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# OCCUPATIONAL EXPOSURE TO SILICATE FIBRES AND PAHs DURING SUGAR-CANE HARVESTING

M. BOENIGER,* M. HAWKINS,* P. MARSIN* and R. NEWMAN†

*National Institute for Occupational Safety and Health, 4676 Columbia Pkwy, Cincinnati, OH 45226, U.S.A. and †Imperial Cancer Research Fund Laboratories, PO Box 123, Lincoln's Inn Fields, London WC2A 3PX, U.K.

**Abstract**—The literature has suggested that many commercially important plant species contain amorphous silica. This report provides a summary of that literature as well as the findings from a field survey in Florida of sugar-cane field workers where airborne concentrations of amorphous silica fibres were determined. In addition to the fibre analysis, concentrations of polynuclear aromatic hydrocarbons (PAHs) and total airborne dust were also determined.

It was confirmed that biogenic amorphous silica fibres exist in the mature sugar-cane leaf and that these fibres become airborne during the manual harvesting of the cane after the leaf is burned. Airborne amorphous silica fibres that were found were 3.5–65 $\mu$m long (mean = 12 $\mu$m) with an average diameter of 0.6 $\mu$m. Air concentrations were calculated to be as high as 300 000 fibres $m^{-3}$ of air during cane cutting. Some PAH compounds were found to be present in the burnt leaf but the concentrations were below the limits of detection in the air. The health significance of these findings to sugar-cane workers as well as to other agricultural workers is discussed.

## INTRODUCTION

A NUMBER of different plant species have been shown normally to contain substantial amounts of silicon in the form of silica ($SiO_2$) and complex silicates. Biogenic silica is insoluble and amorphous, and has therefore been described as opaline silica (FOX *et al.*, 1969). Knowledge of the existence of these bodies was first gathered by Russian botanists in the early 1800s (SMITHSON, 1958).

The presence of plant silica has been most studied in food crops and its presence is thought to be biologically important. In dry plant matter, $SiO_2$ concentrations have been measured at up to 12% by weight in rice (NAYAR *et al.*, 1977), 3.4–5.6% in wheat (KOWALSKI and DAVIES, 1982), up to 16.6% in corn (maize) (LANNING *et al.*, 1980) and 1–11% in oats (HANDRECK and JONES, 1968). Prairie grass has been found to average about 3% silica by dry weight with a range of 1–7.7% (KLEIN AND GEIS, 1978). Wood plant species that have been found to contain biogenic silica include oak, sugar maple and red pine (SANGSTER and HODSON, 1986). It is not surprising therefore that sugar-cane has also been shown to contain biogenic silica (FOX *et al.*, 1969; ARTSCHWAGER, 1930; KAUFMAN *et al.*, 1979; NEWMAN, 1983).

The most prevalent belief regarding the mechanism of deposition of silica in sugar-cane tissue is that soluble monosilic acid ($H_4SiO_4$) is taken up from the soil by the plant and is primarily deposited in the plant epidermal cells (FOX *et al.*, 1969; ARTSCHWAGER, 1930; NEWMAN, 1983). In some species the deposition is believed to be passive since the highest silica concentrations are typically found where the greatest rate of transpiration occurs, such as in the leaves (KOWALSKI and DAVIES, 1982; HANDRECK and JONES, 1968). It also has been shown that the uptake and deposition of silica by some plants is dependent upon the amount of available or soluble silica in the soil (LANNING *et al.*, 1980; HANDRECK and JONES, 1968; NEWMAN, 1983). In sugar-cane, FOX *et al.* (1969)

showed that silica appears to be deposited in the young leaves and remains constant as the leaf matures. However, there is some disagreement on this in that NEWMAN (1983) was able to detect biogenic silica fibres only in mature sugar-cane leaves.

The morphological characteristics of biogenic opal silica have been poorly described for most plant species. However, studies have reported the presence of both cubic and fibre-like opal silica in conifer needles (KLEIN and GEIS, 1978) and a wide variety of ribbed and smooth-sided elongated bodies in grasses (BEAVERS and STEPHEN, 1958). Others have shown the existence of a variety of opal phytoliths (rock-like parts of plants) in oat chaff with widths of only a few micrometres ($\mu$m) and up to 150 $\mu$m long (BAKER, 1960; BAKER *et al.*, 1961). LANNING *et al.* (1958) described a variety of opal phytoliths in grass, corn (maize), wheat and sorghum. Recently, the presence of opaline silica fibres was shown to exist in mature sugar-cane leaves collected in Trinidad (NEWMAN, 1983). The fibres were 10–300 $\mu$m in length and on average 0.85 $\mu$m in diameter.

A number of epidemiological studies suggest a relationship between biogenic silica exposure and cancer. The evidence for these fibres being an aetiological agent in cancer comes from several globally distributed studies. Of six studies identified in the literature, four dealt with biogenic silica fibres as a possible dietary contributor to elevated upper digestive trace cancer while two studies concerned excess respiratory cancer among sugar-cane workers. These studies have been tabulated in Table 1 and have been reviewed recently in detail by NEWMAN (1986).

TABLE 1. ASSOCIATION BETWEEN BIOGENIC SILICA FIBRES AND HUMAN CANCER

| Source of exposure | Cancer implicated | Author |
|---|---|---|
| Consumption of corn, other plants | Upper digestive | ROSE (1968) |
| Consumption of impure flour | Oesophageal | O'NEILL *et al.* (1980) |
| Consumption of bran of millet | Oesophageal | O'NEILL *et al.* (1982) |
| Consumption of rice | Stomach | HENDERSON *et al.* (1975) |
| Sugar-cane farming | Mesothelioma | DAS *et al.* (1976) |
| Sugar-cane farming | Lung and mesothelioma | ROTHSCHILD and MULVEY (1982) |

In an interesting study, BHATT *et al.* (1984) demonstrated that the silica fibres derived from the grass seeds contaminating the diet in Iran acted as powerful tumour 'promoters' on mouse skin that was 'initiated' with a polyaromatic hydrocarbon. The fibres had no tumorigenic effect when used alone. This study may suggest the potential importance of this combination of exposures as a hazard to the skin as well as to the respiratory system in man.

Although it has been previously suspected that exposure to biogenic silica fibres occurs in the sugar cane industry, proof of this exposure had not yet been provided. The purpose of this report is to present the results of an air sampling survey of sugar-cane harvesting operations performed during February 1985 near Clewiston, Florida. Exposures of concern included inorganic fibres, polyaromatic hydrocarbons and total dust. Personal exposure to the above compounds was assessed for workers performing various field tasks by using personal sampling equipment.

## PROCESS AND WORKFORCE DESCRIPTION

The sugar-cane crop is multi-seasonal, perhaps providing up to six satisfactory annual harvests from one planting. Newly planted cane takes 2 years to mature before harvest. In Florida, approximately 160 000 hectares (400 000 acres) of land south and east of Lake Okeechobee are planted with sugar-cane. Because the soil in the area is composed almost entirely of decomposed plant matter, it is extremely soft and light. Until recently, all harvesting was done by hand so as not to uproot the plants, thus assuring future harvests from one planting. In recent years, about 28% of the areas planted has been harvested by machine. In Florida, about 9000 field workers, mostly Jamaican nationals and other British West Indians, are employed each year during a 4–5 month period to hand-cut the cane. The welfare of the foreign national workers is monitored by the West Indies Central Labour Organization. Additional year-round employees work all year operating mechanical field equipment and working in the sugar mills.

The following paragraph describes the overall field operations that are necessary in order to bring sugar-cane to the raw sugar mills or factories in Florida. Minor variations in the basic operations are not presented. Furthermore, harvesting procedures are expected to differ somewhat in other parts of the world.

In Florida, before mature cane can be harvested it must first be burned to remove the leaves. This is typically performed by torching an 8 hectare (20 acre) field at the perimeter on all four sides. Usually, between four and six workers comprise a burning team. Burning is performed during the dry season and the fields will burn completely in about 20 min. Only the dry leaf is removed by the burning process while the stalk is unscathed. One to two days following burning, a harvest crew arrives to cut the standing cane and stack it in rows along the field for mechanical pickup. Sixty to 120 workers will cut one field, starting at one end and working across the field. The cane is cut by hand using a heavy blade cane knife that is about 38 cm long. The cut cane that is gathered by mechanical pickup is first loaded into 4-ton carts. At transfer stations the field carts are unloaded into larger truck semi-trailers or into rail cars. At the transfer station, a line of full 4-ton carts is driven up onto an elevated platform where they are tipped by a loading jackman, and the cane in the large truck trailers or rail cars is then sent to a raw sugar mill for processing into domestic sugar.

## METHODS

### *Air samples*

Air samples were collected for the determination of three potential exposures that were of concern. In addition to the obvious interest in biogenic fibres, gravimetric samples were also taken to use as a basis from which to assess the degree of general dustiness in the fields. Air samples for the determination of polynuclear aromatic hydrocarbons (PAHs) were also collected since these compounds might be formed during the burning of the sugar cane leaf. Only a minimal number of samples were collected during this preliminary evaluation since the PAH and fibre analyses are both difficult and expensive to perform and it was believed that only a small number of samples would be needed to determine exposure qualitatively.

Gravimetric total dust samples were collected and analysed according to NIOSH

method 0500 (NIOSH, 1984a). Samples were collected on pre-weighed PVC filters through which air was drawn at a known rate of about 1–1.3 l $min^{-1}$.

Air samples for inorganic fibre analysis were collected on 25 mm Nuclepore® polycarbonate filters with a pore size of 0.4 μm. The sample air flow rate was 0.6–2.1 l $min^{-1}$. The filters were contained in a polystyrene cassette with a 50-mm extension cowl (NIOSH, 1984a). These filters were collected within 25 mm of the gravimetric samples.

Initially, seven of the polycarbonate filter samples were analysed using scanning electron microscopy (SEM) and electron-probe X-ray micro-analysis. After the presence of inorganic fibres was confirmed, all 25 of the polycarbonate filters were analysed by transmission electron microscopy (TEM) using a modified version of the procedure outlined in EPA Publication No. 600/2-77-178 (ENVIRONMENTAL PROTECTION AGENCY, 1978). One-quarter of each filter was sectioned from the rest of the filter and tacked to a glass microscope slide with double-stick tape and carbon-coated in a vacuum evaporator. From the carbon-coated filter section a piece approximately 4 $mm^2$ was cut and placed on a 200 mesh carbon-coated grid supported by a stack of glass microscope slides wrapped in filter paper in a chloroform bath. The grids were allowed to remain in the chloroform bath for 48 h, which completely dissolved the filter prior to analysis.

At least 100 grid openings (equivalent to 20 000 fields) having a total area of at least 0.706 $mm^2$ were examined on each filter section. The analysis was performed on a JEOL 100B TEM at 10 000 × magnification with an accelerating voltage of 100 kV and a filament current of 90 μA. X-ray spectra were collected for 10 s at a take-off angle of 39°. Photomicrographs were taken at varying magnifications for 3 s with an exposure sensitivity setting of 5. Diffraction patterns were obtained for the fibres that were seen.

Air samples obtained for analysis of 16 specific polyaromatic hydrocarbons were collected by drawing air at a flow rate of 2 l. $min^{-1}$ through a sampling train consisting of a 37-mm PTFE-laminated membrane filter followed by a washed XAD-2 sorbent tube. Sampling and analysis was performed according to NIOSH method 5506 (NIOSH, 1984a).

*Bulk leaf analysis*

In addition to the air samples, bulk leaf ash was collected from a recently burned field and analysed for 16 specific PAH compounds. This ash was analysed by extracting approximately 250 mg of the sample with cyclohexane. The limits of instrumental detection were 2 μg per sample for each compound.

Finally, unburnt leaf samples from 10 sugar-cane varieties and one soil sample were collected and prepared for inorganic fibre analysis. The leaf samples generally consisted of mature, dry material. One of the leaf samples was taken from sawgrass that was growing on the edge of one of the cane fields. Fibre analysis was also performed on a soil sample, collected in a cleared sugar-cane field, and a burnt ash sample which was also submitted for PAH analysis.

The bulk leaf samples were prepared by cutting the leaf into pieces approximately 3 × 3 mm and dried in an oven at 110°C. Enough material was placed in a 50 ml beaker to cover the bottom with approximately two to three layers of the leaf pieces (approximately 0.25 g). The pieces were then ashed in a low-temperature plasma asher (LTA) until only a fine white ash remained (approximate weight, 0.015 g). The ash was

subsequently ultrasonicated in 20 ml of ethyl alcohol and three capillary tubes of the resulting suspension were evaporated onto 200 mesh carbon-coated copper grids and examined on a Phillips 420 scanning transmission electron microscope with an accelerating voltage of 100 kV. One hundred fields having an area of $7.06 \times 10^{-3}$ mm$^2$ each were examined on each preparation at 5000 X magnification. X-ray spectra were collected for 30 s at a take-off angle of 20°. Diffraction patterns were obtained for the fibrous components.

## RESULTS

### *Air samples*

The gravimetric sampling results are reported in Table 2. Personal breathing zone air concentrations are reported for the burning unit and harvesting workers as well as the results of upwind and downwind stationary samples. Most of the burning unit samples produced analytical results which were above the range of six blank samples (range −0.01 to 0.04 mg weight change per sample; mean 0.01 mg). However, some of the burning unit samples had low gravimetric loadings. This might be expected since the sample period, which lasted the length of a single burn, was only 33–72 min.

Generally, the gravimetric samples indicate that airborne concentrations of total dust several hundred metres upwind of the burn are lower (average 0.3 mg m$^{-3}$) than the concentrations measured downwind (average 1.0 mg m$^{-3}$), and lower than the personal samples. Personal samples taken on six burning unit workers ranged from non-detectable to 5.2 mg m$^{-3}$, with a mean of 2.1 mg m$^{-3}$. During the cutting operations, personal exposures to total dust ranged from 0.1 to 1.3 mg m$^{-3}$ (mean = 0.6 mg m$^{-3}$). A sample collected on a conveyor operator at a transfer station indicated a 5-h time-weighted air concentration of 2.6 mg m$^{-3}$ while the air concentration for a loading Jackman was measured at 0.8 mg m$^{-3}$ during this same period.

The results of the analysis of the filter samples for fibres are also reported in Table 2. Inorganic fibres, as confirmed by using an energy dispersive X-ray analyser, were found in a few of the samples that were collected on workers involved with burning as well as cane cutting and material transport. The calculated number of inorganic fibres per cubic metre of air was 15 000 and 58 000 for two of nine samples collected in the burn areas. In the cutting operations, three of the seven samples collected contained inorganic fibres. The air concentrations were calculated as being equivalent to 60 000–300 000 fibres m$^{-3}$ of air. An additional personal sample of a loading Jackman contained fibres which would correspond to a concentration of about 9000 fibres m$^{-3}$ of air. Many of the fibres from each sample contained elements in addition to silicon while some fibres contained no silicon. It is unknown specifically why not more samples contained inorganic fibres. One possibility is that fibre loss or selective sampling bias occurred during collection and/or transport.

Table 3 specifically describes the elemental composition of 30 inorganic fibres that were seen in one air filter sample that was collected on a cane cutter. This analysis was performed using SEM and electron-probe X-ray micro-analysis. The analysis shows that most of the inorganic fibres contained primarily silicon. Calcium and magnesium were also often found, but to a lesser degree. Only one of the fibres observed within the scanning area of this sample contained silicon alone. It was assumed that when silicon

TABLE 2. AIR SAMPLING RESULTS FOR TOTAL WEIGHT AND INORGANIC FIBRES COLLECTED DURING SUGARCANE FIELD HARVEST OPERATIONS

| Location | Total weight: Analytical result (mg) | Total weight: Air concentration (mg m$^{-3}$) | Inorganic fibres: Analytical result | Inorganic fibres: Air concentration (fibres m$^{-3}$) | Location description |
|---|---|---|---|---|---|
| Burning | 0.02 | 0.3 | ND† | | Area sample taken upwind of first burn |
| | 0.03 | 0.5 | ND† | | Area sample taken downwind of first burn |
| | 0.06 | 0.8 | ND† | | Area sample taken downwind of second burn |
| | ND* | — | ND† | | Area sample 100 yards upwind of second burn |
| | 0.08 | 1.8 | | | On water wagon near burn |
| | 0.02 | 0.5 | ND† | | Attached to water wagon downwind of burn |
| | 0.02 | 0.4 | 4 | 58 000 | On water wagon downwind of burn |
| | 0.06 | 1.7 | ND† | | Burner |
| | 0.14 | 2.7 | 1 | 15 300 | Burner |
| | 0.01 | 0.2 | ND† | | Burner |
| | 0.25 | 5.2 | ND† | | Burner yardsman |
| | 0.08 | 1.0 | ND† | | Burner |
| | 0.10 | 1.7 | ND† | | Burner |
| Cutting operations | 0.02 | 0.1 | ND† | | Cane cutter |
| | 0.22 | 1.0 | ND† | | Cane cutter |
| | 0.27 | 0.7 | 38 | 60 000 | Cane cutter |
| | 0.55 | 1.3 | 60 | 300 000 | Cane cutter |
| | 0.33 | 0.8 | ND† | | Cane cutter |
| | 0.15 | 0.3 | ND† | | Cane cutter |
| | 0.32 | 0.9 | 30 | 133 000 | Cane cutter |
| Area samples | 0.91 | 2.6 | ND† | | Conveyor operator at truck station |
| | — | — | ND† | | Attached to cane conveyor |
| | — | — | ND† | | Downwind of cut fields |
| | — | — | 2 | 980 | Upwind of cut field |
| | 0.33 | 0.8 | 19 | 9 300 | Attacked near Jackman at loading platform |

*Sensitivity to 0.01 mg per sample.
†Less than 1 fibre detected in a field area of at least 0.7 mm$^2$.

alone was detected in a fibre it was in association with oxygen as silica, while when silicon was associated with other elements, it was a silicate. The lengths of the silica and silicate fibres on this filter ranged from 3.5 to 65 $\mu$m long with a mean of 12 $\mu$m (median = 6 $\mu$m). The width ranged from 0.3 to 1.5 $\mu$m with a mean of 0.6 $\mu$m.

Additional fibre analysis of the air filter samples was performed using TEM with X-ray diffraction. Approximately 56% of the inorganic fibres found on sample F8 contained silicon only or silicon plus lesser amounts of calcium, potassium, or magnesium. Figure 1 presents four photomicrographs of some of the fibres seen on sample F8. Photomicrographs 1–3 contain fibres that are composed entirely of silicon while the fibre in photomicrograph 4 contains silicon, calcium and magnesium. All diffraction patterns obtained during the analysis indicated that the silicon was amorphous. The X-ray spectra that accompanied the fibres are also shown in Fig. 1.

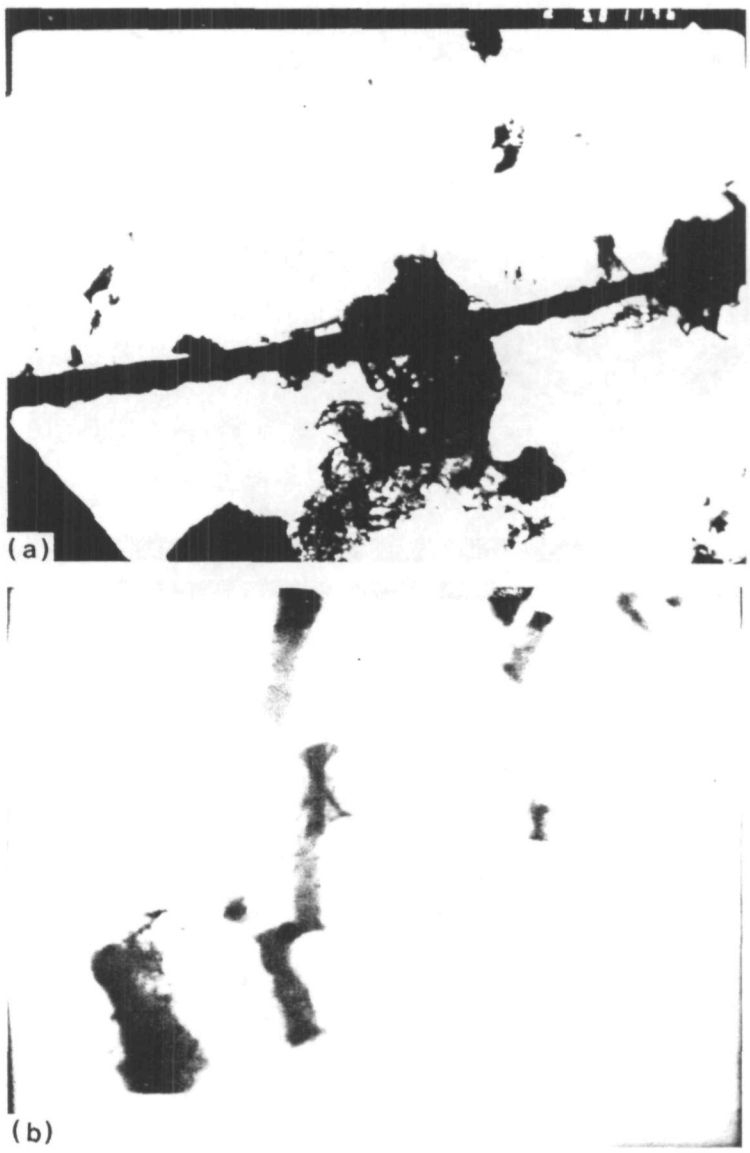


FIG. 1. (a) and (b).

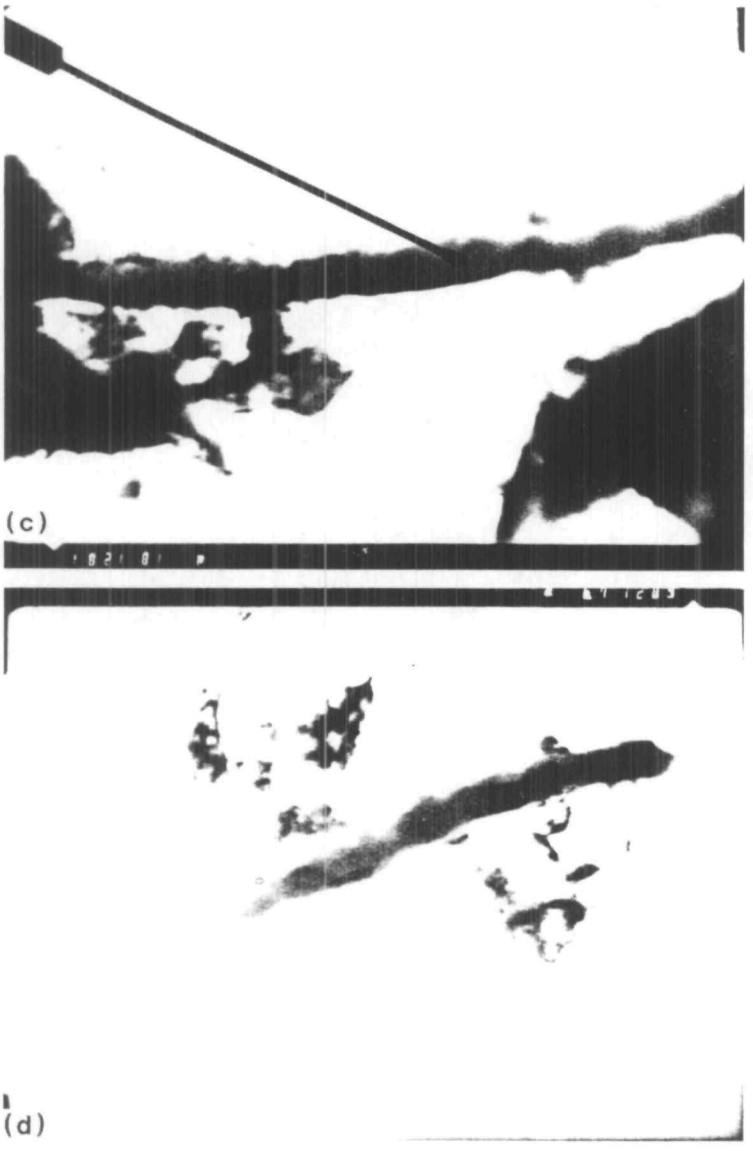


FIG. 1. (c) and (d).

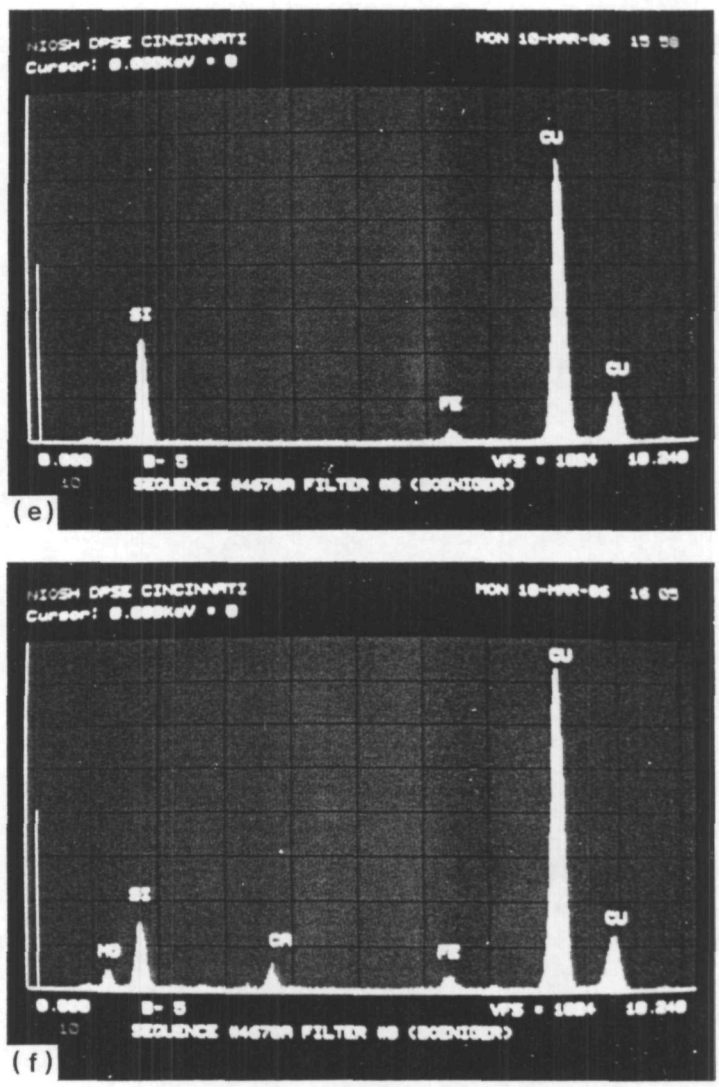


FIG. 1. (e) and (f).

FIG. 1. Photomicrographs of siliceous fibres found on a filter showing (a)–(c) fibre types that contain only silicon in the accompanying energy dispersive X-ray spectra, and (d) a fibre composed of a silicate containing some magnesium and calcium. Iron and copper, shown in the X-ray spectra (e) and (f), are artefacts of the instrumentation.

FIG. 3. (a) and (b).

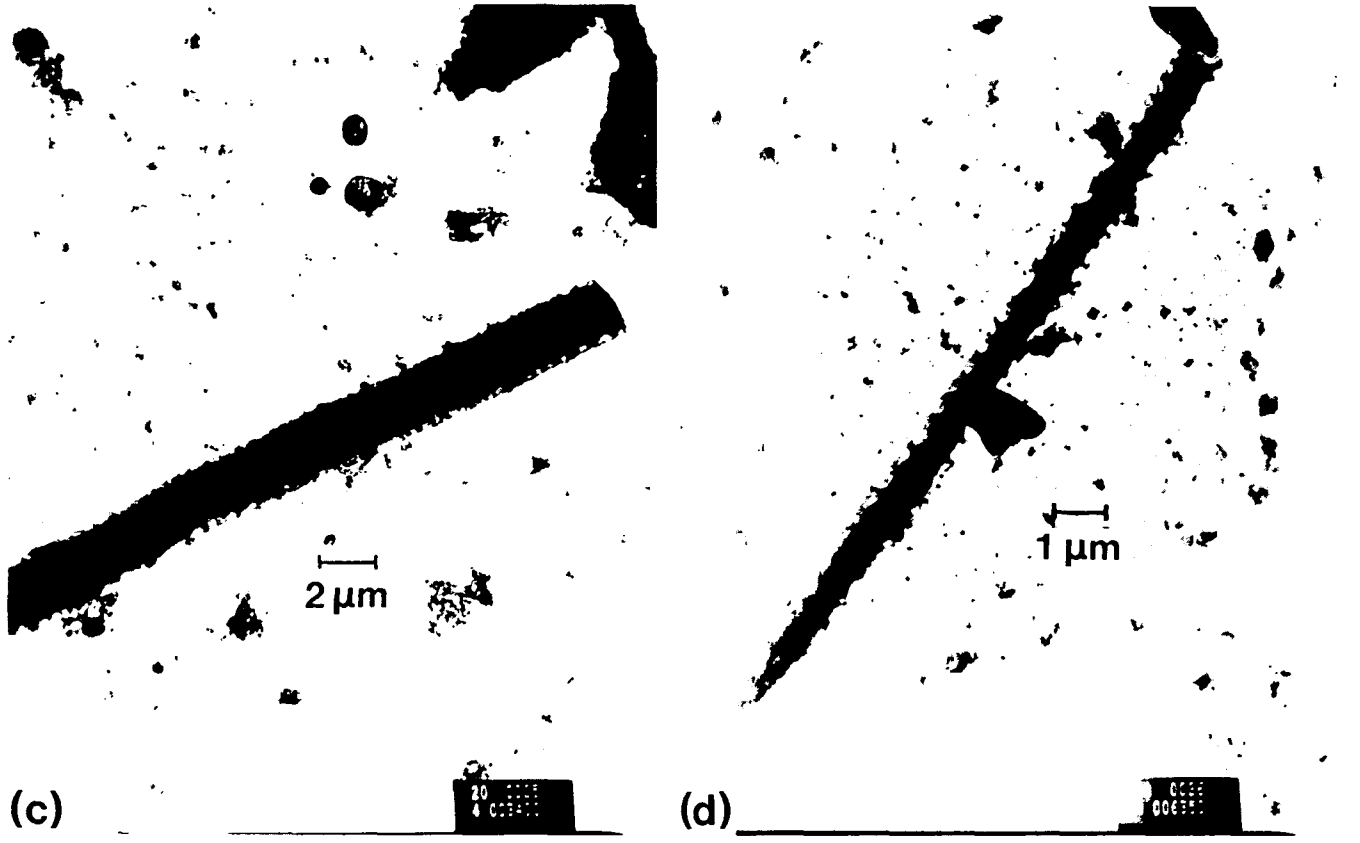


FIG. 3. (c) and (d).

FIG. 3. Photomicrographs of silica fibres found in ashed materials. Fibres (a) and (b) are $1 \times 30$ $\mu$m, respectively, and were found in ash after a cane field was burned. Fibres (c) and (d) are $2 \times 28$ $\mu$m and $0.6 \times 15$ $\mu$m, respectively, and found after mature cane leaf was ashed in the laboratory in a plasma low temperature asher.

TABLE 3. SPECIFIC FIBRE IDENTIFICATION FOR A FILTER SAMPLE

| Elemental composition | Number of fibres* |
|---|---|
| Si only | 1 |
| Si and Ca | 11 |
| Si, Ca and Mg | 6 |
| Si, Ca and S | 3 |
| Si, Ca and K | 2 |
| Si, Ca, Mg and P | 2 |
| Si, Ca, Mg, K and S | 2 |
| Si, Ca, Mg and Cl | 1 |
| Si, Ca, Mg and K | 1 |
| Si, Ca, Mg, K. Cl and S | 1 |
| | 30 |

*An area of 0.244mm$^2$ was examined by taking 20 1000× magnification fields.

Figure 2 is a scatter diagram showing the size distribution of inorganic fibres on an air filter sample that was collected near the Jackman on a loading platform. The sizes of 19 fibres were plotted by diameter and length. Most of the fibres were less than 1 $\mu$m in diameter and 2–10 $\mu$m long. These results also indicate that these fibres may also be determined by phase-contrast microscopy.

Eighteen air samples were submitted for PAH analysis. Included in the samples were three from upwind and downwind stationary sites, eight from burning unit workers and seven collected during cane cutting. Acetonitrile was chosen as the best solvent for extraction of the filters. The instrumental limits of detection for each of the 16 PAH standard compounds were between 0.3 and 0.5 $\mu$g per samples. Because the gravimetric loading on each sample was low, none of the PAH compounds included in the analysis was detected in any of the filter samples, nor were any of the analytes detected in the sorbent tubes.

*Bulk samples*

Bulk fibre analysis results are reported in Table 4. Reported in the first column are the identifies of each sample. The sugar-cane samples are listed by their designated variety, clones or cultivar number. In the second column the number of pure silica fibres are reported. When some of the fibres also contained magnesium and/or calcium, the number of such fibres is reported within parentheses. All of the silicon fibres displayed non-crystalline diffraction patterns. The lower- and upper-size range of the fibre diameters and lengths are provided in the right-hand side of the table. As can be seen, the fibre diameters in the sugar-cane range from 0.1 to 1.75 $\mu$m and the lengths varied from 3 to 50 $\mu$m. Based upon the sample dilutions made during preparation, it was calculated that the number of silica fibres per gramme of dry unburned leaf could be obtained by multiplying the results reported in Table 4 by 320 000. Photomicrographs of some of the fibres seen in the bulk sample analysis are presented in Fig. 3. These fibres are characteristically similar to the fibres found on the air filter samples shown in Fig. 1.

The bulk ash field sample contained about as many silicon fibres as the LTA

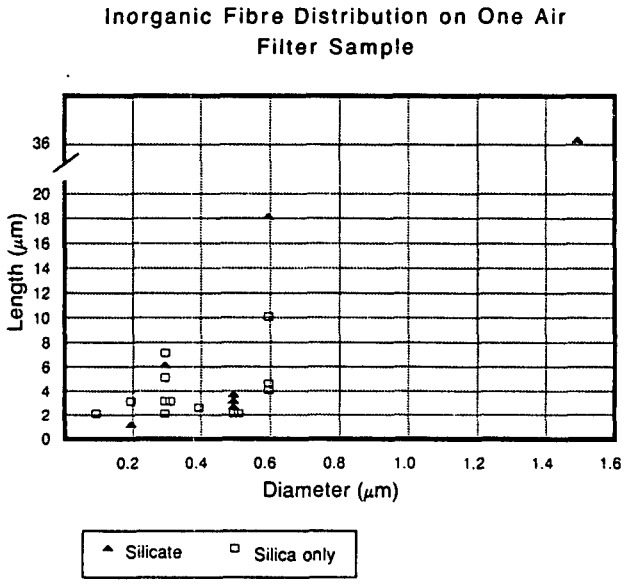


FIG. 2. Inorganic fibre distribution on a sample filter collected during cane harvesting.

TABLE 4. TEM COUNT OF SILICON FIBRES IN ASHED MATERIALS

| Sample type and number | Number of fibres detected | Range (μm) Diameter | Length |
|---|---|---|---|
| Mature sugar-cane leaf | | | |
| CP65-357 | 3 | 0.1–1.5 | 16–44 |
| CL54-378 | 7 (3) | 0.3–1 | 3–17 |
| CP63-588 | 3 (1) | 0.4–1 | 4–50 |
| CL59-1052 | 1 | 1 | 7 |
| CP70-1133 | 11 (2) | 0.1–1.75 | 3–22 |
| CP72-1210 | 4 | 0.3–1 | 5–44 |
| CP70-1527 | 9 | 0.3–1.75 | 3–40 |
| CP75-1632 | 3 (1) | 0.3–1.25 | 3–14 |
| CP74-2005 | 8 (1) | 0.3–3 | 5–30 |
| Sawgrass | 76 (10) | 0.3–1.75 | 6–60 |
| Field ash | 9 | 0.3–2 | 6–56 |
| Field soil | 3 | 0.3–0.6 | 2.5–6 |

The numbers in parenthesis in column 2 indicate that of the number of fibres reported, this many contained small amounts of magnesium and/or calcium, in addition to silicon.
100 fields were examined in each sample.

samples, as might be expected. The soil sample was found to contain silicon fibres but fewer than expected. It is suspected that the soil is a long-term depository of silicon fibres that have originated in the sugar-cane plant. The sample collected was taken only for the purpose of demonstrating the existence of silicon fibres in the sugar-cane leaf and in the soil. To evaluate quantitatively the soil concentration of inorganic fibres, more samples need to be collected.

Of the 16 compounds sought in the analysis of the bulk ash sample collected from a

burnt field, only fluorene (26 $\mu g\ g^{-1}$), phenanthrene (15 $\mu g\ g^{-1}$) and anthracene (13 $\mu g\ g^{-1}$) were detected.

## DISCUSSION

Generally, there are four basic job categories involved in field operations: equipment operators, burning unit workers, cane cutters and supervisors. Several workers from the first three categories were monitored for airborne exposures to total dust, polyaromatic hydrocarbons and fibres.

While machine operators, cane cutters and burning unit workers may all be potentially exposed to dust, soot and smoke, the magnitude of exposures might be expected to vary considerably depending upon weather conditions and the location of the worker. Any exposure monitoring data that are collected outdoors are subject to these conditions. The present study was conducted after several months of drought of a degree that was quite unusual for this area. This area had also recently experienced unusual frost conditions which had stressed the mature cane. Therefore, it is currently uncertain how past weather conditions may have influenced the results reported here or how the present findings would differ if the survey had been conducted following more normal conditions.

NEWMAN (1983) found a greater number of siliceous fibres in the sugar-cane leaf grown in Trinidad than were presently found in the leaf from Florida. Since others have shown that the availability of soluble soil nutrients affects the elemental content of the plant, one might suspect that the soil difference in Trinidad and Florida may account for the difference in the number of siliceous fibres. The Florida everglades area soil is comprised primarily of peat which may be deficient in soluble monosilicic acid. The volcanic island of Trinidad, on the other hand, would be expected to contain a higher proportion of silica.

The fibre counts and size distributions reported here should not be considered quantitatively accurate. Potentially serious quantitative variance of the fibre counts has recently been reported for air samples collected on nuclepore filters (KELLER and KESTNER, 1985). Problems have been attributed to static electric interference during sampling (CHATFIELD *et al.*, 1983; SPEIGHT and MARSH, 1984; PECK *et al.*, 1986) and dislodging of fibres during transport and analysis (HARRIS and PROCTOR, 1968). In spite of these problems which can greatly reduce the actual number of fibres seen on a filter, substantial numbers of inorganic fibres were detected on some of the air samples.

The health effects of inhaling the amorphous siliceous fibres described here are unknown. However, the similarity between these fibres and other fibres which are known to cause serious health effects is reason for concern. Recently, ceramic fibres that are made from aluminium-silicate minerals were found to cause abdominal tumours and mesotheliomas in rats exposed via intrapleural injection (DAVIS *et al.*, 1984). In 1984, NIOSH stated in regard to asbestos that there is no safe concentration of exposure to asbestos (NIOSH, 1984b). Considering the infeasibility of reducing all exposure to zero and the imprecision of the air measuring techniques, NIOSH recommended that exposure to asbestos fibres greater than 5 $\mu m$ in length (as determined by phase-contrast microscopy) should not exceed 100 000 fibres $m^{-3}$ of air. As seen in this study, worker exposure to silicate fibres sometimes exceeded the above recommendation. The two unrelated reports of lung cancer and mesotheliomas among

sugar-cane farmers (DAS *et al.*, 1976; ROTHSCHILD and MULVEY, 1982) support a need for concern.

Total dust exposure was determined to be below all established limits for nuisance dust. Samples that were collected on burning unit workers were generally of a short duration and the workers try to avoid heavy exposure to smoke. Cane cutters usually begin work soon after dawn to avoid the heat. Typically, nights are accompanied by heavy dews which dampen the cane that was burned on the previous day. The above factors may help to reduce overall exposure to total dust and could account for the low concentrations found in this investigation. Possibly because of problems with obtaining an accurate air sample, no correlation existed between measured fibre concentration and total dust weight concentration.

The low gravimetric loading on the sample filters collected here also precluded the chance of detecting polyaromatic hydrocarbons in the air. Detection of only three of the 16 PAH compounds during the analysis of a bulk ashed-leaf sample from the field suggests that these other 13 PAH compounds may not be formed during the burning process. However, our analysis of only 16 PAH compounds is very selective, considering that potentially hundreds of PAH compounds could form during the burning process. Only some of these compounds have been tested for carcinogenicity. Some have been shown to cause cancer directly while others may promote the development of cancer after initiation by another substance. Thus, whether the soot resulting from the burning of cane leaf is hazardous to health is very difficult to predict. The cane cutting operation is extremely dirty work because of the frequent contact the workers have with the cane. Even if respiratory exposure to the inorganic fibres and PAH compounds is minimal, this does not preclude the possibility that a hazard to the skin might exist.

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