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Exposure Assessment of Smoke and Biogenic Silica Fibers During Sugar Cane Harvesting in Hawaii

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Agricultural burning is a worldwide practice performed to reduce trash and pest infestation after the crops are harvested. Although this function is economically beneficial, the large quantities of smoke potentially expose not only the farm workers but also any surrounding communities. Characterization of this smoke is difficult, and there are few published reports on this topic.

Unique to the sugar cane industry is the practice of burning the crop *before* harvesting. This not only produces smoke but also creates a considerable potential for worker exposure to the ash during the harvesting operations.

A previous study had characterized workers' exposures to biogenic silicate fibers during manual harvesting of sugar cane in Florida. In Hawaii, contrary to practice in Florida, all cane is mechanically harvested. An exploratory survey was performed in Hawaii for the purpose of evaluating the feasibility of using gravimetric particulates, organic and elemental carbon, total elemental profiles, polycyclic aromatic hydrocarbons, and biogenic silica fibers to characterize smoke. In addition, personal air sampling was performed to characterize exposure to biogenic silicate fibers and total particulate mass. Results of this assessment indicate that among the above indices evaluated, organic carbon and total elemental analysis of air samples present the most promising means of characterizing smoke.

In addition, it was concluded that harvest workers in Hawaii are exposed to respirable silica fibers which are physically similar to those fibers found previously in Florida. Compared to the National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit (REL) for asbestos of 100,000 fibers/m^3, or the NIOSH REL for fibrous glass of 3 million fibers/m^3 time-weighted average (fibers ≤ 3.5 μm in diameter and ≥ 10 μm in length), the highest partial period air concentration of biogenic silica fibers was 56,000 fibers/m^3 obtained among the harvest workers, and 8,350 fibers/m^3 obtained among the mill workers. The predominant diameters of these fibers ranged from 0.5 to 2 μm with lengths ranging from 10 to 40 μm. Total dust exposures for both the field harvesting and mill workers were below accepted criteria for unclassified particulates. **Boeniger, M.F.; Fernback, J.; Hartle, R.; Hawkins, M.; Sinks, T.: Exposure Assessment of Smoke and Biogenic Silica Fibers During Sugar Cane Harvesting in Hawaii. Appl. Occup. Environ. Hyg. 6:59–66; 1991.**

Introduction

Biogenic amorphous silica is common to the plant kingdom, and the morphology is fibrous in some species, i.e., the length to width aspect ratio is greater than 3.(1,2) It has been demonstrated that amorphous silica fibers are present in sugar cane and can become airborne when fields are burned.(1) In the past few years, public concern in Hawaii has been expressed about the potential for exposure to biogenic fibers released into the air during the common practice of burning the sugar cane fields just before harvest. Reference to these fibers as "asbestos-like" was first made in 1983 and has understandably heightened the public's concern, especially among those who live near sugar cane growing areas.(2) Although far from definitive, there is a diverse body of literature associating biogenic silica fibers with cancer.(3) A previous study of the Florida sugar cane industry demonstrated the potential for workers' exposures to these fibers.(1) The airborne fibers found in Florida were 3.5–65 μm long (mean = 12 μm) with an average diameter of 0.6 μm. Such fibers have the potential to reach the lower lung.(4)

In 1987, as a result of increasing public concern, the Hawaii Department of Health requested the National Institute for Occupational Safety and Health (NIOSH) to investigate the potential for exposure to biogenic silica fibers and disease risks to sugar cane workers. In March 1988, NIOSH investigators responded by performing a preliminary site visit to a sugar cane plantation in Hawaii.

The environmental portion of the evaluation consisted of preliminary sampling to help assess the extent of exposure to sugar cane smoke and to biogenic silica fibers. The objectives of the environmental exposure assessment were 1) to evaluate ways of monitoring the presence of sugar cane smoke in the air and 2) to obtain preliminary information on the extent of sugar cane workers' exposures to airborne inorganic fibers in Hawaii.

Sugar cane in Hawaii is grown in irrigated fields for two years before harvesting. During that time, the cane can grow to 20 feet or more in length—forming dense masses. Harvesting and replanting are performed almost continuously at each plantation. When a field is ready for harvesting, workers will ignite the field while walking around its perimeter. It may take from 15 to 25 minutes for a given field to completely burn. These fires burn off most of the leaf which turns to ash and smoke. During the next day, the cane will be pushed into piles with bulldozers. Claw cranes then load the cane into hauling trucks. The cane is finally taken to a processing mill where it is unloaded and transferred into the mill by a claw crane.

After the sugar cane is pulverized and the sugar extracted, the remaining fibrous plant material, called bagasse, requires removal. At the mill, the waste bagasse is dried and burned in an adjacent electric generating facility.

Methods

To devise our monitoring strategy, basic information on the smoke constituents was considered.(5–8) It was concluded after a review of the literature that the air collection strategy would include samples for: 1) particulate mass; 2) inorganic fibers; 3) organic carbon; 4) soil elements, especially aluminum (Al) and iron (Fe); 5) polycyclic aromatic hydrocarbons (PAHs); and 6) carbon monoxide. Air sampling was divided into personal and general area categories. A general overview of the field methods, followed by information on the materials and analyses performed, is provided below.

General Area Air Samples

Seven stationary area and truck-mounted sample sets were collected for the above analytes near the burning sugar cane fields (henceforth referred to as "smoke" samples). Two additional sample sets were collected away from any fires and are referred to as "clean" air samples. A customized dichotomous particulate sampler that selectively excluded large particles with a theoretical effective cutoff diameter of 10 microns was used only during the collection of particulate mass and carbon in the smoke samples. The dichotomous sampler selectively excluded large, low-density, airborne particles that would not be expected to reach the lower lung.(9) Since the other constituents, such as large particles of soil, were not expected to become and remain airborne due to their higher density, the dichotomous sampler was not used in the collection of these materials.

Elemental profiles on particulate collected in air samples and in the soil were of interest. Once the elemental constituents of the soil were identified, the objective was to determine if the collected particulates on the air sample media had the same elemental profile as the soil. If they did, then the source of these particulates was likely to be the soil, and this information could corroborate an earlier hypothesis that soil particulates become airborne in the updraft created by large fires and are a substantial component of the smoke.(8)

A few grab samples with detector tubes for carbon monoxide gas were also collected. All of these samples were collected to determine their potential as indices of cane smoke in later studies.

To determine the background concentrations of these constituents and for the purposes of comparison, two stationary sites, identified as sample sets 1 and 2, were set up at remote locations within the plantation property. Each set included media from methods 1–5 described above. Although harvesting operations were performed on this day, field burning was not. Sample set 1 was positioned about a mile upwind of the harvesting operations. Sample set 2 was located several miles away from the harvesting operations. The sampling media were located at least 10 feet above ground level. Wind speeds on that date were 3–10 mph.

The field to be burned was located on the lower slope of Haleakala crater, Maui, at 800- to 1075-foot elevation, and covered an area of 359 acres. Only 60–100 acres were usually burned per day, and the entire field required several burns. Smoke samples were collected at various distances downwind during three burns. Media from methods 1–5 identified above were included in each sampling station.

Variable wind directions were often encountered during the times that air samples were collected around burning cane fields. This made it nearly impossible to place stationary samples with any assurance of being downwind of the burning field. Therefore, both stationary as well as mobile truck-mounted stations were used in an attempt to be positioned downwind of the burning fields. The truck-mounted sampling stations positioned the sampling medium on a pole approximately 12 feet above the ground. Distances of approximately 50–3000 feet downwind of the burn sites were chosen for sampling. Most samples were collected for the duration of the burn.

Personal Air Sampling

Cane burning and harvesting operations were monitored by collecting personal breathing zone samples on workers performing most of the required jobs. Only filter samples for total particulate mass and/or inorganic fiber analysis were collected on those workers. The total particulate mass sample was collected primarily to determine if there was a general relationship between total dust exposure and inorganic fiber concentration among different job duties. Although the field workers may spend up to eight hours working, most samples were discontinued after a shorter time period to prevent excessive dust loading.

Personal breathing zone air samples were collected in a sugar mill to characterize workers' exposure to total particulate mass and biogenic silica fibers. Workers were selected because of their likelihood of having the greatest potential for exposure. When more than one sample set was collected on persons with a single job title, the second sample was taken during the second shift. To obtain preliminary information on the size distribution of airborne bagasse dust, a dichotomous sampler was used next to a total dust sampler in the bagasse room. This sample pair was collected over the operator's booth located on the bagasse room floor.

Materials and Analyses Procedures

The above analytes were collected and determined by the following methods:

1. Stationary particulate mass samples were collected on preweighed, 37-mm, 5-μm pore size, polyvinyl chloride filters. The air flow rate was 2 or 7 L/min for collecting the clean air samples. Personal dust samples were collected in closed-face cassettes at a flow rate of 2.5 L/min. These samples were analyzed by equilibrating for humidity and temperature and reweighed to determine the mass of the deposited particulates (NIOSH Method 500—Particulates).(10)
2. Air samples for inorganic fibers were collected on 25-mm, mixed cellulose ester, open-face filters with conductive cowls. Stationary and personal air samples were collected at a flow rate of 3 L/min. Analysis was performed using transmission electron microscopy (TEM) at 10,500× magnification for sizing and counting fibers with a length to width ratio of 3:1 or greater. Energy dispersive X-ray analysis (EDXA) was used for determination of the elemental constituents. Electron diffraction was also employed to determine the crystallinity of a fiber. Only fibers containing predominantly silicon were counted. Bulk dust samples were subjected to low temperature plasma ashing prior to analysis to determine the presence of inorganic fibers, free of an organic matrix.(1)
3. Stationary organic carbon samples were collected on 37-mm, Pallflex Corporation, QAOT quartz fiber filters that had been prefired to reduce organic carbon background. The sampling flow rate was 7 L/min. Analysis was performed by thermal–optical techniques.(11,12) Although the limit of detection for organic carbon is about 2.0 μg/sample, typically the sample absorbs some organic carbon from the atmosphere during storage and handling. Therefore, the results reported were all field blank corrected. These samples were collected using a dichotomous sampler to exclude large ash particles.
4. Trace element sampling was performed using 37-mm mixed cellulose ester filters in closed-face cassettes at an air flow rate of 3 L/min. The filter samples were ashed using concentrated nitric and perchloric acids. The residues were dissolved in a dilute solution of the same acids, and the resulting sample solutions were analyzed for trace metals by inductively coupled argon plasma–atomic emission spectroscopy (ICP-AES). Bulk soil was weighed, digested, and reconstituted in the same manner as the filter samples (NIOSH Method 7300—Elements).(10) A bulk soil sample was also submitted for qualitative X-ray powder diffraction (XRD) and X-ray fluorescence spectrometry (XRF).
5. Stationary samples for PAHs were collected according to NIOSH Method 5506, using a sampling train consisting of a 2-μm pore size, 37-mm, PTFE (Zefluor®) filter followed by a washed XAD-2 sorbent tube.(10) The samples were collected at a flow rate of 2.5 L/min. Because air concentrations were expected to be low, composite samples from the fires were collected by taking successive samples on previously used sampling media. A bulk ash sample was collected from a recently burned field for PAH analysis. Laboratory analysis of the bulk involved weighing a known amount and extraction by sonicating for 30 minutes in 5 ml of benzene. Seventeen specific PAHs were included in the analysis.
6. Grab samples for carbon monoxide were taken by using long-term detector tubes attached to a sampling pump that drew air at a rate of 0.02 L/min. The amount of carbon monoxide present was determined by visually inspecting the tube for stain length.

Bulk Analysis

Bulk cane leaf analysis for inorganic fiber identification and counting was performed by weighing a given amount of dried leaf, ashing this, and suspending an aliquot of the ash in solution to be distributed upon a 25-mm filter. One hundred fields in the resulting filter preparation were examined, and all fibers which met the width to length aspect ratio of 1:3 were counted by TEM at a magnification of 10,500×. Photomicrographs of representative fibers were taken at magnification settings ranging from 3400× to 7750×. Elemental spectra of representative fibers were also obtained during the analysis. A bulk bagasse sample of settled dust collected in the bagasse house was analyzed identically.

Results

Field Burning Operations

The results from the samples collected around the cane fields are reported in Table I. The sample results indicate that very low particulate concentrations exist and that organic carbon and elemental aluminum and iron were not detected in areas removed from harvesting when no burning takes place (sample sets 1 and 2). Analysis of the sample for airborne inorganic fibers also revealed that such fibers were not normally present in air.

When air sampling was performed near burning fields, detection of these components of the smoke was possible. Sample sets 3–9 (Table I) show the results of samples that were collected at various ground locations around the burning fields. In brief, the concentration of airborne particulate mass increased by at least 20 and up to 70 times the measured background level at the sampling sites chosen. Organic carbon was detected in all samples collected near the burning fields. Aluminum and iron are the predominant elements in this soil. These elements were detected in each of the smoke samples, and the ratio of aluminum to iron closely matched that of the native soil.

PAHs were absent (below the limit of detection or LOD) in the filter segment of the air sampling train in all the composite air samples. The limit of analytical detection

TABLE I. Local Air Concentrations of Various Smoke Constituents During Field Burning

Sample Set No.	Sample Minutes	Particulate Mass (mg/m^3)[A]	Organic Carbon (μg/m^3)[B]	Elements (μg/m^3)		Fibers (f/m^3)	Location/Description
				Al	Fe		
1	420	< 0.01	ND[C]	< 0.5	< 0.5	ND	"Clean" air sample, one mile upwind of harvesting operations
2	380	0.01	ND	< 0.5	< 0.5	ND	"Clean" air sample, several miles distant from harvesting operations
3	29	0.5	123	< 11	< 11	ND	Stationary sample 50 ft from burning field but only in smoke about 5 min (Day 1: am)
4	100	0.7	430	—[D]	—[D]	680	Stationary sample 50 ft from burning field but in smoke only 5–10 min; winds 2–9 mph (Day 1: am)
5	70	< 0.2	—[D]	20	18	ND	Stationary sample 3000 ft downwind from burning field (Day 1: am)
6	35	< 0.4	73	35	29	ND	Mobile truck station (Day 1: pm)
7	57	—[D]	29	20	11	2140	Mobile truck station (Day 1: pm)
8	60	0.5	92	39	30	6200	Mobile truck station near highway about 25 min in direct smoke (Day 2: am)
9	60	0.3	73	14	12	ND	Mobile truck station by highway about 15 min in direct smoke (Day 2: am)

[A] Blank corrected based on a 5-blank average of 0.05 mg/sample. A sampler with a 10-cm cut-off diameter was used.
[B] Blank corrected based on a 2-blank average of 2.18 μg/sample.
[C] Sample value below the blank value.
[D] Sample voided for technical reasons.

was between 0.3 and 0.5 μg/sample for each PAH. Traces of chrysene and benz(a)anthracene were detected on the sorbent tubes; however, these were at the limits of detection and could not be confirmed. Analysis of the bulk sample of fresh cane ash revealed a trace (2.3 μg/g) of fluorene which was below the limit of quantitation (LOQ = 3 μg/g). None of the other 16 PAHs included in the analysis were detected in the bulk sample (LOD = 1 μg/g).

Because of the short time in which most of the samples were in the direct line of smoke, many of the dichotomous samplers contained particulate mass that was only equivalent to or below the blank sample value (Table I). These results do indicate that the inspirable dust mass was minute during the days sampled and was only a small fraction of the concentration established by workplace and ambient air quality criteria for particulates.

The results from the dichotomous samplers for organic carbon indicate that this substance may be a more sensitive determinant of cane smoke than particulate mass. All samples which were successfully collected and analyzed, with the exception of those samples taken when no smoke was present, contained measurable amounts of organic carbon. The highest concentrations were detected adjacent to the fields (sample sets 3 and 4).

Bulk soil analysis was performed to ascertain its mineral composition. As was expected from prior analysis of this soil, hematite (Fe_2O_3) and magnetite (Fe_3O_4) were detected by qualitative XRD analysis. Microscopic analysis also identified, in addition to hematite, the presence of some quartz particles. XRF analyses indicated that the sample consisted mostly of aluminum, silicon, iron, and titanium, with lesser amounts of potassium, calcium, and zirconium, with traces of zinc, strontium, and manganese. Although the most likely combination of these elements would be in the form of aluminum silicates mixed with different elements, the XRD analysis indicated low intensity peaks in the diffractogram which made it very difficult to specifically identify any silicates. The ratio of the two most abundant elements in the soil, aluminum and iron, was 1.4:1.

Samples from nine air sample stations were also analyzed for elemental constituents. The concentration was below the limit of detection for aluminum and iron in the clean air samples used to determine background levels. However, these elements were detected in five of seven smoke samples. The average ratio of aluminum to iron in these air samples (1.3 ± 0.3) was relatively similar to the ratio obtained in the bulk soil sample analysis. These results support an earlier postulate that the smoke from these fires contains substantial quantities of fine soil particles.(8) However, the possible contribution of road dust from moving vehicles and from wind-borne soil off of cleared fields means that this analysis is not specific to the occurrence of burning fields. Nevertheless, elemental analyses of air filter samples appears to offer potential as a sensitive complement to the determination of smoke from agricultural fires.

Airborne inorganic fibers were detected at low concentrations in less than half of the samples collected. These fibers were found to match the biogenic silica fibers found in ashed sugar cane leaf. Typically, workers were not in the areas of these downwind samples.

The detector tubes used to sample carbon monoxide (CO) did not indicate substantial amounts of CO. These samples were taken next to the fires and would be as close

TABLE II. Personal Air Concentrations of Total Particulate Mass and Inorganic Silicate Fibers Among Field Harvesting Crews

Sample Set Number	Sample Minutes	Location/Description	Particulate Conc. (mg/m³)	Fiber Conc. (fibers/m³)
1	88	Burner	ND	ND
2	378	Burner and rake operator	0.6	—*
3	103	Burner and rake operator	—*	56,280
4	85	Water wagon driver	—	3,220
5	87	Supervisor during burn	—	4,480
6	475	Utility worker	3.2	—
7	474	Small rake operator	2.1	1,250
8	361	Rake operator	—	3,720
9	360	Rake operator	—	3,970
10	100	Rake operator	3.4	30,270
11	75	Field supervisor	—	5,950
12	302	Dozer operator (part-time)	—	4,560
13	161	Dozer operator	—	10,250
14	435	Crane operator	0.2	1,390

*No sample taken.

to the fires as any worker could tolerate. Results ranged from nondetectable to about 5 ppm, the latter sample collected in the midst of high levels of smoke for 5 minutes. Because these results were time-integrated over a duration of at least 5 minutes, short-term peak concentrations could be higher. While CO may be present in the interior of the burning fields due to oxygen deficiency, concentrations appear to be low within a small distance from the fires.

Harvesting Operations

The air sampling results from samples collected on harvesting crew workers are reported in Table II.

The gravimetric analysis indicates varying degrees of exposure to particulates. These exposures ranged from as little as 0.2 mg/m^3 to as much as 3.4 mg/m^3. These gravimetric results are less than the specified limits for unclassified dusts (4 mg/m^3, Threshold Limit Value;[13] 15 mg/m^3, Permissible Exposure Limit;(14) no criteria, NIOSH). Application of these workplace criteria for dusts to our results may or may not be appropriate. Although only a few samples were collected, they are believed to fairly represent typical conditions during harvesting.

Also reported in Table II are results from the inorganic fiber analysis of the personal samples collected on harvesting crew workers. Eleven of twelve personal samples contained inorganic fibers. These fibers were typically pure amorphous silica, probably existing as silicon dioxide (SiO_2). The fiber counts have been converted to units which reflect the number of fibers per cubic meter of air (fibers/m^3). These results ranged from nondetectable to 56,000 fibers/m^3. The highest concentration measured was less than the NIOSH recommended exposure limits (RELs) of 100,000 fibers/m^3 for asbestos and 3 million fibers/m^3 for fibrous glass.(15,16) Figure 1 presents the combined size distribution of fibers found on these personal samples. The majority of these airborne fibers were 0.5 to 2 μm in diameter and 10 to

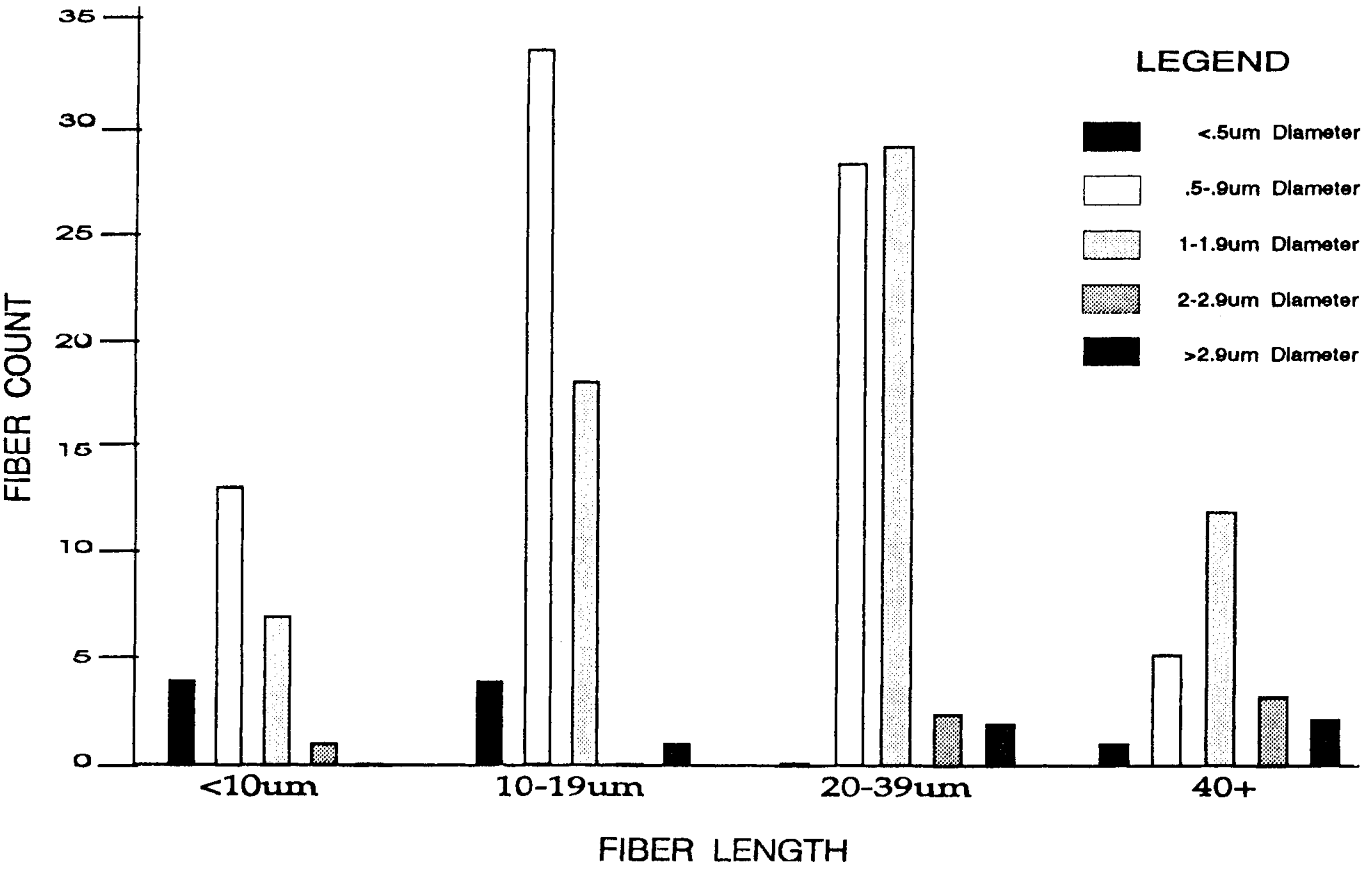

FIGURE 1. Distribution of airborne fibers by diameter and length from field harvesting operations.

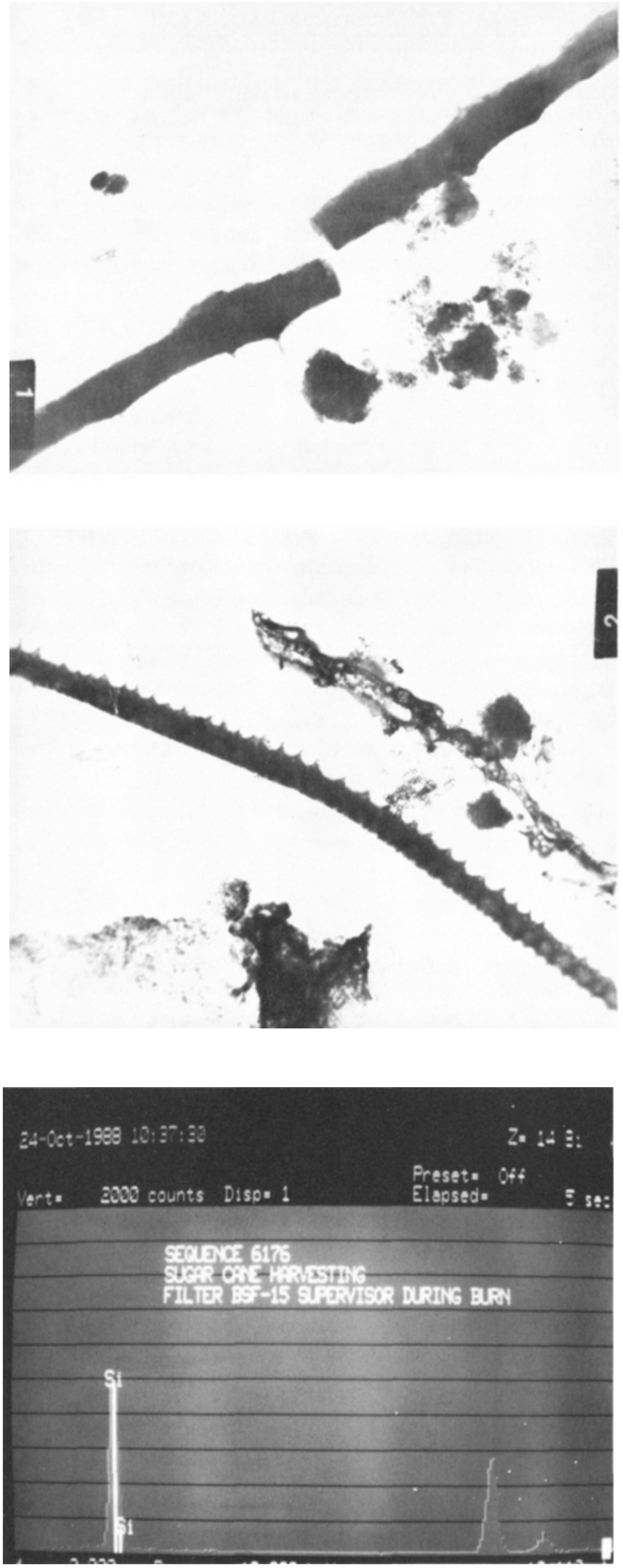

FIGURE 2. Photomicrographs and energy dispersive X-ray analysis spectrum of fibers collected on air filter samples from sugar cane harvesting workers. The broken fiber on photomicrograph 1 appears to have been initially greater than 25 µm long with a diameter of 2 µm. The fiber on 2 has a length of 20 µm and an average diameter of 1.25 µm. The copper peak in the EXDA spectra is from the grid used.

TABLE III. Personal Air Sampling Results for Total Particulate Mass and Inorganic Silicate Fibers in a Sugar Mill

Sample Set Number	Sample Minutes	Location/Description	Particulate Conc. (mg/m³)	Fiber Conc. (fibers/m³)
1	410	Crane operator	0.4	2490
2	220	Crane operator	1.5	8350
3	380	Cane cleaner operator	0.3	1410
4	409	Cane cleaner operator	0.2	1200
5	410	Trash truck operator	0.1	620
6	401	Utility operator	—*	1340
7	422	Cane hauler	0.9	ND
8	470	Cane hauler	1.7	ND
9	147	Bagasse dozer operator	1.2	ND
10	404	Bagasse dozer operator	2.1	ND

*Sample voided.

40 µm in length.

Mill Operations

The results of samples taken in the cane processing mill for total particulate mass and for inorganic fibers are presented in Table III. The highest measured total dust exposure concentration was 2.1 mg/m^3 on a bagasse dozer operator. All results for total particulate mass were below the criteria for unclassified total dust. Sampling results from the stationary pair of total and dichotomous head dust samplers in the bagasse room indicate that about half of the total collected dust is larger than the 10-µm cutoff diameter [1.34 mg/m^3 (< 10 aerodynamic diameter) versus 2.7 mg/m^3 (total)].

Fiber analysis of the refining mill air samples revealed that only the equipment operators on the outside of the mill were exposed to measurable numbers of inorganic fibers. These workers move the cane into the mill as it is received from the fields. These samples indicated air concentrations for inorganic fibers of between 1200 and 8350 fibers/m^3. The bagasse dozer operator and cane hauler truck drivers had no evidence of fiber exposure in their air samples.

Examples of the fibers seen in the air samples by TEM are provided in the photomicrographs shown in Figure 2. Elemental spectra accompany these samples. The vast majority of these fibers appeared only to contain silicon, which probably exists as silica. This is contrary to the findings from similar work performed in Florida, where almost all fibers contained traces of other elements in addition to silicon, i.e., they were silicates.(1) No selected area electron diffraction patterns were displayed by any of the fibers, and they are considered to be of an amorphous (noncrystalline) nature.

Only a total of eight sample pairs, consisting of a total particulate sampler and an inorganic fiber sampler, were collected in both the field and mill. Unfortunately, events leading to the voiding of some samplers and insufficient equipment prevented collecting more sample pairs. Nevertheless, these data suggest a significant correlation between the particulate air concentration and the fiber count (r =

0.99, p = 0.0001). This relationship would only apply to workers exposed to the dry cane materials, as would be experienced in the fields and at the receiving area of the mill.

Bulk Analysis

Analysis for inorganic fibers in a bulk sample of dry cane leaf and in a sample of dried bagasse dust was performed. The specific weights and fiber count totals are presented in Table IV. The total number of fibers found in equal initial weights of sugar cane leaf and bagasse dust was 29,700 fibers and 5,000 fibers, respectively. These counts are equivalent to 10 million and 1.7 million fibers per gram of material (dry weight).

TABLE IV. Transmission Electron Microscopic Fiber Count in Bulk Samples

	Sugar Cane Leaf	Bagasse Dust
Weight taken for ashing (g)	0.0694	0.0697
Weight used per 25 mm filter (mg)	2.92	2.90
Number fields counted	100	100
Number fibers counted	59	10
Fibers/filter	29,700	5000

In the bulk cane leaf sample, 39 percent of the total fibers (N = 59) were less than 5 μm long and 15 percent were less than 0.25 μm in diameter. The majority were 0.25 to 1.0 μm in diameter and between 2.5 and 15 μm in length. The size distribution of fibers found in the bagasse sample were essentially similar, although fewer fibers made this comparison tentative. Elemental spectra from these fibers essentially ruled out the presence of elements other than silicon. Thus, these fibers were not silicates but essentially silica. No crystalline diffraction patterns were detected, indicating an amorphous form. Examples of fibers seen by TEM and their elemental spectra are provided in Figure 3.

Discussion

Mobile sampling stations were used to assist in locating the sampling media downwind of the burning fields. However, this did not allow complete collections of smoke due to the unpredictable and ever changing variation in wind direction. In addition, road dirt could become airborne during each move and bias the contribution of detected analyte on the samples. Jarring of the samples when the trucks were in motion over rough roads may also have had an unpredictable effect on these results. Although not evaluated during this survey, airborne sampling stations using high-lift balloons which could be attached to the perimeter of the burning fields might best be used to position the sampling media in the path of the smoke plume. Such positioning would minimize the land-based problems mentioned and might be able to characterize the smoke constituents more accurately.

Inorganic amorphous silica fibers were also found in three of seven area samples located near the burning sugar cane fields. These samples were difficult to collect due to the shifting wind directions and were intended to produce only qualitative information about the suspected presence

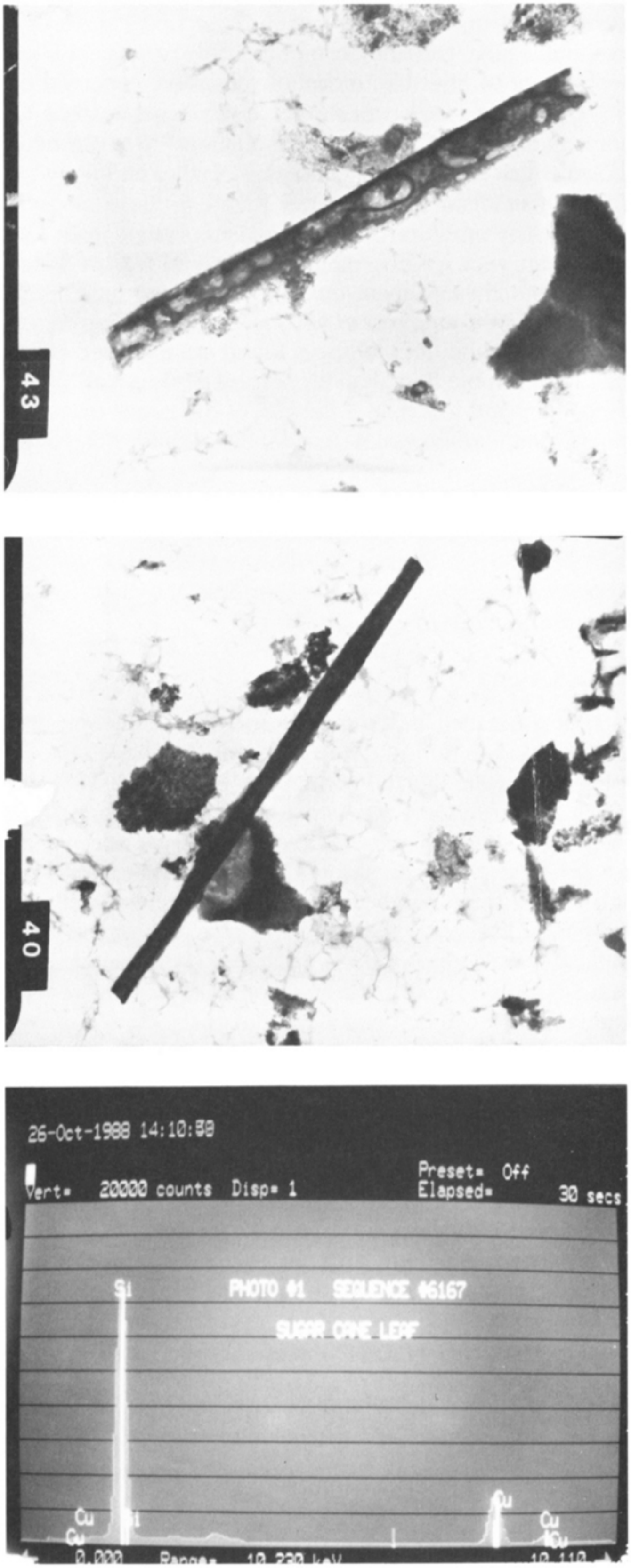

FIGURE 3. Photomicrographs and a typical energy dispersive X-ray analysis spectrum of fibers in ashed sugar cane leaf.

of these fibers as a constituent of smoke.

Inorganic amorphous silica fibers were present in almost all personal air samples that were collected on field crew workers and among mill workers involved with receiving and unloading raw cane. These fibers were of a respirable size, generally composed only of silica. A wide assortment of fiber-like morphologies were observed by TEM, showing a variety of surface and internal features. Of interest because of their possible relationship to mesothelioma is that small fibers, consisting of silica and less than 0.25 μm in diameter, were not found in these air samples.(17) The predominant fiber diameters range from 0.25 to 2.0 μm with lengths ranging from 5 to 80 μm. Some fibers with these dimensions (e.g., asbestos) have been associated with lung cancer and nonmalignant respiratory disease.(15) Although the fibers found are expected to be highly inspirable, less than 20 percent of the small diameter fibers and less than 5 percent of the larger diameter fibers found are expected to reach the alveoli.(4) The fiber counts ranged from nondetectable up to almost 0.06 fiber per cubic centimeter of air. The highest concentration measured was less than the NIOSH RELs of 0.1 fiber/cc for asbestos and 0.3 fiber/cc for dibrous glass. Fiber counts appeared to correlate with the dustiness of the job, as was expected.

Conclusions

It is concluded that sampling for organic carbon and elemental aluminum and iron may provide the most promising means among those methods evaluated for objectively measuring airborne smoke originating from sugar cane fires. Although these indices of smoke are not specific to agricultural fires, background air concentrations during this survey were nondetectable. Although these methods have the capacity to provide quantitative and unbiased results, it is unlikely that they can imitate the excellent sensitivity of the human nose and eye to detect smoke. Additional work will be needed to validate these preliminary observations.

The toxicity/carcinogenicity of biogenic silica fibers is unknown, although there is some suggestion in the literature that chronic health effects may be related to past exposure to these fibers.(3) While such "opaline" fibers have been known to persist in nature for centuries, it is not known if they are long lived in the lung. Both laboratory experimentation and medical/mortality studies of exposed populations should be performed in order to address these and other questions concerning biogenic silica fibers.

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