-1} and that precautions to protect the workforce by wetting the soil, providing respiratory protection etc., are taken. Spraying with water can provide a very effective suppression of airborne fibre concentrations. Fibre concentrations in excess of 5 fibres ml^{-1} were reduced to levels below 0.01 f ml^{-1} by the addition of 50% water. With soils containing 0.001% asbestos or less such action may not be necessary.

Methods used to assess soil asbestos contents should be of appropriate sensitivity.

1. INTRODUCTION

Asbestos contamination can occur both naturally and as a result of man's activities on sites such as shipbreakers' yards, asbestos factories and waste tips. Depending on circumstances, the asbestos may simply lie on the surface of the soil, it may have been buried in pits or it may be intimately mixed with the soil and present to a considerable depth.

The potential hazards associated with disturbing grossly contaminated soils are obvious but those associated with soil contaminated with trace amounts of asbestos are unknown. Mesotheliomas in Cyprus and Turkey have been attributed to environmental exposure to asbestos or asbestiform minerals present in the soil (Baris *et al*, 1982; McConnochie *et al*, 1987). The extent of the contamination in these situations has not been quantified but it has been shown that other materials contaminated by trace quantities of asbestos can produce relatively high airborne concentrations of asbestos fibres in dust clouds where dust mass concentrations are low e.g. vermiculite and tremolite (Addison and Jones; in preparation).

No fixed safe limit is given by the Department of the Environment regarding the asbestos content of soils before redevelopment can take place. They recommend that if fragments of asbestos are visible on the surface some action is needed, but when only instrumental techniques can detect asbestos, 'careful consideration' is required before deciding whether the site is so contaminated that action is required (Department of Environment, 1985). It is clear that further guidance is necessary. One approach to the problem is to insist that before redevelopment takes place the soil must be free of asbestos. However, even this approach requires further clarification as the clearance of a site using this criterion will depend on the sensitivity of the analytical method used to assess the asbestos content of the soil. The sensitivities of the common techniques currently used range from around 0.0001% to around 1%. As the risks of disturbing asbestos contaminated soils are unknown it would be desirable in many regards to specify the most sensitive technique. Unfortunately, past experience has shown that this approach could lead to great practical difficulties in obtaining site clearance and the real benefits in terms of reducing risks to health are unknown. On the other hand, if the technique is not sufficiently sensitive substantial hazards may not be detected.

There is therefore a clear need for information to assist in establishing levels of asbestos contamination in soils at which action should be taken to reduce risks from exposure to airborne asbestos.

In addition, it is known that airborne fibre concentrations generated during the removal of asbestos insulation can be reduced by factors of up to 1000 by the adoption of proper wetting procedures (Willey and Black, to be published). Although no work has been reported to date on similar effects in soils, the addition of water to asbestos contaminated soils may be an important control mechanism in the suppression of airborne asbestos fibres in working environments.

This report describes preliminary investigations into the relationships between asbestos fibre release from soils and the asbestos type and content, the soil type and the soil moisture content. A series of artificial mixtures of soil and asbestos have been used in the study whose three main aims were to establish:

a) the levels of respirable airborne asbestos fibre and dust concentrations generated during the production of dust clouds from soil contaminated with small amounts of asbestos;

b) the relationship between airborne asbestos fibre concentrations and airborne dust concentrations and how these are affected by changes in the proportions of asbestos in soil, soil type and asbestos type;

c) the effects of soil moisture content on airborne concentrations with a view to establishing effective on-site dust suppression techniques.

The practical implications of the results upon the assessment of sites contaminated with asbestos are considered with respect to possible health hazards.

The research has been carried out jointly by the Institute of Occupational Medicine and Glasgow College of Technology. The Institute was primarily concerned with aims (a) and (b) above and the work on soil moisture content and dust suppression was carried out by Glasgow College of Technology.

2. MATERIALS AND METHODS

2.1 Soils

Three different soil types (sand, clay and intermediate) were identified as representatives of the range of common soils found in Great Britain. Reference was made to different volumes of the 'Memoirs of the Soil Survey of Great Britain' (e.g. Avery 1964; Ragg and Futty, 1967). The well described soil types were collected from locations in East Lothian described by Ragg and Futty (1967).

The sandy soil was collected from the alluvial deposits at Barley Mill (NT 458670) about 11 miles East of Edinburgh and was predominantly fine sand and silt with less than 5% clay (<5 μm) (Alluvium).

The intermediate soil was collected from Merryhatton, 11 miles ENE of Edinburgh (NT 471746) and consisted of about 70% sand and silt with about 25% clay (<5 μm)(Winton Series, Winton Association).

The clay soil was collected from Cauldside, about 20 miles NE of Edinburgh (NT 591794) and was composed of about 40% fine silt and 60% clay (<5 μm)(Cauldside Series, Stirling Association).

At each location the top soil was removed and discarded and about 25 kg of subsoil were collected and coarsely sieved to remove any stones greater than 3 mm diameter. The soils were dried and thoroughly mixed at the University of Edinburgh, Department of Agriculture.

Each soil was screened using phase contrast optical microscopy at 600X magnification. Soils were rejected if asbestiform fibres were detected.

2.2 Asbestos Materials

The asbestos minerals used had previously been supplied by the Central Asbestos Company Ltd., London, as typical production grades of amosite, crocidolite and chrysotile. All were relatively coarse grades of fibres so approximately 50g of each were ground in batches for about 15 seconds before being thoroughly mixed to produce a fibre sample with the consistency of soft asbestos lagging.

2.3 Mixing and Validation of Mixtures

All mixtures of asbestos and soil used in the tests were prepared at IOM.

Four mixtures of asbestos and soil were produced for each asbestos-soil combination with asbestos mass concentrations of 1%, 0.1%, 0.01% and 0.001% making thirty-six mixtures in total.

Two different procedures were used in producing the four asbestos concentrations in homogeneous mixtures.

For the 1.0% and 0.001% mixtures, preweighed amounts of asbestos and soil sufficient to make about 1 kg were mixed thoroughly in ethanol in a food blender for approximately 15 minutes. These were allowed to dry over several days, before final processing using a slow action food processor. Five per cent mixtures were similarly produced.

The 0.1 and 0.01% mixtures were prepared and mixed by diluting aliquots from the 5% mixtures with the required amount of soil. As with the other preparations blenders and food processors were used.

Homogeneity was checked by one of the following two methods. In both instances, aqueous suspensions were prepared using weighed portions of the mixtures and measured aliquots were taken for filtration. For mixtures containing chrysotile, low density deposits were prepared on 0.8 μm pore size membrane filters from five separate aliquots for optical fibre counting by phase contrast optical microscopy (HSE, 1986 A). For amphibole mixtures, higher density deposits (≈ 3.0 mg) were prepared on Nuclepore polycarbonate filters for assessment by X-ray diffraction (XRD). The integrated intensity of the 001 ($10.5^{\circ}2\theta$) diffraction peak was used as a measure of the asbestos content of the mixture. The samples were considered to be homogeneous if XRD peak areas for equivalent soil loadings on filters differed by less than 10%.

Asbestos-soil mixtures of defined moisture content were prepared at GCT. The soils were dried at 50 °C until they were of stable weight then water was added to 2 g sub-samples with moisture content defined as weight of water/weight of soil x 100. 2 g sub-samples of each asbestos/soil mixture were prepared with moisture content ranging from 0% to 50% with a total number of 248 sub-samples.

2.4 IOM Experimental Chambers and Dust Generation

The experimental chambers used were the 1.3 m^3 aluminium and Perspex boxes designed for animal dust inhalation experiments (Beckett, 1975). The chambers were vented to atmosphere through a high efficiency filters. Negative pressure was maintained in the chambers to prevent leakage of fibres to the laboratory during dust generation. A flow of air of between 10 and 40 $l\ min^{-1}$ (depending on soil type) was passed into the chamber after mixing with dust continuously generated from a modified Timbrell dust dispenser (Beckett, 1975).

The respirable dust concentrations were maintained at around 5 mg/m^3 by setting the flow at rates established by tests on the original soils. A period of thirty minutes from the start of dust generation was allowed for the dust concentration to stabilise before sampling.

Each asbestos soil combination was tested in a sequence from the lowest to the highest concentration in order to minimise the effects of cross contamination. After each test run the chamber was washed down with water and allowed to dry overnight with clean air passing through the chamber. After the tests for each soil/asbestos combination (0.001% to 1.0%) were completed the input pipework was also renewed in a further attempt to minimise cross contamination.

2.5 GCT Experimental Chamber and Dust Generation

An experimental chamber of 0.9 m^3, constructed of Perspex, was used for all dust cloud experiments. A method of generating a transient dust cloud was used: a small charge of contaminated soil was placed inside a vertical chimney-type container situated at the centre of the chamber. Compressed air was blown through this chimney via a solenoid valve. By means of an electronic timer, the solenoid valve could be opened for a precise (± 10 m s) and repeatable time interval. The requirements of the dust generation system were to produce a uniform dust cloud throughout the central region of the chamber. The effects of air pressure, time of air blast and weight of soil charge were all investigated, together with their inter-relationships. It was found that the most appropriate dust and fibre concentrations were obtained when a 2 g charge was made airborne by a 2 sec blast of air at 20 psi.

Each asbestos/soil combination was tested in sequence from lowest to highest asbestos concentration. After each test the walls of the chamber were sprayed with fine water sprays and wiped clean. They were then sprayed with an anti-static spray. An air extractor fitted with high efficiency filters was then attached to the chamber and the latter evacuated for a minimum of one hour. After evacuation, airborne fibre concentrations were measured inside the chamber and experimentation was only resumed when the airborne fibre concentration was found to be less than 0.01 f/ml.

2.6. IOM Dust Sampling

The respirable and 'total' dust from each mixture was sampled using a MRE type 113A gravimetric dust sampler (Dunmore *et al*, 1964) and an IOM vertical elutriator dust sampler respectively (Beckett 1975).

The high dust concentrations permitted the evaluation of fibres by counting by optical microscopy (OM) only on low volume samples. A sequence of low volume samples (6-8 samples of 8-20 litres) was therefore collected throughout most of the test period on 0.8 μm pore size cellulose nitrate membrane filters in cowled open head dust samplers (HSE, 1986 A). Sampling rates of 500 mls/minute and 1 litre/minute were used and the total sampling periods covered most of the duration of each test (2½ - 3 hours out of 4 hours). Further samples were collected using the same method with Nuclepore polycarbonate filters (0.4 μm pore size) for evaluation by Scanning Electron Microscopy (SEM).

Measurements were carried out using uncontaminated soils with the SIMSLIN Mark II continuous dust monitor (Blackford and Harris, 1978) to assess the consistency of dust concentration during individual experiments. Membrane filter samples were also collected to provide a series of blank soil fibre concentrations.

2.7 GCT Sampling

Initial experiments recorded the variation in airborne fibre concentration as a function of time for samples of dry soil and wet soil. The results, shown in Figures 1 and 2, indicate a typical exponential type decay. Although the fibre levels were significantly reduced by the addition of water, the general time dependence of each curve was the same. The curves were not substantially different for any of the three soil types. Sampling conditions were standardised at 20 minutes and started 30 minutes after the initial generation of the cloud.

As described above (2.6) the high dust concentrations restricted the sample volumes. Experiments showed that volumes of 80 l were suitable when using dry soils, whereas volumes of 260 l could be collected for wet asbestos/soil mixtures.

In all cases samples were collected on 0.8 μm cellulose nitrate membrane filters in cowled openhead dust samplers (MDHS 39,1988).

Respirable dust was sampled during the same test periods as above by drawing air at 1.9 l min^{-1} through 0.8 μm cellulose nitrate filters fitted in a Casella Cyclone sampling head.

2.8 IOM Repeat Tests

A proportion (about one quarter) of the tests were repeated to provide a quality control check on the results. Also, results were rejected if any of the gravimetric dust estimates were unreliable, e.g. when the respirable dust mass concentration was too low (<3 mg/m^3) or if the 'total' dust:respirable dusts ratios were anomalous. Major contamination of chrysotile by needle-like fibre was observed in a few samples and the tests where these occurred were also repeated.

2.9 Analytical Methods

2.9.1 Airborne dust concentrations

In all tests (IOM, GCT) preweighed filters used for collection of respirable and 'total' dust samples were reweighed, the mass of dust deposited determined by difference (HSE 1986 B) and airborne concentrations calculated from the volumes of air sampled.

The SIMSLIN dust sampling instrument was calibrated for individual soil types by comparing integrated dust counts with the results from the MRE type 113A samples (Bradley *et al.* 1983).

2.9.2 Airborne respirable fibre concentrations by optical microscopy

In all tests the membrane filters were cleared with acetone vapour on microscope slides and mounted with triacetin according to MDHS 39 (HSE, 1986A). Fibres were counted at IOM using Phase Contrast Optical Microscopy (PCOM) in two ways, the first according to the counting rules established in the European Reference Method (ERM)(HSE, 1986A) for asbestos fibre counting, and the second according to the counting rules of the Central Reference Scheme (Crawford and Thorpe, 1982). The main difference between the two sets of rules is that the former ignores fibres which are touching non-respirable particles (> 3 μm diameter) while the latter includes such fibres in the count.

The fibre counts at GCT were produced by PCOM using a modification of the ERM essentially the same as the CRS rules.

At each laboratory, two principal fibre counters were employed and a proportion of the filters were recounted by a different counter to provide for quality control checks on the results. All six counters participate satisfactorily in RICE quality assurance scheme for fibre counting (Crawford *et al*, 1984).

For the IOM tests a cumulative assessment was made of the average fibre concentration throughout the period of each test. For each individual test the sequential samples (Section 2.6) were used to calculate the time weighted average fibre concentrations from the sums of the fibres found, the total volumes of air sampled and the proportion of the filter areas examined.

2.9.3 Statistical analysis of data

Fibre counts used to determine airborne fibre concentrations are distributed as Poisson variables suggesting that a log-linear model could be appropriately fitted to the data (MILLER, 1984).

A generalised linear model was formulated for the relationship between the logarithm of the observed airborne fibre concentration and factors for asbestos type, soil type, asbestos content of the soil and for interactions of these factors which was expressed as

$$\log f_{ijk} = m + a_i + s_j + c_k + (as)_{ij} \; (ac)_{ik} + (cs)_{jk} + e_{ijk}$$

f = airborne fibre concentration
m = airborne fibre concentration from 0.001% amosite in clay
a = variable factor for asbestos type
s = variable factor for soil type
c = variable factor for asbestos content of soil
as, ac, cs = interactive factors involving a, c and s
e_{ijk} = any residual systematic errors

Regression analysis of the model fitted to the data and analysis of deviance was carried out using the GENSTAT computer program (ALVEY *et al.*, 1983)

2.9.4 Airborne Asbestos and other Fibre Concentrations by Scanning Electron Microscopy (IOM)

The polycarbonate filters were cut, mounted on standard 13 mm diameter sample holders and coated with gold prior to examination by SEM. The filters were searched at 5000X magnification and all respirable fibres (>5 μm long, <3 μm diameter, aspect ratio >3:1) were measured, counted, analysed by energy dispersive X-ray spectroscopy and identified. Six hundred fields of view were searched or 50 respirable fibres were analysed, whichever came first.

3. IOM RESULTS

3.1 General Comments

The results from the individual dust generation tests are shown in Table 3.1. These are the respirable and 'total' dust concentrations, the airborne fibre concentrations for fibres counted by conventional ERM rules and for those fibres counted using the CRS rules (Section 2.7.2) and the normalised airborne fibre concentrations obtained by dividing the fibre concentrations by the respirable dust concentrations (f $\mathrm{ml^{-1}/mg\ m^{-3}}$).

The fibre concentrations produced by the CRS rules were higher than the ERM concentrations and the ratios between the two differed considerably. The samples were heavily contaminated with non-fibrous particulates. The modified CRS rules are considered to be analytically more reliable since they permit the counting of fibres which touch or appear to touch particles. This avoids subjective decisions concerning the exclusion of such fibres from counts using ERM rules.

Table 3.2 shows the average airborne respirable fibre concentration and the average normalised fibre concentrations for the tests grouped by asbestos type, by soil type and as overall average.

3.2 Dust Concentrations

Table 3.3 gives the averages of the dust concentrations achieved for each of the soil types in the tests.

The average concentration of respirable dust achieved in the chambers was 5.53 mg $\mathrm{m^{-3}}$ (SD 1.61) which was close to the target concentration of 5 mg $\mathrm{m^{-3}}$. There was some variation between the individual soils, with the average clay dust concentration the highest at 6.9 mg $\mathrm{m^{-3}}$ compared to 5.1 mg $\mathrm{m^{-3}}$ for the sand and 4.6 mg $\mathrm{m^{-3}}$ for the intermediate soil.

The average 'total' dust concentration was 7.3 mg $\mathrm{m^{-3}}$ (SD 2.37) with the average for the clay soil of 9.4 mg $\mathrm{m^{-3}}$ compared to 6.9 mg $\mathrm{m^{-3}}$ for the sand and 5.7 mg $\mathrm{m^{-3}}$ for the intermediate soil.

The ratios between the respirable and 'total' dust concentration were very similar for the different soils at 0.74 for the clay, 0.81 for the intermediate soil and 0.75 for the sand; the combined average was 0.77 (SD 0.09).

Calibration of the SIMSLIN was carried out by comparing the average voltage reading, obtained by direct reading from the integrator of the SIMSLIN and calculated from the printed record, with the mass concentration obtained from the MRE gravimetric dust sampler. These allowed the SIMSLIN voltage readout to be converted directly to respirable dust concentrations in other tests. The clay had a calibration of 0.66 mg $\mathrm{m^{-3}}$/volt, the intermediate soil 0.94 mg $\mathrm{m^{-3}}$/volt and the sand 1.2 mg $\mathrm{m^{-3}}$/volt on the reading of the SIMSLIN.

3.3 Airborne Respirable Fibre Concentrations by Optical Microscopy

The average respirable fibre concentrations by PCOM for all soil and all asbestos types were highest for the 1% mixtures at 10.8 f ml^{-1} and were progressively lower for each of the lower concentration mixtures in turn, with 0.11 f ml^{-1} found for the 0.001% mixtures.

While the tenfold reduction in asbestos content of the mixtures from 1.0% to 0.1% produced almost a tenfold reduction in airborne fibre concentration, subsequent reductions by factors of ten in the asbestos content brought only reductions in fibre concentration by factors of about 3 and 4 (Table 3.2).

This general picture for all mixtures was repeated in average figures for each asbestos type and for each soil type as shown in Table 3.2. The differences between the asbestos types are clear, with chrysotile consistently producing the lowest fibre concentration in each test, and crocidolite the highest concentrations.

Similarly, in all but the 0.001% asbestos mixtures the fibre concentrations varied systematically with soil types. The fibre concentrations generated from the clay mixtures were the lowest and those from the sand soil mixtures were the highest.

Of the airborne fibre concentrations found in the individual tests (Table 3.1) the highest were those from the 1% crocidolite–sand mixture (average 21.6 f ml^{-1}) while the lowest concentration for the 1% mixtures were those from the chrysotile mixtures with the clay and intermediate soils (average 5.8 f ml^{-1}).

Within the 1% and 0.1% mixtures the higher fibre concentrations were found with the amosite and crocidolite, sand and intermediate combinations while the combinations including chrysotile or clay were usually lower. Similar patterns were also found with the lower asbestos content mixtures although the trend was less clear.

A summary of the analysis of deviance in the log–linear statistical model is shown in Table 3.4.

The reduction in deviance introduced by the progressive inclusion of the various factors (asbestos content and type, and soil type, 2.9.3) into the model and the mean deviance ratios can be used as a test of the significance of each factor. These show that the asbestos content of the soil is a very significant factor controlling airborne fibre concentrations and that the effects of soil type or asbestos type, although minor in comparison, are still significant. Similar analysis carried out including factors for interaction between these primary influences showed no significant improvement in fit between the model and the data.

Table 3.5 enumerates (as exponentials or as multipliers) the factors used in the log–linear model (as in 2.9.3) for each combination of asbestos type, soil type and asbestos content, and could be used to produce an estimate of fibre concentration. For example, the expected airborne fibre concentration (in a 5 mg m^{-3} dust cloud) from the crocidolite/sand combination at the 1% asbestos content level is

$$\exp(-2.534 + 0.128 + 0.837 + 4.568) = 20 \text{ f ml}^{-1}$$

The actual measured concentration during the test was 21.6 f ml^{-1}.

3.4 Airborne Respirable Fibre Concentrations Normalised for Respirable Dust Concentrations

The airborne fibre concentrations assessed using the CRS method (modified ERM) were normalised to 1 mg m^{-3} respirable dust concentration to reduce the influence of experimental differences between the tests.

Because the dust concentrations were fairly consistent during the tests the patterns already indicated for the airborne fibre concentrations repeated with the normalised concentrations.

The normalised concentrations were highest for the 1% content asbestos mixtures and reduced progressively along with the asbestos content (Table 3.2, Figure 3). The reductions in the normalised concentrations were not generally proportionate to the reductions in asbestos content; only that between the 1% and 0.1% produced a decrease in normalised concentration by a factor of ten. The overall thousand-fold reduction from 1% to 0.001% in asbestos content produced only a one hundred-fold reduction in the concentrations.

There were clear differences between the average normalised concentrations for the asbestos types (Table 3.2, Figure 4), with the crocidolite consistently producing the highest normalised concentration and chrysotile the lowest.

The average normalised fibre concentrations for the sandy soil were generally the highest except for the 0.001% mixtures, and the clay soil ratios were always the lowest.

The highest normalised concentration for any of the tests was found with the crocidolite/sand 1% mixture (3.78). The mixtures containing sand, crocidolite or amosite gave generally higher concentrations than the clay and chrysotile mixtures. The lowest concentration among the 1% mixtures was found with the clay/crocidolite combination (0.83) although the chrysotile:clay concentration (0.84) was very similar.

The normalised airborne fibre concentrations for the individual mixtures are shown grouped by fibre types in Figures 6a, b and c and grouped by soil types in Figures 7a, b and c. The concentrations from the sand mixtures are higher than those for the clay mixtures for all asbestos types (Figure 6). The normalised concentrations for intermediate soil are similar to the concentrations from clay mixtures for chrysotile, similar to those from the sand mixtures for crocidolite and in between for the amosite mixtures.

This point is further brought out in Figure 7, where the lines for normalised fibre concentrations for the three asbestos varieties in the clays are close together and low (Figure 7a), and those for the mixtures in the sands close together and high (Figure 7c) while the lines are widely spread for the intermediate soils (Figure 7b). In other words the influence of fibre type on the normalised fibre concentrations is greatest with the intermediate soil.

3.5 Fibre Concentrations associated with Uncontaminated Soils

The airborne respirable fibre concentrations found using the CRS rules for samples from dust clouds produced using blank soils were all low, with the sand producing an average normalised concentration of 0.003 f ml^{-1}/mg m^{-3}, the intermediate soil

0.005 f $ml^{-1}/mg\ m^{-3}$, and the clay 0.01 f $ml^{-1}/mg\ m^{-3}$.

3.6 Variations of Dust and Fibre Concentrations within Tests

Tests carried out with the blank (uncontaminated) soils using the SIMSLIN continuous dust monitor showed that the dust concentrations within the chambers would not have been constant throughout the tests. Almost all tests showed a higher dust concentration (voltage reading on the SIMSLIN) at the start of the test 15–30 minutes after starting the dust generator. This sometimes reduced steadily to maintain a reasonably consistent concentration as in the sandy soil shown in Figure 8a. Alternatively the dust concentration might vary by factors of up to 3 with a pattern of sharp rises followed by more gradual reductions as in Figures 8b and c. Other variations, such as that shown in Figure 8d where a very high concentration was recorded in the middle of the test run, were only rarely seen.

The airborne fibre concentrations (CRS) measured in sequence throughout the tests with the asbestos mixtures demonstrated patterns of variation similar to those recorded by the SIMSLIN instrument with the blank soils. Figures 9a, b, c and d show examples of these. Fibre concentrations and sampling periods are arranged chronologically for comparison with the SIMSLIN traces from blank soils of Figure 8. The variability in the fibre concentrations for the low asbestos content soils (0.001%) was greater than for the high asbestos content soils. Fibre counts for the former would be subject to a greater range of statistical variation because of the lower fibre numbers involved and this in combination with the likely variation in dust concentrations would explain the wider variation in the resulting airborne fibre concentrations.

3.7 Scanning Electron Microscope Evaluations

Scanning Electron Microscope evaluations were carried out on selected samples.

The airborne respirable fibre concentrations from these evaluations are shown in Table 3.7 along with the average PCOM fibre concentrations from the same tests.

The proportion of non-asbestos fibres in the respirable size range (> 5 μm, less than 3 μm diameter) was generally low for soils with 1% or 0.1% asbestos. However, in the low asbestos concentration mixtures (0.01% and 0.001%) two thirds of the fibres found were non-asbestos.

The fibre concentrations measured by SEM were generally a little higher than the PCOM concentrations but with the 1% chrysotile mixtures the SEM concentrations were much higher.

Typical asbestos fibres found in the dust samples are shown in the electron micrographs (Plates 1 and 2).

3.8 Repeat Tests

A summary of the repeated tests is given in Table 3.7. Repeat runs were largely carried out using the mixtures with low asbestos contents (0.01 and 0.001%) because of the higher fibre counting errors associated with assessing low fibre concentrations (Crawford *et al.* 1984).

In general, the results were consistent and showed little variation in the fibre/dust ratios although two (0.01% amosite in sand and 0.1% chrysotile in sand) differed by factors of about 4.

4. GCT RESULTS

4.1 Dry Soils

The respirable dust concentrations achieved with the dry soils shown in Table 3.3a were much lower than those obtained in the IOM chamber experiments.

The airborne fibre concentrations for dry asbestos/soil mixtures normalised to 1 mg m^{-1} respirable dust are shown in Table 4.1. They range from 13.7 f ml^{-1} mg m^{-3} for 1% amosite in sand to 0.01 f ml^{-1} mg m^{-3} for some of the 0.001% mixtures.

The average respirable fibre concentrations generated by all soils and all asbestos types were highest for the 1% mixture and were progressively lower for each lower concentration mixture.

Table 4.2 shows the overall average normalised fibre concentrations grouped by asbestos type and by soil type.

Generally the tenfold reduction in asbestos concentration of the soils from 1% to 0.1% produced correspondingly large changes in the airborne fibre concentrations. Subsequent reductions by factors of ten brought much smaller reductions in fibre concentrations.

Chrysotile produced the lowest airborne fibre concentrations from all soil types. Amosite consistently gave higher airborne concentrations than crocidolite in all tests. The fibre concentrations were also found to depend on soil type, with sand mixtures always generating the highest fibre concentrations.

The results obtained from chrysotile in sand are clearly anomolous - fibre concentrations are well below those obtained from chrysotile in clay. The tests were repeated, with similar results. However, it was not possible to repeat the experiments with a different batch of soil.

4.2 Effects of Soil Wetness

Table 4.3 shows the results of the 248 (36 asbestos/soil combinations and 7 moisture contents, 6 for amosite/sand) separate tests to assess the effects of water concentration on each soil/fibre combination. In all cases the airborne fibre concentration decreased with initial wetness of the soil.

The results suggest that the introduction of the first 5 or 10% water had the greatest effect, particularly in the case of amosite, and that subsequent additions of water were less effective although still necessary to achieve 0.01 f ml^{-1}.

The application of water to the soil reduced the airborne fibre concentration to below the clearance indicator of 0.01 f/ml in all soil/asbestos combinations. Larger asbestos concentrations in soil required more water to achieve this. (50% for 1% amosite in sand).

For a given concentration and fibre type, the results suggest that sandy soils require more water than other types but no clear pattern has emerged and further work would be required to confirm the suggestion.

5. DISCUSSION

5.1 Airborne Fibre Concentrations from Dry Soils

Analysis of the data shows that the most important factor controlling airborne fibre concentrations in the experiments with dry loose aggregate mixtures was the bulk asbestos content. The results from both IOM and GCT studies show that, irrespective of fibre type or soil type, high airborne fibre concentrations (over 20 f ml^{-1}) can be generated from 1% asbestos in dry soil while restricting the respirable dust concentration to the nuisance dust occupational exposure limit (OEL) of 5 mg m^{-3} (HSE, 1987).

There was good agreement between the results from both sets of tests with dry soils. The similarity of the results for given dust concentrations and bulk asbestos contents suggests that the dust generation techniques were of secondary importance in establishing the relationship between dust and fibre concentrations.

The results for the chrysotile tests at GCT were somewhat lower than the equivalent IOM results and than the GCT results from the other fibre types. This may be the result of differing suppressant effects of particles on chrysotile as discussed later or to difficulties in dust generation.

The fibre concentrations measured in both studies are generally consistent with those reported Davis (1978) for 100% asbestos dust clouds produced by Timbrell Dust Generator where between 275 and 975 fibres ml^{-1} were found in a respirable mass concentration of 5 mg m^{-3} (i.e. 2.75 and 9.75 for 0.05 mg m^{-3}, i.e. 1% of 5 mg m^{-3}). There was a progressive reduction in airborne fibre concentrations at a given dust concentration with reducing amounts of asbestos in the mixtures but this reduction was not proportionate to the reduction in asbestos content below 0.1%. With 0.1%, and often 0.01%, of asbestos in soils the 0.5 f ml^{-1} Control Limit for chrysotile and the 0.2 f ml^{-1} Control Limit for crocidolite and amosite (HSE, 1987) could be exceeded while respirable dust concentrations were below 5 mg m^{-3}, the nuisance dust OEL. Similarly it is apparent that the clearance limit of 0.01 f ml^{-1} could be exceeded with any of the 0.01% and 0.001% asbestos mixtures if respirable dust concentrations approached the nuisance dust OEL.

There are problems of fibre counting with these low asbestos concentrations which make correct assessment of the potential hazards very difficult. For individual IOM tests, samples of between 8 and 24 litres of air were collected because of the presence of large amounts of other mineral dust. The fibre concentrations were calculated from cumulative counts over 6-8 samples collected sequentially during each test. The cumulative counts would then provide reasonable assessments of the fibre concentrations down to about 0.01 fibres per ml. This is borne out by the good agreement between the two sets of tests and the generally good repeatability of the experiments.

The airborne fibre concentrations associated with the blank soils were always lower than those associated with the test mixtures with the exception of the mixture of 0.001% amosite in clay. These background fibre concentrations while contributing substantially to some of the fibre concentrations from 0.001% asbestos mixtures measured by optical microscopy had only a limited effect on the overall results of the study.

The electron microscope examinations carried out on the IOM tests confirmed that asbestos fibres were present in the dust clouds produced from the low concentration mixtures and that there were few asbestiform minerals in the blank soils. The non-asbestos fibres which accounted for substantial proportions of the respirable fibres found by EM in samples collected from mixtures with low asbestos content consisted largely of elongated clay particles or chains of particles. It is likely that many of these would not have been counted as fibres by phase contrast optical microscopy; not because they were discriminated against during counting but rather because they would not have been perceived as fibres at all (Plate 1).

5.2 The Effects of Different Soil and Asbestos Types

The effects of fibre type and soil type on the airborne fibre concentrations are minor in comparison to the bulk asbestos content. However, the natures of the fibre and of the soil do have a real effect. For a given asbestos concentration in soil it is predicted from the model that the airborne fibre concentrations could differ by factors of around 5 according to the asbestos type/soil type combinations being tested (e.g. chrysotile in clay in comparison to crocidolite in sand).

In considering all asbestos fibres it is apparent that the increasing clay mineral content does have an effect on the normalised airborne fibre concentration. This could be due to various factors. It may be that the proportion of respirable dust in the clay mixture was higher and, therefore, to achieve a 5 mg m^{-3} respirable dust cloud would require smaller amounts of bulk mixture thus reducing the airborne fibre concentration with respect to respirable dust concentration. Alternatively there could be a dust suppressant effect from the clay particles binding on to the fibres. This could either prevent the fibres from being made airborne or otherwise reduce the sampling efficiency of particulate coated fibres.

Both these factors appear to be important. It seems as if there is a genuine suppressant effect with the clay minerals, both from the similarity of the ratios of respirable to total dust concentrations from the different soils and from the fact that the effect is most marked with chrysotile which is the fibre type most susceptable to entanglement (Plate 2). The effect is also quite marked for mixtures of chrysotile in intermediate soils which contain 25% clay. On the other hand, it is difficult to explain the variations in normalised fibre concentrations from the amosite mixtures in terms of binding effects as amosite is much less susceptible to entanglement of this type (Plate 3) because of its surface, shape and other physical properties (Hodgson, 1965).

There are consistent effects on the normalised airborne respirable fibre concentrations from different fibre types in a given soil. Crocidolite almost invariably produces higher normalised fibre concentrations than does chrysotile while the position of amosite varies with soil type. This may reflect an inherent ability for crocidolite to generate more airborne fibres per unit mass or it may be a difference in the suppressent effects of clay particles binding to the three different asbestos types as mentioned earlier. Given the established differences in the surface properties of chrysotile and the amphibole minerals in general (Hodgson 1965) and the tendency for chrysotile to produce more and finer fibres than amosite at least it is suggested that the differences in the normalised fibre concentrations for the three asbestos types are largely the result of the differing suppressant effects of the clay minerals.

5.3 Dust Generation

The choice of dust generation method could influence the results. No single generation method could be considered as representative of the wide range work practices which may produce dust on a contaminated site. The method of dust generation used at IOM (Modified Timbrell Dust Generator)(TDG) was recognised as moderately aggressive in comparison to other methods but was selected because of its lower tendency to blockage by grit particles and because of the necessity to generate dust at relatively constant concentrations over a four hour period. It operates by advancing a plug of the loosely packed material down a hollow tube into a small cylindrical chamber inside which a rotating vane scrapes dust from the front of the plug. A compressed air feed then lifts the dust to the input pipe of the chamber. This beating action of the vanes may release fibres from binding particles more effectively than other dust generation methods thus increasing airborne fibre concentrations.

The main difficulty arising from the use of the TDG appeared to occur when the face of the advancing soil plug collapsed (because of its lack of physical strength) leading to an increase in dust and fibre concentration within the chamber followed by a gradual reduction as shown by the SIMSLIN records. These variations could arise at any point in the dust generation and could not be avoided without artifically binding the soils. In spite of these difficulties, the final dust concentrations measured over the four hour periods were still close to the target concentration of 5 mg m^{-3} for respirable dust.

The fact that the dust concentrations could increase by a factor of 4 over a short period during the blank soil tests could account for most of the variability observed in the individual sample fibre concentrations. Very large differences between individual sample fibre concentrations were observed during runs with low asbestos content mixtures. These were primarily associated with the large statistical errors associated with counting low density samples (Crawford *et al*, 1984). The use of continuous sampling for gravimetric dust concentrations and sequential sampling for airborne fibre concentrations with the use of time weighted averages did much to reduce the effects of such variations, providing more reliable estimates of the normalised fibre concentrations. This is borne out by the repeat tests where the differences between test runs were generally small.

The transient dust cloud generation method used at GCT was simple in comparison to that used at IOM, and the sampling strategy, involving a 30 minute delay after dust generation to allow the dust to settle, was very different. The fact that the normalised fibre concentrations from the two tests are similar indicates that there may be a general relationship between respirable dust and airborne fibre concentrations. It is therefore possible that the normalised airborne fibre concentration is independent of the type of dust generation method adopted but further research would be required to confirm this.

5.4 Effects of the Addition of Water to the Asbestos/Soil Mixtures

The results from the GCT study show that the airborne fibre concentrations generated from contaminated soils are greatly reduced by the addition of water to the soil. The amount of water required to reduce levels to a given value depends primarily on the amount of contamination of the soil and to a lesser extent on the type of soil.

Starting with initial fibre concentrations of more than 5 f ml^{-1} from dry soil, the fibre concentrations can be reduced to less than the clearance indicator of 0.01 f ml^{-1} by the addition of between 20 and 50% water.

The introduction of the first 5 or 10% water had a greater effect than subsequent additions. The differences observed in the progressive additions would require further research to explain them. However, given the effectiveness of addition of large amounts of water to the mixtures it is unlikely that this factor would be of practical importance.

The work with the dry asbestos/soil mixtures has shown that significant airborne fibre concentrations can be generated from soil contaminated with very small traces of asbestos. In practice this would mean that virtually any work functions on a contaminated site which generate dust could liberate airborne asbestos concentrations greater than the normal clearance indicator or even the control limits for occupational exposure. Spraying the contaminated soil with sufficient water prior to the work can suppress the generation of respirable asbestos fibres. In most cases the level would be reduced well below the control limits of 0.5 f ml^{-1} and 0.2 f ml^{-1} and, by suitable and continued water treatment, the level would be reduced to that of the clearance indicator. Whilst not suggesting that this method should be used in place of respiratory protection and accepted asbestos work methods, it clearly can be used in conjunction with normal practices to reduce risk on asbestos working sites and surrounding areas.

The benefits of water addition however are emphasised by recent studies carried out in the USA which have demonstrated that the protection offered by high efficiency respirators is considerably less than previously believed (Myers and Peach, 1983).

6. CONCLUSIONS

1. Even small proportions of asbestos in loose, dry soil can give rise to high airborne respirable asbestos concentrations when these materials are worked.

2. After the overall dust concentration, the most important factor governing the airborne respirable asbestos concentration that can be generated from any dry contaminated soil is the amount of asbestos in the mixture.

3. Mixtures of asbestos in dry soils with asbestos content as low as 0.001% can produce airborne respirable asbestos concentrations greater than 0.1 f ml^{-1} in dust clouds where the respirable dust concentrations are less than 5 mg m^{-3}.

4. There are differences between airborne respirable asbestos fibres normalised for respirable dust concentrations which depend on the nature of the asbestos and of the soil. These differences are not as important as the gross asbestos content.

5. An action limit is recommended of no higher than 0.001% asbestos in soils above which steps should be taken to minimise exposure to airborne fibres (e.g. by wetting). Any analytical method used to assess asbestos contamination in soil should be capable of detecting less than this proportion.

6. Airborne fibre concentrations are reduced by wetting the soil, larger reductions being achieved by increasing the level of wetness.

7. The addition of relatively small quantities (10%) of water can reduce the airborne fibre concentrations by an order of magnitude.

8. To decrease levels to a given value the amount of water required depends principally on the level of contamination of the soil and to a lesser extent on the type of soil.

9. For the range of soils and asbestos types investigated the fibre levels can be reduced from approximately 5 f ml^{-1} to below the clearance indicator of 0.01 f ml^{-1} by the application of some 50% water to the soil.

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TABLE 3.1

Airborne respirable fibre and dust concentrations generated from the 36 tests

		Dust Concentration mg m^{-3}		Fibre Concentration f ml^{-1}		Normalised fibre concentration f ml^{-1}/mg m^{-3}	
Asbestos /Soil Type	Asbestos Conc.%	Resp dust	Total dust	TWA ERM[1]	TWA CRS[2]	TWA ERM	TWA CRS
Amosite/Clay	0.001	8.7	10.7	0.05	0.07	0.01	0.01
	0.01	4.6	6.2	0.07	0.10	0.02	0.02
	0.1	6.5	8.6	0.38	0.69	0.06	0.11
	1.0	7.2	8.9	4.54	6.30	0.63	0.88
Amosite/Int.	0.001	3.0	4.0	0.08	0.10	0.03	0.04
	0.01	4.3	6.9	0.14	0.23	0.03	0.05
	0.1	3.3	3.8	0.32	0.43	0.10	0.13
	1.0	7.9	9.0	8.47	12.36	1.08	1.56
Amosite/Sand	0.001	4.1	4.6	0.12	0.14	0.03	0.04
	0.01	5.8	8.4	0.46	0.86	0.08	0.15
	0.1	6.0	7.5	2.00	2.33	0.33	0.39
	1.0	5.4	7.3	16.10	19.20	2.98	3.56
Chrys/Clay	0.001	4.6	5.9	0.07	0.08	0.02	0.02
	0.01	7.8	9.9	0.08	0.17	0.01	0.02
	0.1	6.5	12.1	0.33	0.42	0.05	0.07
	1.0	6.9	10.6	4.44	5.76	0.64	0.84
Chrys/Int	0.001	6.5	7.9	0.06	0.08	0.01	0.01
	0.01	4.5	4.8	0.08	0.14	0.02	0.03
	0.1	4.9	5.6	0.19	0.28	0.04	0.06
	1.0	3.3	5.0	4.16	5.76	1.26	1.74
Chrys/Sand	0.001	3.1	4.5	0.02	0.02	0.01	0.01
	0.01	4.0	5.5	0.21	0.24	0.05	0.06
	0.1	6.2	7.1	1.24	2.23	0.20	0.36
	1.0	4.8	5.1	3.98	6.89	0.83	1.44
Croc/Clay	0.001	6.4	8.5	0.18	0.25	0.03	0.04
	0.01	7.0	9.1	0.18	0.23	0.03	0.03
	0.1	7.0	9.6	0.84	1.12	0.12	0.16
	1.0	9.2	12.4	4.58	7.67	0.50	0.83
Croc/Int	0.001	3.9	4.7	0.19	0.19	0.05	0.05
	0.01	4.5	5.3	1.02	1.11	0.23	0.25
	0.1	5.2	6.3	0.98	1.42	0.19	0.27
	1.0	4.2	4.9	9.77	12.17	2.33	2.90
Croc/Sand	0.001	7.7	11.6	0.03	0.06	0.01	0.01
	0.01	4.0	5.7	0.43	0.67	0.11	0.17
	0.1	4.4	7.1	1.31	1.77	0.30	0.40
	1.0	5.7	8.9	13.30	21.60	2.33	3.78

TWA indicates time weighted average

[1] European Reference Method

[2] Central Reference Scheme Method

TABLE 3.2

Average fibre concentrations (f ml^{-1}) and
average normalised fibre concentrations for
(a) each asbestos type in all soils
(b) all asbestos types in each soil
(c) all asbestos types in all soils

C - Central Reference Scheme Method
N - Normalised to 1 mg m^{-3} respirable dust concentration

	Airborne fibre concentration (f ml^{-1})							
Concentration of asbestos in Soil	0.001		0.01		0.1		1.0	
Asbestos/Soil type	C	N	C	N	C	N	C	N
(a)								
Chrysotile	0.06	0.01	0.18	0.04	0.98	0.16	6.1	1.34
Amosite	0.1	0.03	0.40	0.07	1.15	0.21	12.6	2.0
Crocidolite	0.17	0.03	0.67	0.15	1.43	0.28	13.8	2.5
(b)								
Clay	0.13	0.02	0.17	0.02	0.74	0.11	6.6	0.85
Intermediate	0.12	0.03	0.49	0.11	0.71	0.15	10.1	2.10
Sand	0.07	0.02	0.59	0.13	2.11	0.38	15.9	2.93
(c)								
Overall averages	0.11	0.02	0.41	0.10	1.19	0.21	10.8	1.96

TABLE 3.3

Average Respirable Dust and Total Dust concentrations achieved for each soil type

Soil Type	Respirable.dust (mg/m^3)		Total dust (mg/m^3)		Resp.dust/ total dust
	Mean	Std.Dev.	Mean	Std.Dev.	
Clay	6.87	1.31	9.40	1.91	0.74
Intermediate	4.63	1.34	5.68	1.50	0.81
Sand	5.10	1.22	6.94	1.97	0.75
Overall soil	5.53	1.61	7.33	2.37	0.77

TABLE 3.3a

Respirable dust concentrations measured during sampling period of GCT test

	mg m^{-3}
Clay	0.60
Intermediate	0.71
Sand	0.37

TABLE 3.4

Analysis of deviance in fitting log-linear model to the airborne fibre concentration data from the tests

y = m + a + s + c

y = airborne fibre concentration

m = intercept on y at 0.001% asbestos content level

a = deviation from m due to asbestos type

s = deviation from m due to soil type

c = deviation from m due to asbestos content

Initial Model	Degrees of Freedom	Residual Deviance	Reduction in Deviance	Mean Change	Mean Deviance ratio
Intercept only	35	209.3			
Modifications to Model					
c - content of asbestos	32	27.3	182.0	60.7	212.4
a - asbestos type	30	18.3	9.1	4.5	15.9
s - sand type	28	8.0	10.3	5.1	18

TABLE 3.5

Enumeration of factors in Log-linear regression of airborne fibre concentrations (see Table 3.4 for formula)

		Exponential	Multiplicative
m - intercept at 0.001%		-2.534	0.079
a - asbestos type	- Amosite	0.0	1.0
	- Chrysotile	-0.61	0.54
	- Crocidolite	0.13	1.14
s - soil type	- clay	0.0	1.0
	- intermediate	0.35	1.42
	- sand	0.84	2.31
c - asbestos content	- 0.001%	0.0	1.0
	- 0.01%	1.34	3.80
	- 0.1%	2.38	10.79
	- 1.0%	4.57	96.35

TABLE 3.6

Scanning electron microscope fibre counts and average respirable fibre concentrations

Asbestos/Soil	Bulk Conc.	Respirable fibre concentration ($f\ ml^{-1}$) All types	Asbestos	Optical[1] (average)
Amosite/sand	1%	24.0	24.0	19.2
Chrysotile/ intermediate	1%	49.9	48.5	5.76
Chrysotile/clay	1%	25.5	24.5	5.76
Amosite/sand	0.1%	3.73	2.79	2.33
Crocidolite/ clay	0.1%	3.06	2.75	1.12
Chrysotile/clay	0.1%	1.42	1.17	0.42
Crocidolite/ clay	0.01%	0.7	0.21	0.23
Amosite/ intermediate	0.01%	0.21	0.08	0.23
Chrysotile/ intermediate	0.001%	0.68	0.23	0.08

[1] CRS averaged for entire test

TABLE 3.7

Normalised airborne concentration

		CRS fibres ml^{-1}/mg m^{-3}		
		Test 1	Test 2	Test 3
1.	Amosite/clay 0.001%	0.01	0.01	
2.	Amosite/clay 0.01%	0.02	0.02	
3.	Amosite/Intermediate 0.01%	0.05	0.05	0.03
4.	Amosiite/sand 0.01%	0.04	0.15	
5.	Chrysotile/clay 0.01%	0.01	0.02	
6.	Chrysotile/ Intermediate 0.001%	0.01	0.01	0.03
7.	Chrysotile/sand 0.1%	0.08	0.36	

TABLE 4.1

Average normalised fibre concentrations
(f ml^{-1}/mg m^{-3}) for dry soils as determined
in the GCT tests

CLAY	0.001%	0.01%	0.01%	1.00%
Crocidolite	0.01	0.01	0.12	1.57
Amosite	0.02	0.02	0.92	4.98
Chrysotile	0.03	0.05	0.12	2.12

INTERMEDIATE	0.001%	0.01%	0.1%	1.00%
Crocidolite	0.01	0.03	0.13	0.82
Amosite	0.04	0.08	0.73	3.46
Chrysotile	0.01	0.01	0.08	0.34

SAND	0.001%	0.01%	0.1%	1.00%
Crocidolite	0.11	0.24	0.27	4.22
Amosite	0.05	0.22	2.24	13.7
Chrysotile	0.03	0.05	0.06	0.11

TABLE 4.2

Average normalised fibre concentrations ($f\ ml^{-1}/mg\ m^{-3}$) for dry soils as determined in the GCT tests

(a) each asbestos type in all soils
(b) all asbestos types in each soil

CONCENTRATION

(a)	0.001%	0.01%	0.1%	1.00%
Chrysotile	0.02	0.04	0.09	0.84
Amosite	0.04	0.11	1.30	7.38
Crocidolite	0.04	0.09	0.17	2.20

(b)	0.001%	0.01%	0.1%	1.00%
Clay	0.02	0.03	0.39	2.89
Intermediate	0.02	0.04	0.31	1.54
Sand	0.06	0.17	0.86	6.00

TABLE 4.3a

Airborne fibre concentrations (f ml^{-1}) measured in individual tests with increasing proportions of water (GCT)

% WET	1.0%	0.1%	0.01%	0.001%
Chrysotile in Clay				
50	nd	nd	nd	nd
40	nd	nd	nd	nd
30	nd	nd	nd	nd
20	nd	nd	nd	nd
10	0.02	nd	nd	nd
5	0.04	0.02	nd	nd
0	1.27	0.07	0.03	0.02
Chrysotile in Intermediate				
50	nd	nd	nd	nd
40	nd	nd	nd	nd
30	nd	nd	nd	nd
20	nd	nd	nd	nd
10	nd	nd	nd	nd
5	0.16	0.01	nd	nd
0	0.24	0.06	0.01	0.01
Chrysotile in Sand				
50	nd	nd	nd	nd
40	nd	nd	nd	nd
30	nd	nd	nd	nd
20	nd	nd	nd	nd
10	nd	nd	nd	nd
5	0.02	0.01	nd	nd
0	0.04	0.03	0.02	0.01

nd - not detected

TABLE 4.3b

Airborne fibre concentrations (f ml^{-1}) measured
in individual tests with increasing proportions of water (GCT)

% WET	1.0%	0.1%	0.01%	0.001%
Amosite in Clay				
50	nd	nd	nd	nd
40	nd	nd	nd	nd
30	nd	nd	nd	nd
20	0.08	0.02	nd	nd
10	0.25	0.07	0.01	0.01
0	2.99	0.55	0.02	0.01
Amosite in Intermediate				
50	nd	nd	nd	nd
40	nd	nd	nd	nd
30	nd	nd	nd	nd
20	0.01	nd	nd	nd
10	0.50	0.01	nd	nd
5	0.43	0.03	nd	nd
0	2.46	0.52	0.06	0.03
Amosite in Sand				
50	nd	nd	nd	nd
40	0.01	nd	nd	nd
30	0.04	nd	nd	nd
20	0.07	nd	0.01	nd
10	0.06	0.01	nd	0.01
5	0.11	0.01	nd	nd
0	5.08	0.83	0.08	0.02

nd - not detected

TABLE 4.3c

Airborne fibre concentrations (f ml^{-1}) measured
in individual tests with increasing proportions of water (GCT)

% WET	1.0%	0.1%	0.01%	0.001%
Crocidolite in Clay				
50	nd	nd	nd	nd
40	nd	nd	nd	nd
30	nd	nd	nd	nd
20	nd	nd	nd	nd
10	0.29	0.02	nd	nd
5	0.17	0.03	nd	nd
0	0.94	0.07	0.01	0.01
Crocidolite in Intermediate				
50	nd	nd	nd	nd
40	nd	nd	nd	nd
30	nd	nd	nd	nd
20	nd	nd	nd	nd
10	nd	nd	nd	nd
5	0.21	0.03	0.01	nd
0	0.58	0.09	0.02	0.01
Crocidolite in Sand				
50	nd	nd	nd	nd
40	nd	nd	nd	nd
30	nd	nd	nd	nd
20	nd	nd	nd	nd
10	nd	nd	nd	nd
5	0.01	nd	nd	nd
0	1.56	0.10	0.09	0.04

nd - not detected

FIGURE 1 Example of airborne fibre concentration variation with time (dry soil, 2g charge, GCT tests)

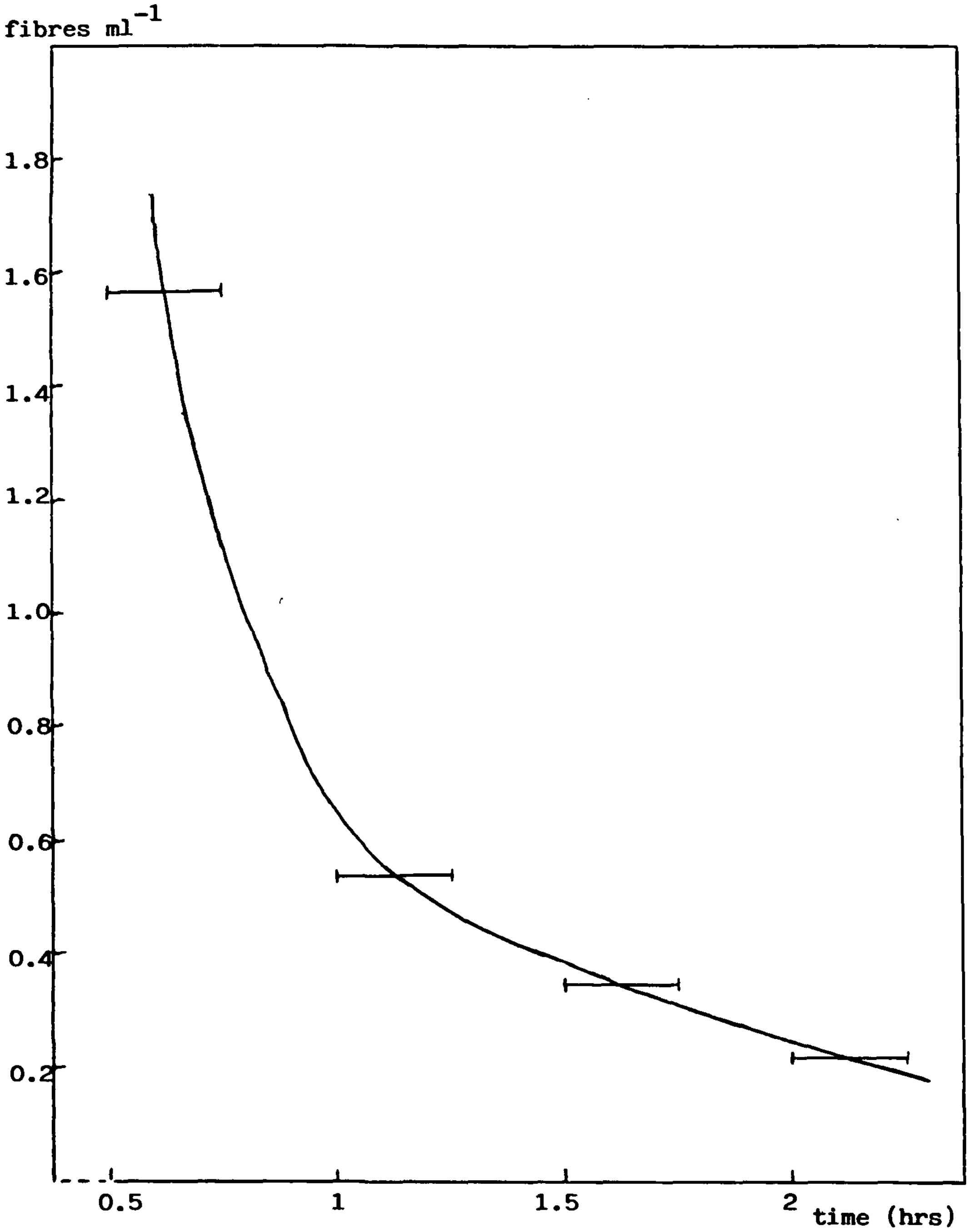


FIGURE 2 Example of airborne fibre concentration variation with time (100% wet soil, 2g charge, GCT tests)

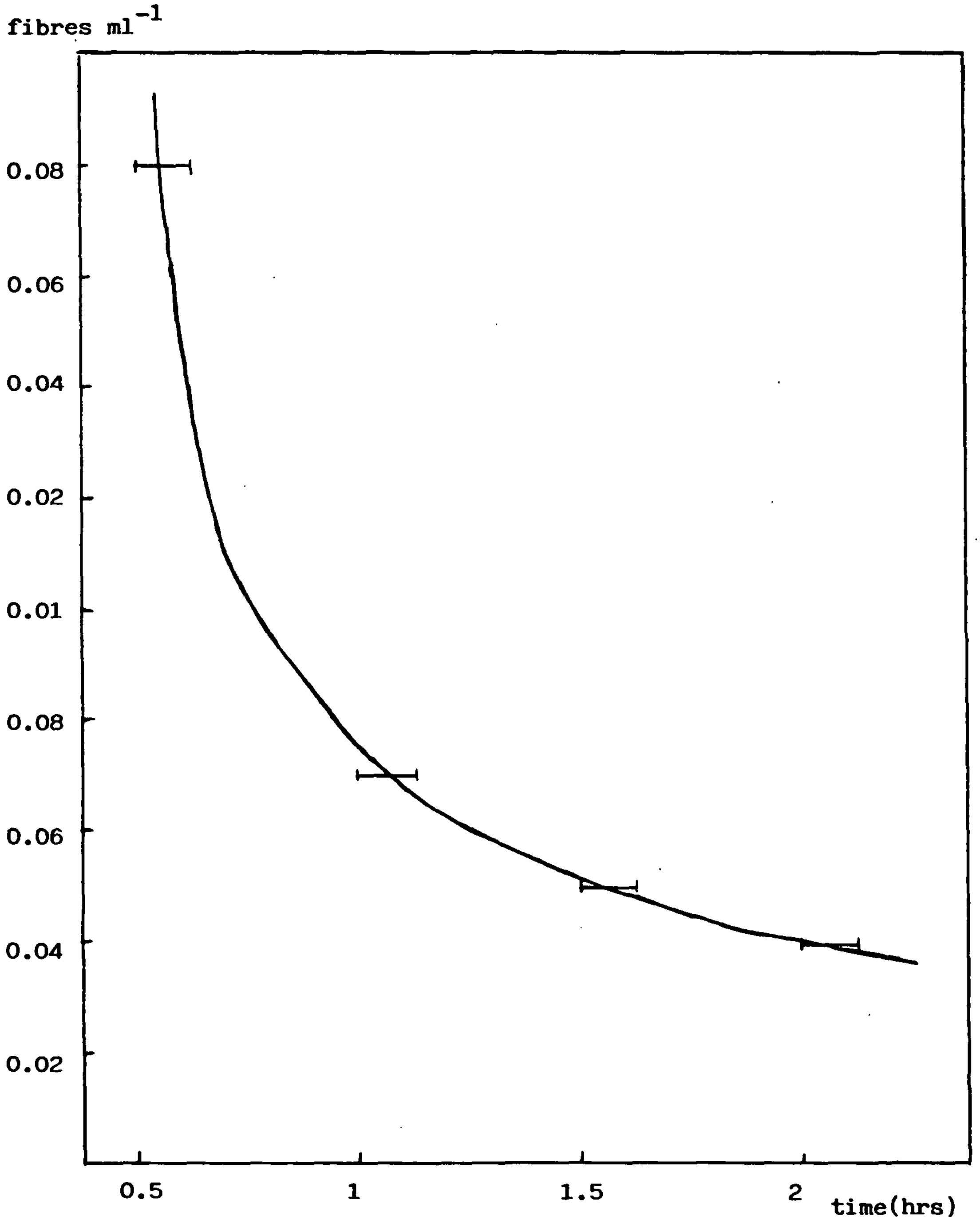


FIGURE 3 The relationship between the normalised airborne fibre concentration (f ml^{-1}/mg m^{-3}) and the proportion of asbestos in soil; average results from all test runs

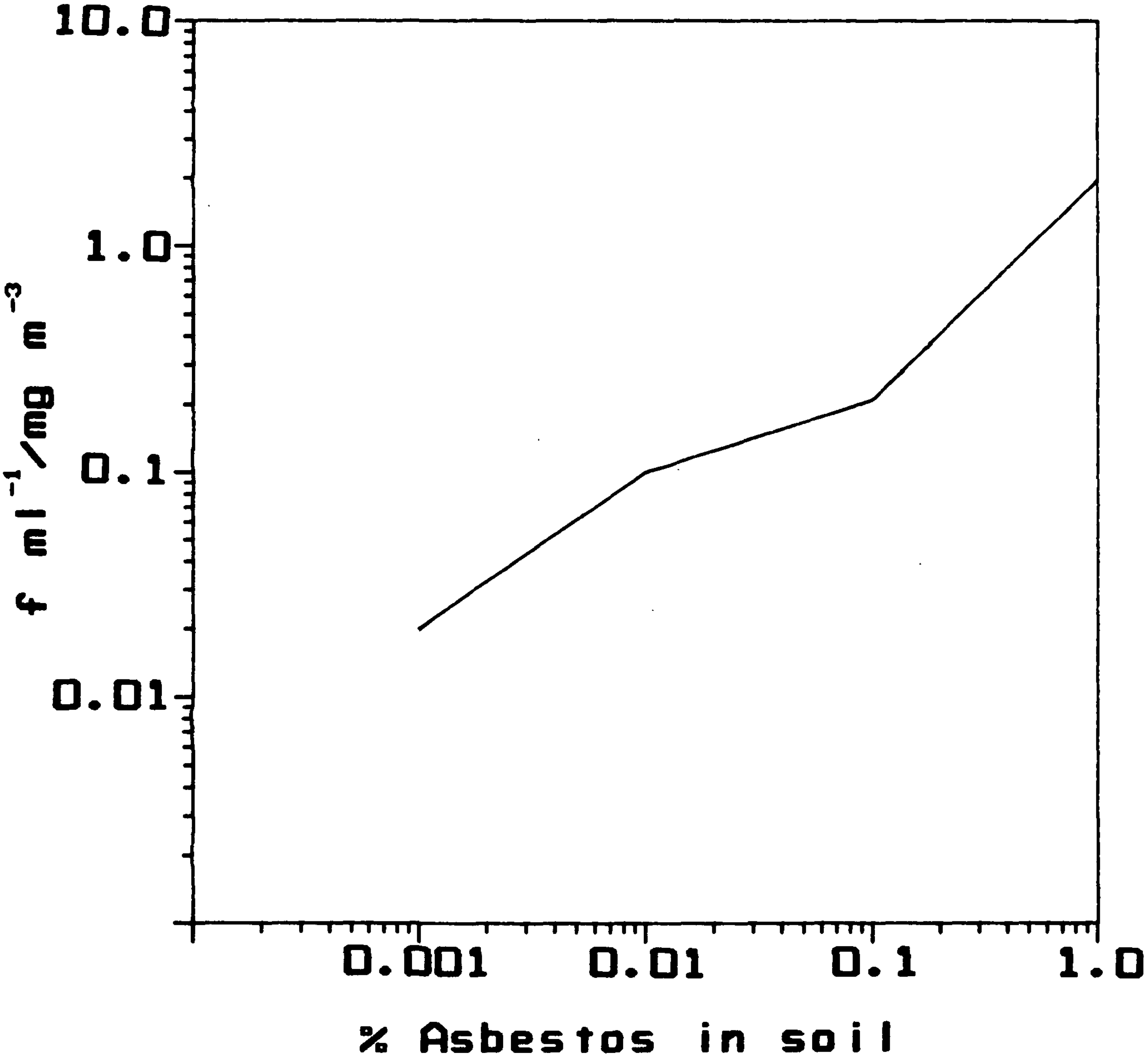


FIGURE 4 Variation in the normalised airborne respirable fibre concentrations (f $ml^{-1}/mg\ m^{-3}$) in relation to asbestos content of soil for the three different asbestos types averaged for all soils

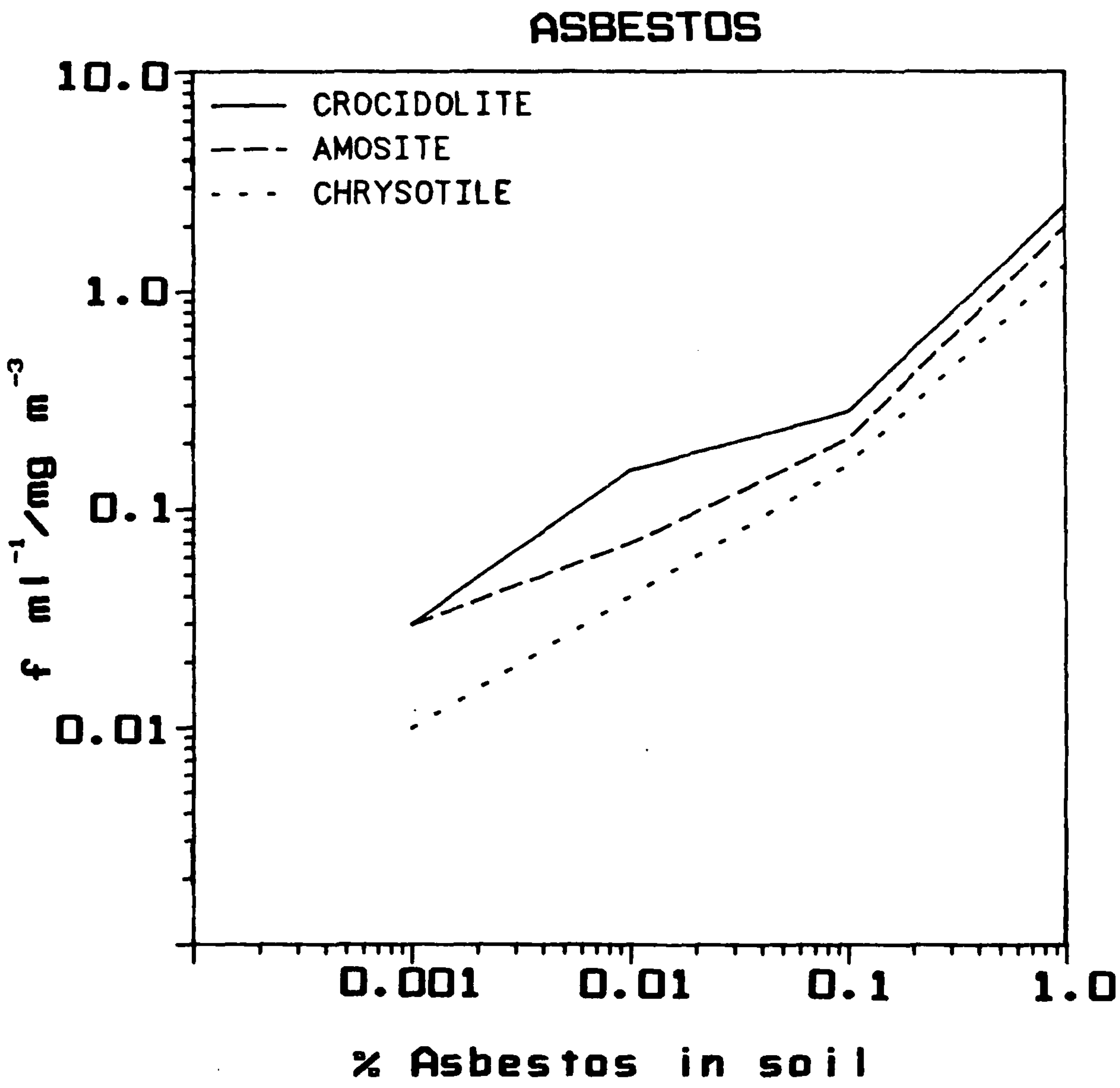


FIGURE 5 Variation in the normalised respirable asbestos fibre concentration (f $ml^{-1}/mg\ m^{-3}$) in relation to asbestos content of soil for the three soil types averages for all asbestos types

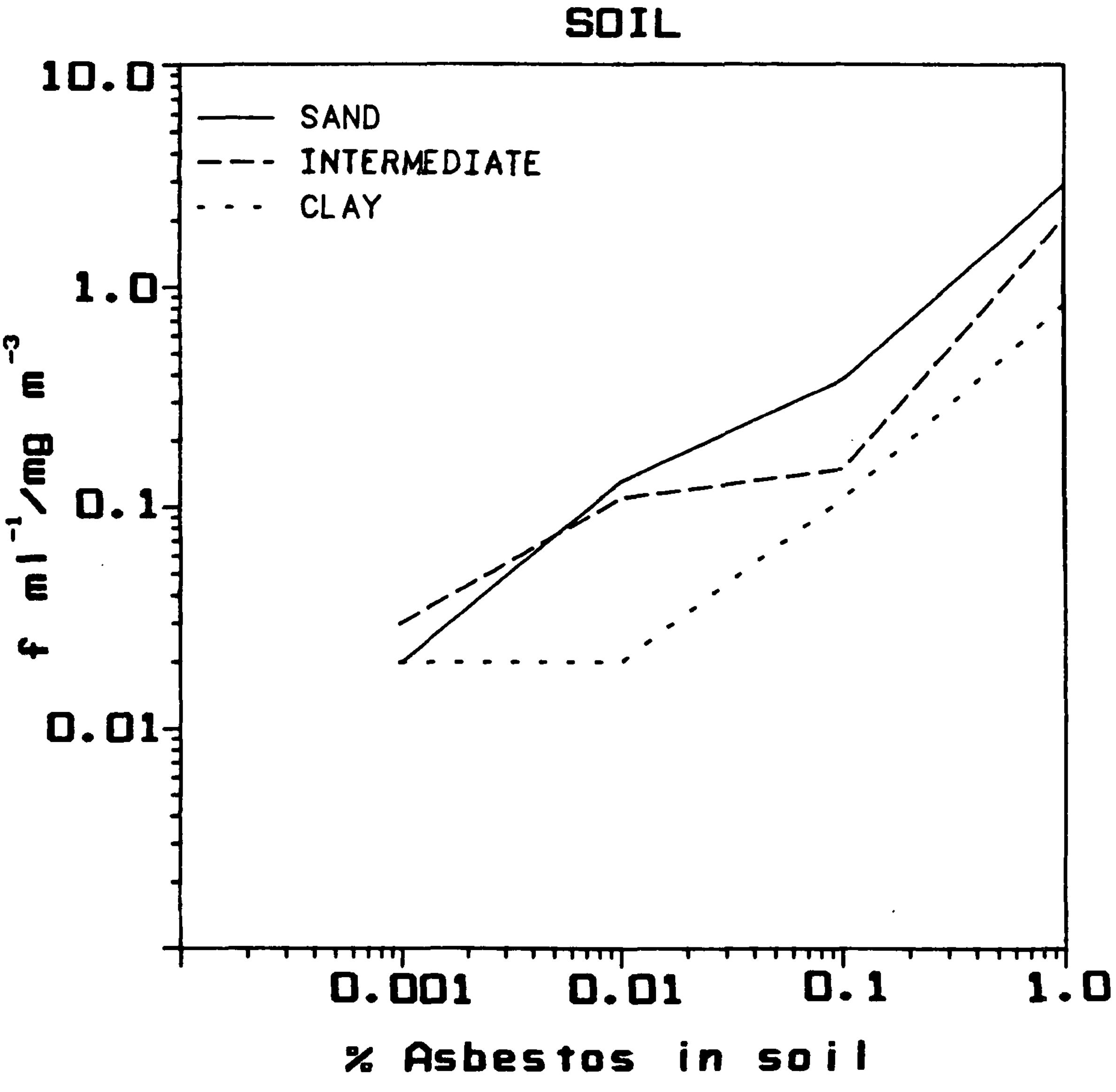


FIGURE 6 Variation in the normalised airborne respirable fibre concentrations (f ml^{-1}/mg m^{-3}) in relation to bulk asbestos content for each of the soil types with the different asbestos varieties

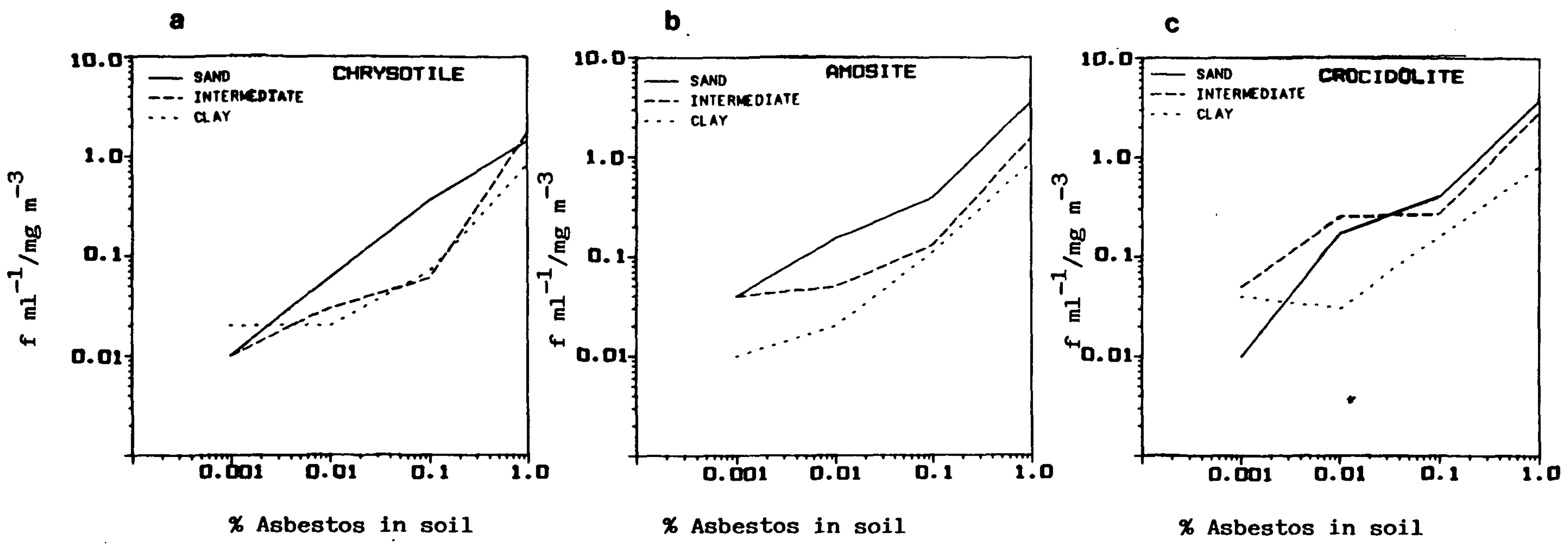


FIGURE 7 Variation in the normalised airborne respirable fibre concentrations (f $ml^{-1}/mg\ m^{-3}$) in relation to bulk asbestos content for each of the asbestos varieties in the three soils

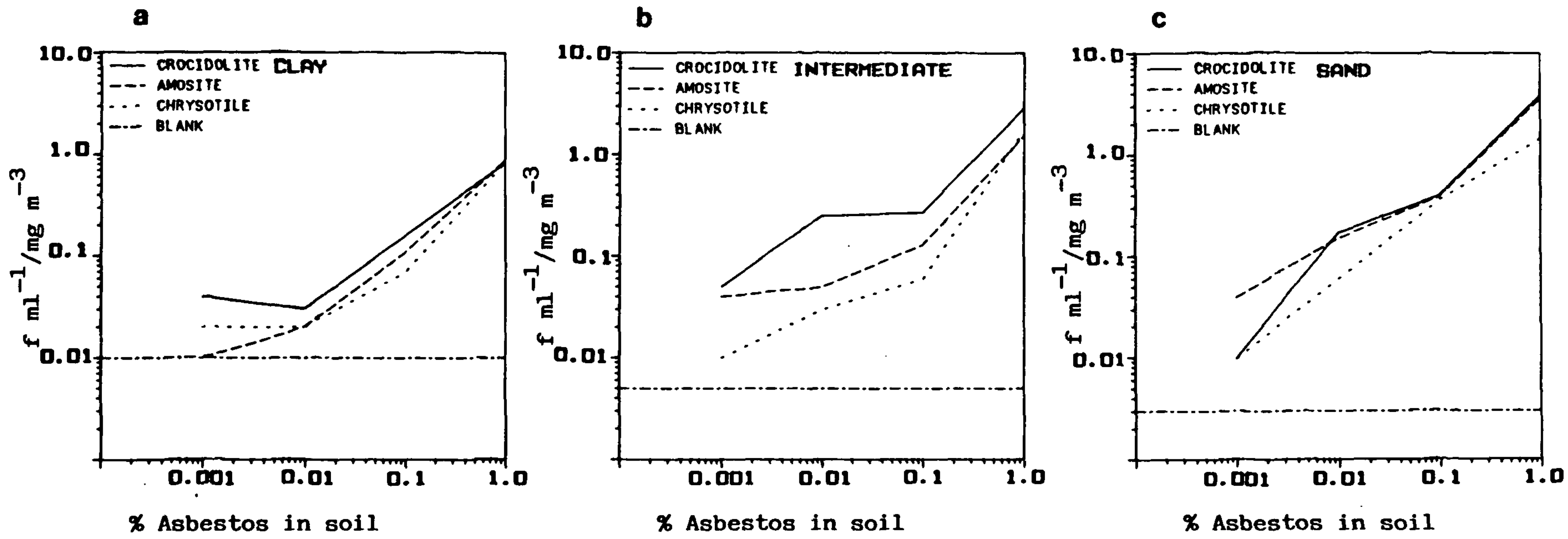
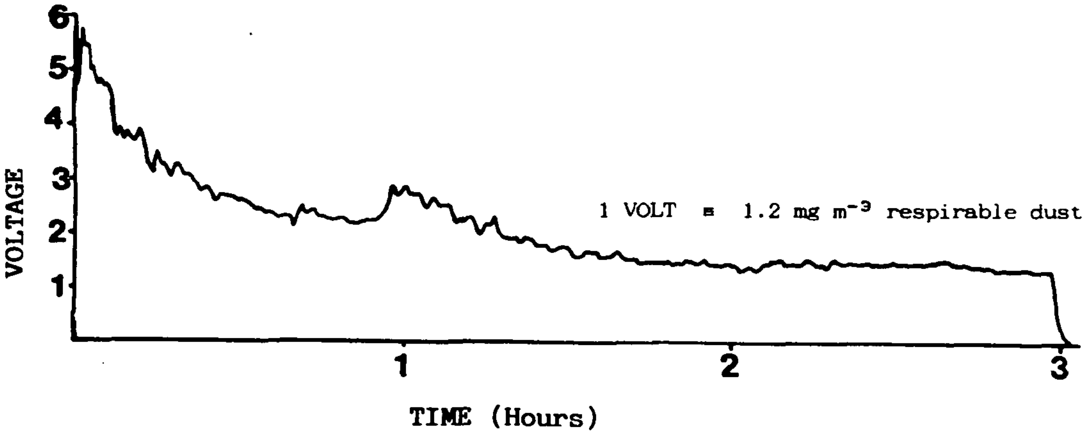
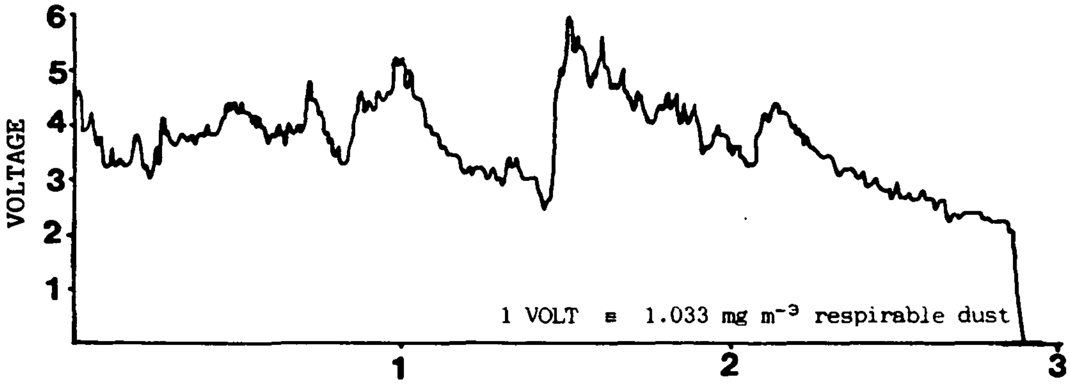


FIGURE 8 SIMSLIN dust monitor voltages recorded throughout a series of tests run with blank soils. Voltages are proportional to respirable dust concentrations. The direct relationship depends on the size distribution of the dust

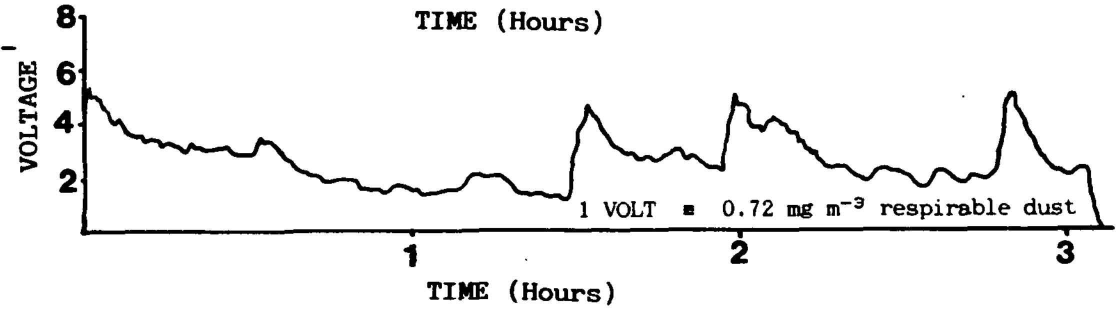
(a) Clay



(b) Clay



(c) Inter-mediate



(d) Sand

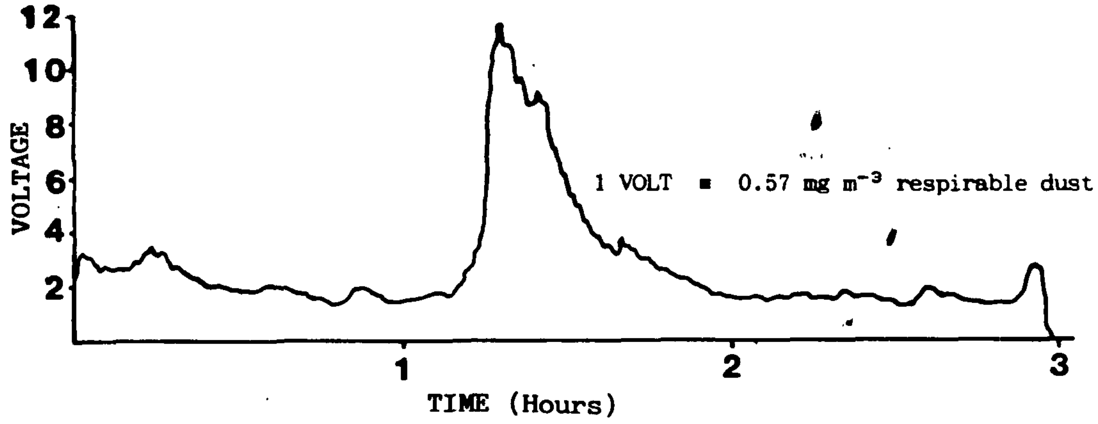
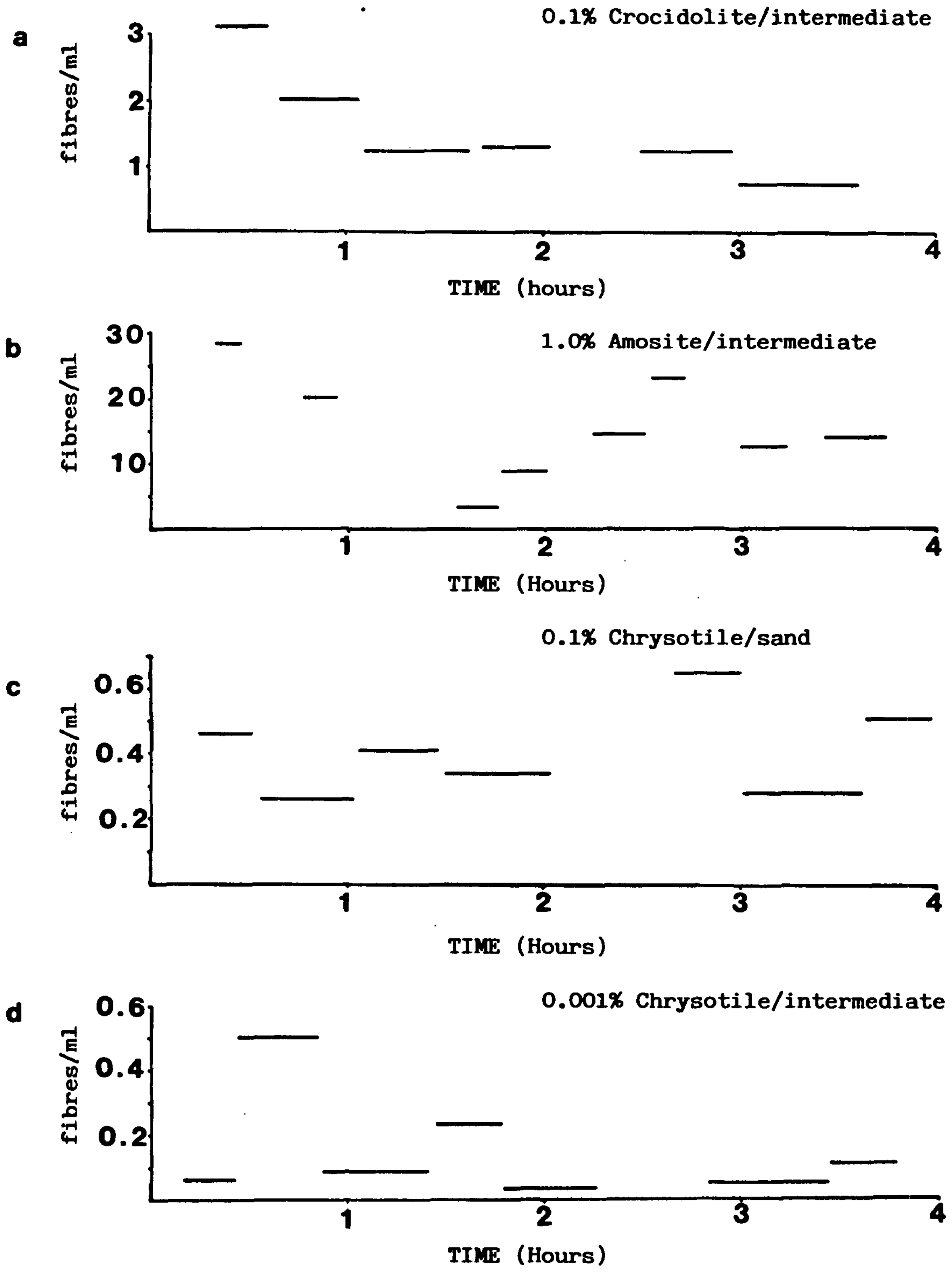


FIGURE 9 Variation in airborne respirable fibre concentrations throughout full test periods for selected asbestos/soil mixtures



0.1% Crocidolite/intermediate

1.0% Amosite/intermediate

0.1% Chrysotile/sand

0.001% Chrysotile/intermediate

PLATE 1 Clay particles in airborne dust from clay/crocidolite 0.001% mixture. The particle on RHS would be counted in the SEM evaluation as a respirable non-asbestos mineral fibre but would be unlikely to be perceived as a fibre by optical microscopy. (SEM X4500 magnification).

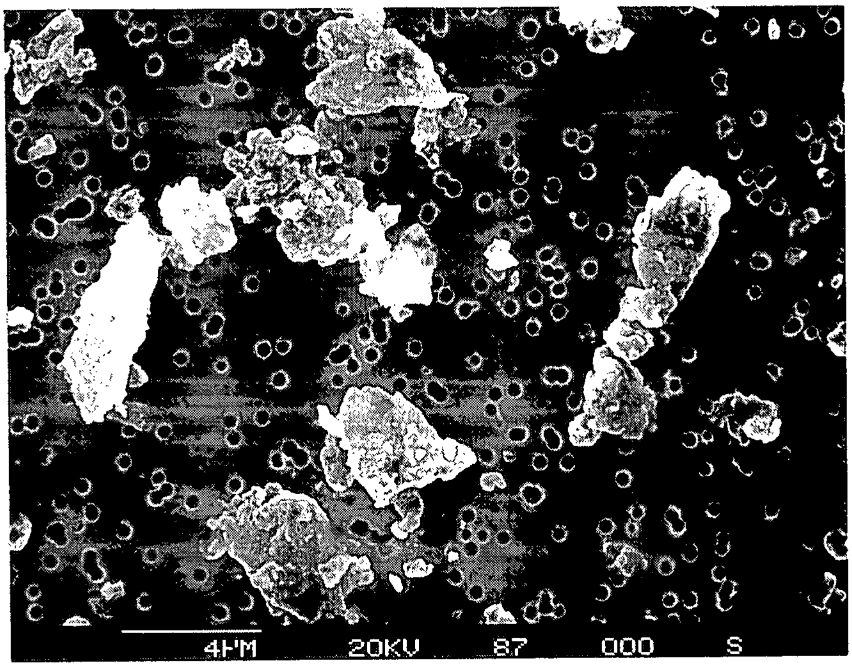


PLATE 2 Clay particles entangled in a bundle of chrysotile fibres in airborne dust from Clay/Chrysotile 1% mixture. (SEM X4500 magnification).

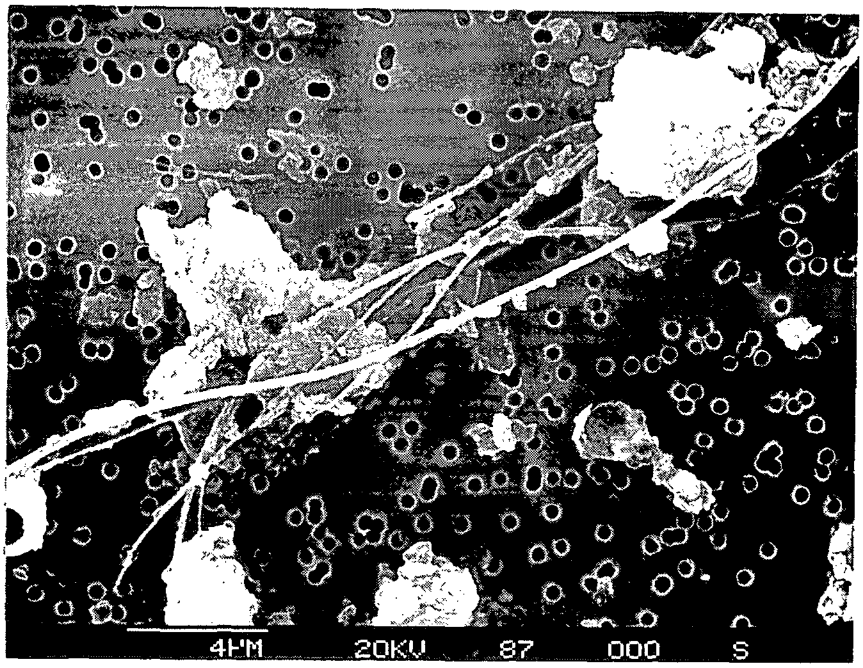
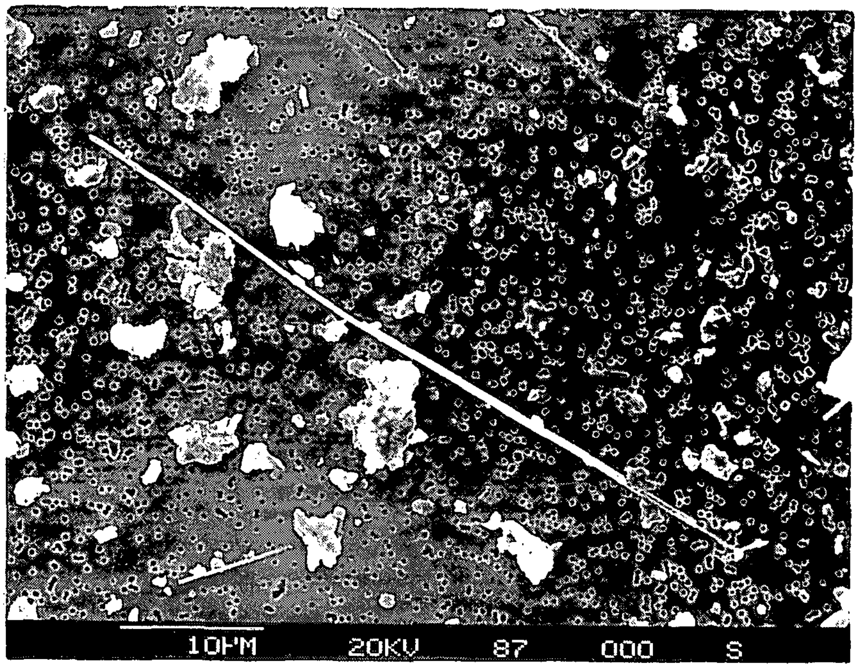


PLATE 3 Amosite fibres in airborne dust from Sand/Amosite 1% mixture. The fibres are practically free from adhering particles. (SEM X1800 magnification).



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