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HAWAIIAN COMMERCIAL & SUGAR COMPANY
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HAMAKUA SUGAR PLANTATION
HONAKAA, HAWAII

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I. SUMMARY

On December 29, 1987, the Hawaii Department of Health requested that the National Institute for Occupational Safety and Health (NIOSH) investigate chronic health effects of sugarcane smoke among sugarcane workers. Since the smoke contains "biogenic silica" fibers (BSF), chronic respiratory diseases were of particular concern. During March 1988, NIOSH investigators measured BSF in air near the Hawaiian Commercial and Sugar Company (HC&S) Plantation on Maui, and in August 1989 conducted further medical and environmental evaluations at the HC&S Plantation and at the Hamakua Sugar Plantation at Honakaa (Island of Hawaii). In addition, NIOSH investigators conducted a case-control study of mesothelioma and BSF exposure using records of the Hawaii Tumor Registry to identify cases and select controls, and ascertaining employment in the sugarcane industry from union records, death certificates, and a special 1942-43 Hawaii census.

At the HC&S mill, equipment operators, who move sugarcane into the mill as it is received from the harvested fields, were exposed to BSF; air concentrations of inorganic fibers ranged from 1200 to 8350 fibers per cubic meter (fibers/m^3). In the fields, rake operators had the highest exposures, ranging from 1,250 to 56,280 fibers/m^3, with a median of 3,970. Exposures of other employees ranged up to 10,250 fibers/m^3, with a median of 4480. There are no standards or recommendations for limiting exposures to BSF.

Ten air samples, from machinists, mechanics, and planting machinery operators, had detectable asbestos. The highest concentration was 0.77 fibers/cubic centimeter, in a bagasse tractor driver (two-hour sample period). Two subsequent samples from this employee during the same work shift had no detectable asbestos. NIOSH recommends that exposure to asbestos be reduced to the lowest possible concentration.

The medical study included 355 sugarcane workers. Neither respiratory symptoms or chest X-ray abnormalities were associated with BSF exposure. The ratio of 1-second forced expiratory volume to forced vital capacity (FEV_1/FVC, a measure of lung air flow obstruction) was lower among workers with ten or more years in jobs with the highest BSF exposures than among those with less time in such jobs [0.72 vs 0.77, p=0.04 (one-way analysis of variance)], but not significantly different from that among workers who never had such jobs (0.72 vs. 0.75).

From 1960 to 1987, 93 cases of mesothelioma in Hawaii residents were listed in the Hawaii Tumor Registry. These were compared to 281 residents with other types of cancer category-matched for age at diagnosis, decade of diagnosis, and sex. After adjusting for exposure

to asbestos, the odds ratio for sugarcane workers was 1.1 (95% confidence interval [CI]: 0.4-2.9). The odds ratio was 1.3 (95% CI: 0.4-3.8) when controls with asbestos-related cancers were excluded.

This investigation found no association between occupational exposure to BSF and respiratory symptoms, X-ray signs of chronic lung disease, or mesothelioma. Evidence of an association between BSF exposure and airways obstruction was equivocal. Mill employees were episodically exposed to asbestos at the time of our environmental survey. Recommendations to abate asbestos hazards are contained in Section VIII of this report.

KEYWORDS: SIC 0133 (Agricultural Production - Sugarcane and Sugar Beets), sugarcane workers, biogenic silica fibers, pneumoconiosis, pulmonary function, respiratory symptoms, cross-sectional study, asbestos, mesothelioma.

II. INTRODUCTION

On December 29, 1987, the Hawaii Department of Health requested that the National Institute for Occupational Safety and Health (NIOSH) investigate chronic health effects of sugarcane smoke among sugarcane workers. Since the smoke contains "biogenic silica" fibers (BSF), chronic respiratory diseases were of particular concern. During March 2-11, 1988, NIOSH investigators met with representatives of the Hawaii Department of Health, the Hawaiian Sugar Planters' Association, the Hawaiian Commercial and Sugar Company (HC&S), the International Longshoremen's and Warehousemen's Union (ILWU) Local 142, and various other interested parties; visited the HC&S Plantation on Maui; collected air samples for BSF; reviewed medical records of a sample of current and former sugarcane workers; and evaluated various record systems for their utility in an epidemiologic study. During the period August 16-September 1, 1989, further environmental and medical evaluations were conducted at the HC&S Plantation and at the Hamakua Sugar Plantation at Honakaa (Island of Hawaii). Findings and future plans were reported to the principal parties in letters dated March 31, 1988, December 1, 1988, December 19, 1988, September 11, 1989, April 4, 1990, June 4, 1992, and December 22, 1992.

III. BACKGROUND

Field preparation is the initial phase in sugar production. The soil must be loosened to a depth of 18 to 24 inches via subsoilers drawn by large tracked vehicles. Disked plows are then used as the final preparation process prior to seeding. The most popular planting method, flat culture, uses sugar cane stalks, several inches in length, planted via specialized machinery. Stalks are deposited in furrows and covered with several inches of soil. Field laborers follow the planting machines to assure proper deposition. The planting machines also bury perforated irrigation hose, which provides drip irrigation (water) and nutrients to the growing cane.

At 23 to 24 months of age, the sugar cane is ready for harvesting. Burning is the initial step in the harvesting process. Sugar cane leaf or "trash" burning was originally practiced to reduce populations of the sugar cane borer. Later, it was found to significantly reduce leaf trash, reduce labor costs, and require less equipment for harvesting and milling. Burning also significantly increases the juice quality. Because the juice in cane stalks begins to deteriorate soon after a field is burned, only enough sugar cane acreage is burned each day to supply the processing factories with cane for one day's operation. This may range from 10 to 100 acres depending on the size of the factory. Once burned, the sugar cane is uprooted and stacked into rows by tracked vehicles with blades or rakes. Cranes then hoist the cane into specialty transport trucks.

Once at the factory (mill), the cane juice is extracted, milled (crystallized into raw sugar) and refined (molasses removed). The process initially cleans the cane of dirt and trash. Rollers and knives chop the cane and extract the juice. The remaining fiber, bagasse, is used to fire boilers for generating electricity. The juice is clarified, filtered, and evaporated to produce raw sugar. Some of the mills have asbestos-containing materials, such as pipe lagging and boiler insulation.

IV. METHODS

A. Environmental

Environmental sampling was conducted for the following constituents of smoke: (1) total particulate mass; (2) biogenic amorphous silica fibers; (3) organic carbon; (4) minerals, especially aluminum (Al) and iron (Fe); and (5) polycyclic aromatic hydrocarbons (PAHs). The purpose of the environmental sampling was to obtain preliminary information on the extent of worker exposure to BSF in air and to evaluate ways of monitoring the presence of sugarcane smoke in the air.

1. Particulate mass samples were collected on pre-weighed 37-mm, 5-um polyvinyl chloride filters at an air flow rate of 2 to 7 liters per minute (lpm). The samples were analyzed by equilibrating for humidity and temperature, and the mass of the deposited particulates was determined by NIOSH Method 500.[1]

2. Trace element sampling was performed by using 37-mm cellulose filters in closed cassettes at an air flow rate of 3 lpm. 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 content by inductively coupled argon plasma-atomic emission spectroscopy (ICP-AES). Bulk soil was weighted, digested and reconstituted in the same manner as the filter samples (NIOSH Method 7300).[2] A bulk soil sample was also submitted for qualitative X-ray powder diffraction (XRD) and X-ray fluorescence spectrometry (XRF).

3. Samples for inorganic fibers were collected on 25-mm cellulose open-faced filters with conductive cowls. Stationary and personal breathing zone samples were collected at a flow rate of 3 lpm. Analysis was performed using transmission electron microscopy (TEM) at 10,500X magnification for sizing and counting fibers with a length to width ratio of 3:1 or more. Energy dispersive X-ray probe analysis was used for confirmation of the elemental constituents of each fiber. Bulk cane leaf and bagasse dust analysis for inorganic fiber identification and counting, free of an organic matrix, was performed by weighing a given amount of dried leaf, ashing this, and suspending an aliquot of the ash in solution to be distributed on a 25-mm filter. One hundred fields in the resulting filter preparation were examined, and all fibers which met the width to aspect ratio of 1:3 were counted at a microscope setting of 10,500X magnification. Fibers in which silica was not a primary constituent were not counted.

4. Samples for PAHs were collected according to NIOSH Method 5506, using a sampling train consisting of a 2-mm polytetrafloro-ethylene (Zefluor^R) filter followed by a washed XAD-2 sorbent tube. The samples were collected at a flow rate of 2.5 lpm. Because air concentrations were expected to be low, composite samples were collected by using the same filter at each sampling site during multiple fires. Laboratory analysis involved extraction by sonication for 30 minutes in 5 ml of benzene a known amount of sample. High-performance liquid chromatography (HPLC) was used to determine the presence of seventeen specific PAHs.

5. Organic carbon samples were collected on quartz fiber filters at a flow rate was 7 lpm. Analysis was performed by thermal-optical techniques, and the limit of detection (LOD) for organic carbon was 0.2ug/sample. Typically, the sampling

technique results in carbon from organic gases in the atmosphere settling onto the filter during storage and handling. Therefore, the results reported have been field blank corrected.

6. Samples of carbon monoxide (CO) were taken using long term detector (length of stain) tubes attached to a sampling pump with a flow rate of 0.02 lpm.

The area samples for particulates and organic carbon were collected using a dichotomous particulate sampler. As a result, particulate mass and organic carbon area samples included only particles with an aerodynamic size smaller than 10 microns. Personal breathing zone samples, however, included all particulates.

Sugarcane burning at the HC&S plantation took place in Field 301, located on the lower slopes of the Haleakala crater at
800-1075 feet above sea level. Field 301 covers 359 acres. Each day approximately 60-100 acres were burned as either one large burn or two to three smaller burns. Each burn lasted 30-45 minutes, and general area field sampling was limited to this time period. Samples were collected 50 to 3000 feet downwind of Field 301 during three burns. Each sampling station included the five media described above. Variable wind directions were encountered when samples were collected during sugarcane burning. As a result, there was no assurance that stationary samplers would always be located downwind of the burn. To supplement the data, mobile stations were set up on two vehicles. Samplers were positioned approximately twelve feet from the ground. Workers' personal breathing zone samples during cane burning and harvesting were collected on March 8-9.

On Sunday, March 6, when no sugarcane fields were burned, two sets of samples were collected. Sample set #1 was collected upwind of Field 301, where harvesting activities were in progress. Sample set #2 was collected at reservoir 90, approximately 6 miles southeast from the harvesting operations. The sampling media was placed at least 10 feet above ground level. The wind was from the southeast and varied from 3 to 10 mph.

Samples were also collected during the processing of cane at the Paia Sugar Mill on March 10, 1988. Ten personal breathing-zone samples were collected on workers who the NIOSH industrial hygienists identified as having the greatest potential for exposure. To obtain preliminary information on the size distribution of airborne bagasse dust, a two-stage sampler and a total dust sampler were placed in the bagasse house. Samples were collected over the operator's booth on the bagasse house floor.

Samples were analyzed quantitatively for asbestos fibers by phase contrast microscopy (NIOSH Method 7400),[3] and their identity was confirmed by electron microscopy (NIOSH Method 7402).[4] The limits of detection and quantitation depend on sample volume and quantity of interfering dust. The limit of detection (LOD) is 0.01 fiber/ cubic centimeter (cc) of sampled air in a 1000-liter air sample for atmospheres free of interferences. The quantitative working range is 0.04 to 0.05 fiber/cc in a 1000-liter air sample.

B. Medical

1. Medical record review

Hourly employees of HC&S receive medical benefits through a local health maintenance plan (HMP). Retired workers are also entitled to continuing medical care through the same HMP. The HMP provides HC&S monthly billings that are based on a per capita basis rather than fee-for-service. As a result, HC&S could provide the NIOSH investigators with a list of the 823 hourly and 970 retired workers receiving medical benefits. From these lists, a 13% sample of current workers and a 7% sample of retired workers were selected. A total of 110 current workers and 66 retired workers was selected. The HMP clinic records for these individuals were then abstracted for the information listed in Table 1. For current workers, information from personnel records was also collected. These data included date of birth, gender, job title, department, day of hire, and seniority date.

2. Respiratory effects study

A BSF job-exposure matrix was developed. The sampled jobs were placed into one of four categories based on previous sampling and our understanding of the sugarcane farming and milling process: 1) harvest rake operators; 2) all other field workers; 3) truck drivers, those involved in cleaning and unloading cane, and workers in the bagasse or power houses; and 4) all other workers. Analysis of variance was used to test the difference between the group mean fiber concentrations.[5]

We used the worker's detailed job history card to assign each job held into one of approximately 100 unique job titles and then classified each of these job titles into one of the four BSF exposure categories. A sugarcane worker's duration of employment in each of the four exposure categories was then summed. We used an arbitrary cut-off of 0.050 BSF fibers/cc to define a job as exposed. We summed the duration of employment for each job that was placed into an exposure category with a mean exposure of greater than 0.050 fibers/cc as our measure of BSF-exposure.

Assessment of asbestos exposure was based on our environmental sampling data, as well as an industrial hygienist's opinion of jobs involving asbestos exposure. Each job was classified as probably or probably not exposed to asbestos.

Male workers were selected on the basis of age, work status, job category, and total years employed. We included those workers (current and retired) with the longest duration of employment in harvesting jobs. One hundred workers with nine or more years experience in harvesting-related jobs were chosen from each plantation. Category matching[6] was used to randomly select an equal number of non-harvesting workers by plantation, age, and duration-of-employment strata. Workers who were not available or were not willing to participate were replaced by randomly selected workers with similar work histories in order to maintain sample size.

A questionnaire sought basic demographic information, work history, past medical history, active medical problems, and current symptoms (especially respiratory complaints). The questionnaire incorporated pertinent parts of the American Thoracic Society (ATS) questionnaire[7] and was self- administered in the presence of trained personnel, who reviewed it for accuracy after completion. Filipino translators assisted workers born in the Philippine Islands. Using self-reported symptoms and standardized definitions, we determined the prevalence of chronic cough, chronic bronchitis, grades 1 and 2 shortness of breath, wheezing, and wheezing with shortness of breath.

Pulmonary function testing was performed using procedures that conformed to the ATS criteria for screening spirometry.[8] All participants who attempted spirometry were included in the analyses. A forced vital capacity (FVC) of less than 80% of predicted, with a forced expiratory volume in 1 second (FEV_1) to FVC ratio of 70% or more was considered a restrictive pattern. A FEV_1/FVC ratio less than 70% was considered an obstructive pattern. Predicted values for FEV_1 and FVC were calculated using the Knudson regression equations as described by Hankinson.[9] Predicted values were not adjusted for differences in race or ethnicity. Ethnicity was considered as a potential confounder in the analysis of the data.

Chest X-rays were initially read by two B-readers trained in the use of the International Labour Organisation's standardized interpretation and classification of radiographs for pneumoconiosis.[10] Two additional readers reviewed the films if the reports of the original readers were not in agreement. A case of possible interstitial fibrosis (parenchymal opacities with a score of 1/0 or greater) or pleural abnormalities (pleural thickening or pleural plaques) depended upon agreement between any two readers.

We tested the associations between the health status measurements (respiratory symptoms, pulmonary function, and chest radiograph results) and age, race, smoking, employment status, and years of employment in BSF-exposed or probable asbestos-exposed jobs. Analyses of categorical data used Chi-square tests.[5] Tests for the difference between means involved Student's T-test[5] and analysis of variance.[5]

3. Mesothelioma study

In this case-control investigation we examined the possible association between exposure to BSF and the risk of mesothelioma. Cases of mesothelioma were ascertained through the Hawaii Tumor Registry, a population-based cancer registry that participates in the Surveillance, Epidemiology, and End Results (SEER) program. The registry is estimated to include more than 95% of all incident cancers diagnosed in the state of Hawaii since 1960.

Controls were selected from the Hawaii Tumor Registry list of people with other incident cancers. We elected to use cancer controls because doing so was convenient and we wanted to use controls diagnosed over the time period during which the cases had been diagnosed. Category-matched controls[6] were randomly selected by using decade-at-diagnosis, age-at-diagnosis (5-year categories), and gender-specific strata. Each decade, age, and gender stratum included three times as many controls as cases.

For the second analysis, we used a subset of controls that excluded persons diagnosed with cancers of the larynx, trachea, bronchus, lung, and stomach because these cancers have been associated with exposure to asbestos, a recognized risk factor of mesothelioma. Data on cases and controls who were not listed in the tumor registry records as residents of Hawaii were excluded from the analysis because they had little opportunity to work in the sugarcane industry.

We used three data sources to establish whether a person had worked in the sugarcane industry: 1) the occupation and industry information found on death certificates; 2) the occupation and industry data from a special 1942-43 Hawaii population census; and 3) the 1961-1988 lists of active and retired members of the ILWU. We asked the sugar plantations for detailed personnel records of workers identified through the union. On the basis of data from all three sources of information on employment we created a variable representing any evidence of employment in the sugarcane industry.

We also evaluated the association between mesothelioma and exposure to asbestos. Occupation and industry data on death certificates and in the Hawaii 1942-43 special population census were coded according to a job-exposure matrix[11] regarding potential exposure to asbestos. In addition, we determined if cases and controls were members of a previously identified cohort of Pearl Harbor Naval Shipyard workers[12] who were exposed to asbestos. Data from these three sources were used to create a single measurement of occupational exposure to asbestos.

Factors used for comparing cases and controls included age at diagnosis, decade at diagnosis, sex, industry in which they were employed, whether they had worked in the sugarcane industry, and occupational exposure to asbestos. Statistical analyses included univariate analysis of categorical data and multivariate analysis using unconditional logistic regression.[13] Maximum likelihood statistics were used to determine the contribution of each variable to the overall model. Several potentially confounding variables (age at diagnosis, race, decade at diagnosis), employment in the sugarcane industry, and occupational exposure to asbestos were considered in the multivariate analysis. Variables that were not statistically significant or did not change the regression coefficient of the significant risk factors were dropped from the final model. All two-way interactions between significant variables were tested.

V. EVALUATION CRITERIA

1. General

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to ten hours a day, forty hours a week for a working lifetime without experiencing adverse health effects. However, it is important to note that not all workers will be protected from adverse health effects if their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled to the limit set by the evaluation criterion. These combined effects are often not considered by the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus potentially increase the overall exposure. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent becomes available.

The primary sources of environmental evaluation criteria for the workplace are the following: 1) NIOSH Criteria Documents and Recommended Exposure Limits (RELs), 2) the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs), and 3) the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs).[14-16] The OSHA PELs may be required to take into account the feasibility of controlling exposures in various industries where the agents are used; in contrast, the NIOSH-recommended exposure limits are primarily based upon the prevention of occupational disease. In evaluating the exposure levels and the recommendations for reducing those levels found in this report, it should be noted that employers are legally required to meet those levels specified by an OSHA PEL.

A time-weighted average exposure level (TWA) refers to the average airborne concentration of a substance during a normal eight- to ten-hour workday. Some substances have recommended short-term exposure limits or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from brief high exposures.

2. Biogenic silica fibers (BSF)

Sugarcane, like many plant species, has been shown to contain insoluble amorphous (non-crystalline) opaline silica in fibrous form.[17] These biogenic silica fibers are highly respirable, ranging in size from 0.25 to 2.0 micrometers (um) in diameter and from 5 to 80 um in length.[18] A report of a series of mesothelioma cases among sugarcane workers living in an agricultural region of India,[19] where there was no (reported) opportunity for asbestos exposure, led to speculation that exposure to BSF could cause mesothelioma.[20] Later an excess of mesothelioma among Swedish sugar refining workers[21,22] and an association between lung cancer and sugarcane farming in Louisiana[23] were reported. A possible increased risk of cancer in the Florida sugarcane industry has also been reported.[24] There are no NIOSH, OSHA, or ACGIH exposure limits for BSF.

3. Polynuclear (or polycyclic) aromatic hydrocarbons (PAHs or PNAs)

Polynuclear aromatic hydrocarbons are compounds that contain two or more fused aromatic rings. They are often associated with the combustion or pyrolysis of organic matter, especially coal, wood, and petroleum products. Several PNAs are carcinogenic in experimental animals.[25] The NIOSH REL for PNAs [technically the cyclohexane- or benzene-extractable fraction of coal tar pitch volatile (CTPV)] is a full-shift TWA of 0.1 milligrams (mg) per cubic meter (m^3). Since the source of the PNAs in this case is not CTPV, the appropriateness of the 0.1 mg/m^3 criteria is questionable. However, since many PNAs are carcinogenic, reducing exposures to the lowest feasible level will minimize any cancer risk. The OSHA PEL and ACGIH TLV are 0.2 mg/m^3.

4. Carbon monoxide (CO)[26,27]

Carbon monoxide is a colorless, odorless, tasteless gas; the most common sources are combustion of hydrocarbon fuels (in vehicle engines and heating devices), burning wood (or other vegetation), and cigarette smoke. Motor vehicle exhaust is the major source of CO in urban areas. CO combines with hemoglobin molecules in the red blood cells to form carboxyhemoglobin. This interferes with the blood's oxygen-carrying capacity. Symptoms of CO poisoning include headache, nausea, dizziness, weakness, and confusion. Accuse exposure to high concentrations of CO may be fatal. Chronic exposure to CO can cause central nervous system and cardiovascular effects. The NIOSH REL and the OSHA PEL for CO is a full-shift TWA of 35 part per million (ppm), with a ceiling limit of 200 ppm. The ACGIH TLV is 25 ppm. Outdoor levels are typically less than 1 ppm in rural areas away from roads, 3-4 ppm around roads and parking areas and up to 10 ppm (with peaks as high as 50 ppm) in heavy traffic.[28]

5. Asbestos[29,30]

Chronic exposure to asbestos causes asbestosis, a lung disease characterized by fibrosis (scarring) of the lung tissue and pleura (the membrane covering the lungs and lining the chest cavity) and manifested by a decrease in lung capacity and shortness of breath. Asbestos exposure can also cause lung cancer, mesothelioma [cancer of the pleura or peritoneum] the membrane covering abdominal organs and lining the abdominal cavity), and certain cancers of the gastrointestinal (digestive) tract.

NIOSH recommends as a goal the elimination of asbestos exposure in the workplace; where it cannot be eliminated, the occupational exposure to asbestos should be reduced to the lowest possible concentration.[31] NIOSH contends that there is no safe concentration for asbestos exposure,[32] and that any detectable concentration of asbestos in the workplace warrants further evaluation and, if necessary, the implementation of measures to reduce exposure.[33] The OSHA PEL for asbestos is an 8-hour TWA of 0.2 fiber/cc. OSHA has also established an excursion limit for the construction industry that restricts worker exposures to 1.0 fiber/cc averaged over a 30-minute exposure period.[34]

6. Other environmental measurements

The OSHA PEL (8-hr TWA) for particulates not otherwise classified is 15 mg/m^3 and the ACGIH TLV is 10 mg/m^3. These "nuisance dust" or "total particulate" criteria apply to dusts that contain no asbestos and less than 1% crystalline silica. Their application to dusts that contain irritants, allergens, or toxic substances is inappropriate. Also, "total particulate" includes all airborne dust particles, even those too large to be respired (of sufficient size to be "filtered" in the upper areas of the respiratory system - respirable particulates are usually considered to be those less than 10 microns in diameter). Measurements of CO, organic carbon, and trace elements were made as indicators of the presence of sugar cane smoke.

VI. RESULTS AND DISCUSSION

A. Environmental

Sampling for background levels:

The results from the samples collected around the cane fields are reported in Table 2. Sample sets 1 and 2 represent background samples and were collected on Sunday, March 6, 1988, either upwind of, or six miles distant from, harvesting operations when no burning took place. The results indicate very low ambient particulate concentrations and no detectable organic carbon, elemental aluminum, or inorganic fibers.

Sampling during field burning:

Also reported in Table 2 are sample sets 3-9, which were collected at various locations downwind of the burning fields. Airborne particulate mass concentrations increased from 20 to 70 times the measured background level. Organic carbon was detected in all samples collected near the burning fields.

PAHs were not found in the filter segment of the air sampling train in any of the composite air samples; the LOD was 0.3-0.5 ug/sample. Traces of chrysene and benz(a)anthracene were detected on the sorbent tubes, in amounts below the limit of quantification (LOQ) of 1 ug/sample. Analysis of the bulk sample of ashed sugarcane revealed a trace of fluorine, below the LOQ of 3.0 ug/g.

Area samples had respirable particulate mass in amounts equivalent to or below the blank sample value. Most samplers were inside the smoke plume for a brief period of time.

Respirable organic carbon was measurable in all samples collected while smoke was present (29 - 430 $ug/^3$). The highest concentrations were detected adjacent to the fields (sample sets 3 and 4).

Analysis of bulk soil samples was performed to determine the elemental composition of the soil. As expected, hematite (Fe_20_3) and magnetite (Fe_3O_4) were detected by qualitative XRD analysis. Microscopic analysis also detected the presence of quartz particles. XRF analysis indicated that the sample consisted mostly of aluminum, silicon, iron, and titanium, with lesser amounts of potassium, calcium, and zirconium, and traces of zinc, strontium, and manganese. The ratio of the two most prevalent elements in the soil, aluminum and iron, was 1.4:1. Air samples from nine locations were also analyzed for elemental constituents. Neither aluminum nor iron were detected in the background samples. Both elements were detected in five of seven field samples collected during field burning, and the average ratio of aluminum to iron in these samples was 1.32 (standard deviation 0.29). These results support an earlier hypothesis that the smoke from these fires contains fine soil particulates.[35]

Concentrations of CO from detector tube samples ranged from non-detectable (ND) to 5 ppm. The highest was in a sample collected in the midst of high levels of smoke for 5 minutes. The other samples were taken next to the fires and would be as close to the fires as a worker could tolerate. Short-term peak concentrations for CO may have been higher.

Samples collected during harvesting operations:

The personal breathing zone air sampling results from samples collected on harvesting crew workers are reported in Table 3. Samples for particulate mass and inorganic fibers were collected. Samples were removed when the worker either completed a specific task or when dust loading on the sampler approached its limit.

The concentration of total particulates ranged from ND to 3.4 mg/m^3, well below the ACGIH TLV of 10 mg/m^3. For the five samples with detectable particulates, the average concentration was 1.9 mg/m^3 (standard deviation 1.46 mg/m^3).
Two rake operators and a utility worker had the highest exposures.

Exposure to inorganic fibers ranged from ND to 56,280 fibers/m^3. All but one of the twelve samples contained fibers. The fibers were typically pure amorphous silica, probably existing as silicon dioxide (SiO_2). The rake operators had the highest exposures, averaging 19,098 fibers/m^3 (5 samples, standard deviation 23,933; median 3,970; range 1,250-56,280). Exposures for a burner, a water wagon driver, two supervisors, two dozer operators, and a crane operator averaged 4564 fibers/m^3 (standard deviation 3325; median 4480; range ND-10,250).

Samples collected during mill operations:

The results of samples taken in the Paia Mill for total particulates and inorganic fibers are presented in Table 4. The highest measured personal breathing zone concentration of total particulates was 2.1 mg/m^3, on a bagasse dozer operator. Results for total and respirable particulates, from the stationary samplers located in the bagasse room, indicate that the respirable fraction of the 2.7 mg/m^3 of total particulates was 48%.

Results of the fiber analysis from samples collected at the Paia Mill indicate that only the equipment operators on the outside of the mill were exposed to inorganic fibers. These workers move the cane into the mill as it is received from the harvested fields. Air concentrations ranged from 1,200 to 8,350 fibers/m^3. Fibers were not detected in samples collected from two bagasse dozer operators and two drivers of cane haulers.

Analysis of bulk samples:

Bulk samples of sugarcane leaf and bagasse house dust were analyzed for amorphous silica fibers. In the bulk sample of sugarcane leaf, 39% of the 59 fibers that met the criteria for counting were less than 5 um long, and 15% were less than 0.25 um in diameter. The majority of the fibers were 0.25 to 0.50 um in diameter and between 2.5 and 10 um in length. Ten fibers were detected in the bagasse house bulk sample, 5 (50%) were less than 5 um in length and 6 (60%) were less than 0.25 um in diameter. Elemental spectra from these fibers essentially ruled out the presence of elements other than silicon. Therefore these fibers were not silicates but essentially silica. Since no crystalline diffraction patterns were detected, the fibers should be considered as amorphous in form.

Overall BSF exposure assessment:

A total of 147 personal breathing zone samples were submitted for BSF analysis. BSF concentrations ranged from non-detectable to 0.71 BSF/cc. BSF averaged 17.7 um in length (median=12.2 um, range: 1.5 um to 83.5 um) and 1.2 um in diameter (median=1.0 um, range: 0.15 um to 10.5 um). Eighty-four percent of the fibers were greater than 2 um in length and between 0.15 and 2 um in diameter.

Summary statistics of BSF concentrations by departments, activity, and plantation are presented in Table 6. We found a qualitative difference in exposure to BSF concentrations between each of the four exposure categories (F_{3df}=34.0, $p<0.001$; after tests indicated that each mean differed from each other mean). The harvest rake operator category was the only category with a mean BSF concentration that exceeded 0.05 BSF/cc (35 samples, mean=0.089 BSF/cc). BSF exposures for all other workers were substantially lower (all other field workers, 57 samples, mean=0.02 BSF/cc; truck drivers, cleaning and unloading cane, bagasse and power house workers, 38 samples, mean=0.003 BSF/cc; all other workers combined, 17 samples, mean = 0.001 BSF/cc).

Ten samples had asbestos fibers and the asbestos fiber concentrations ranged from 0.001 to 0.774 fibers/cc. As expected, most asbestos-exposed workers were machinists or mechanics. Samples from two workers operating planting machinery (one from each plantation) had low concentrations (0.017 and 0.018 fibers/cc) of asbestos. A bagasse tractor driver had a single airborne asbestos concentration of 0.77 fibers/cc. Two additional samples on this same worker, taken sequentially on the same day, found no detectable asbestos fibers.

B. Medical

1. Medical record review

One hundred sixty-eight (96%) of the 176 clinic records we sought were available. Of these, 94% of the current workers' records and 99% of the retired workers' clinic records were abstracted. The eight records not abstracted were either not available (2), or no clinic record existed because the worker had never visited the HMP (6).

As described above, individual medical records were not selected because of known medical illness or respiratory complaints and the variety of reasons for last visit demonstrates this. More than 20% of those seeking care were at the clinic for follow-up visits for non-respiratory complaints. Thirty-one percent sought evaluation for trauma or symptoms of a flu-like nature. Another 6% were seen for routine physical examinations.
Nine individuals sought treatment for respiratory complaints, including shortness of breath, asthma, and bronchitis.

On the average, a worker's most recent visit had been 166 days before our site visit (standard deviation 295 days, range 0 to 2114 days). For current workers, the average was 219 days, while for retired workers this average was 161 days.

The age of the current workforce averaged 44 years (standard deviation 12 years, range 22 to 64). Age was not available for the retired workers. The current workforce was predominantly male; only 10% were female. Slightly more of the retired workers were female (17%), but information about gender was not available for 21% of the retired workers. Women and men differed by job title and department. Men were more likely to have been tradesmen or to work on heavy equipment than were women, who mostly worked in cultivation, installing or repairing irrigation lines, controlling weeds, and planting cane.

The clinic records of 47 current and 51 retired workers contained a radiologist's interpretation of a chest X-ray. Many of the interpretations included signs compatible with, but not specific for, pneumoconiosis. These notes are summarized in Table 6. Average age did differ significantly (p=0.05) for the 13 current workers with an abnormal chest X-ray (52.8 years) compared to the other 34 current workers who had a chest X-ray (45.5 years). However, no such difference was found for the number of years worked at HC&S (16.8 yrs vs. 15.6 yrs, p=0.76). These findings were not the result of a systematic evaluation of chest X-rays for evidence of occupational lung disorders and are therefore extremely difficult to interpret in that context. At the same time, the X-ray findings, which included bilateral scarring, interstitial infiltrates, and pleural thickening/plaques, are suggestive of exposure to fibrogenic dust.

Since tuberculosis (TB) may also result in lung scarring visible on a chest X-ray, we also noted any reference to past TB or a positive TB skin test. Six workers (5 current and 1 retired) had a history of a positive skin test; five workers (1 current and 4 retired) had a history of tuberculosis. Two of these latter five (both retired) also had chest X-rays compatible with fibrotic lung conditions. Overall, there was no association between a positive TB skin test and a chest X-ray abnormality.

Among retired workers, those with abnormal chest X-rays were almost twice as likely to have had tuberculosis than those with a normal chest X-ray [odds ratio (OR)=1.94; 95% confidence interval (CI): 0.13-28.66], but this difference was not statistically significant. Furthermore, the remaining
16 retired workers with chest X-ray abnormalities had no mention in their charts of tuberculosis or a positive skin test. It thus seemed unlikely that tuberculosis, by itself, would explain the chest X-ray abnormalities seen in this sample of sugarcane workers.

Chronic cough and shortness-of-breath were the most common respiratory condition noted in the clinic records. Twenty-nine workers (17%) had multiple notations in their clinic record of a nagging cough or shortness-of-breath. Another ten workers (6%) had been diagnosed with asthma. Chronic obstructive pulmonary disease (COPD) was diagnosed in six workers. The chest X-rays of 11 workers were described as showing some degree of hyperinflation, a sign seen in persons with a history of asthma or COPD. None of the workers had been diagnosed with bagassosis, allergic alveolitis, or hypersensitivity pneumonitis.

The clinic records indicated that 12 of the 168 workers had been diagnosed with cancer. These workers had been diagnosed with colon or rectal cancer (3), bladder cancer (2), prostate cancer (2), breast cancer (1), pancreatic cancer (1), thyroid cancer (1), skin cancer (1 basal cell cancer), and laryngeal cancer (1). None of the records indicated lung cancer, mesothelioma, or stomach cancer (tumors that have been related to asbestos exposure). Laryngeal cancer has also been related to asbestos exposure, but other risk factors include cigarette smoking and alcohol consumption.

It was not possible to ascertain cigarette smoking patterns among this workforce from the clinic records. The records of only 36 workers noted cigarette habits. Of these 36, 15 (42%) workers were current cigarette smokers, 7 (19%) workers were ex-cigarette smokers, and 14 (39%) were non-smokers.

2. Respiratory effects study

Four hundred eight-six workers were selected for the study, and 355 participated in at least some part. The study group included 213 (60%) current and 130 (37%) retired workers, as well as 12 (2%) workers on disability leave or with an unknown work status (Table 7). The average participant was 54 years old, began working in the sugarcane industry at 22 years of age, had worked in the industry for 30 years, and had completed nine years of education. Age, education, and duration of employment were similar for the two plantations. Filipinos represented the largest ethnic group (42%), followed by Japanese (23%), whites (18%), and Pacific Islanders (16%). Workers from the Hawaii plantation were more likely than workers from Maui to be current workers [rate ratio (RR)=1.5; 95% CI: 1.3-1.8] or Pacific Islanders (RR=2.8; 95% CI: 1.6-4.9).

The prevalence of respiratory symptoms and their associations with cigarette smoking status, years worked in BSF-exposed jobs, and years worked in potentially asbestos-exposed jobs are given in Table 8. Shortness of breath was the most common symptom (24% of all workers had grade 1 or higher), followed by wheezing (7%), and chronic cough (5%). As expected, respiratory symptoms were associated with cigarette smoking. Respiratory symptoms were not associated with years in BSF-exposed or asbestos-exposed jobs.

Three hundred and fifty three workers attempted pulmonary function testing; the spirometry curves of 25 did not meet ATS reproducibility criteria. Sixty-six workers (23%) had an obstructive pattern and 18 workers (6%) had a restrictive pattern (Table 8). As expected, obstruction was associated with cigarette smoking. Workers with an obstructive pattern averaged a 31.6 pack-year history compared to an 18.4 pack-year history for workers without obstruction (Student's $t=3.8$, $p<0.01$). Neither an obstructive pattern nor a restrictive pattern were associated with duration of employment in BSF-exposed or asbestos-exposed jobs, or with ethnic background.

Pack-years of smoking and years in jobs with BSF-exposure were related to a decrease in the FEV_1/FVC ratio (Table 9). Adjustments for age, overall duration of employment, ethnicity, and asbestos exposure did not alter this association. There was no interaction between smoking and BSF exposure. The percent of predicted FVC was not statistically associated with smoking or BSF-exposure.

A total of 344 workers had chest radiographs. Seventy-one percent of the films were scored the highest quality rating,
23% were scored the second highest rating in quality, and 6% were considered of poor, but readable, quality. Two films were unreadable.

Two workers had diffuse interstitial opacities consistent with pneumoconiosis. Both workers had bilateral, irregularly shaped opacities, 1.5 to 3.0 mm in diameter, throughout all lung fields. Neither had worked in a heavily BSF-exposed job.

Seventeen workers had pleural thickening or pleural plaques. This condition was unilateral in six workers and bilateral in eleven workers. The prevalence of pleural thickening or plaques was slightly greater for those workers employed for more than ten years in BSF- or asbestos-exposed jobs, but this observation was based on very few persons, and the increased prevalence was modest (Table 8). Workers with pleural thickening or plaques were slightly older than those without this condition (63 years versus 54 years, Student's $t=3.7$, $p<0.01$). The presence of pleural plaques was associated with a decrease in the mean percent predicted FEV_1 (81.0% compared to 101.9%, Student's $t=3.8$, $p<0.01$), and a decrease in the mean percent predicted FVC (92.6% compared to 109.1%, Student's $t=3.4$, $p<0.01$).

Discussion

We confirmed that Hawaii sugarcane workers are exposed to BSF fibers, primarily during harvesting. More than 80% of the fibers we measured had physical dimensions that are thought to pose the greatest risk of asbestosis and lung cancer.[36] Even so, our results did not indicate any relationship between BSF fiber exposure and fibrotic lung disease. We did not evaluate the association between lung cancer and BSF exposure.

In general, the study participants appear to have been in good health. After adjusting for differences in smoking status, the prevalence of chronic cough, shortness of breath, and wheezing in this work force was lower than that in a study of blue collar workers not exposed to fibrogenic dusts.[37] We identified only two workers with signs of interstitial fibrosis and this is less than the 0.9% prevalence found in a study of 1422 non-exposed blue collar workers.[38] At the same time, we identified 17 workers with pleural thickening or pleural plaques, signs that have been associated with exposure to asbestos. Among those with pleural thickening of pleural plaques, five workers reported respiratory symptoms and eight had abnormal spirometry results. Two of these workers reported a history of occupational asbestos exposure outside of the sugarcane industry, three held BSF-exposed jobs for ten or more years, and five worked in sugarcane industry jobs for ten or more years that had potential for asbestos exposure.

There were several limitations to this study. Our assumptions about BSF and asbestos exposures may have resulted in some misclassification. We collected environmental samples during a two-week period that may not have been representative of exposures during different seasons, weather conditions, or on different plantations. Harvesting methods have remained essentially unchanged in Hawaii for the past 40 years and it is unlikely that BSF exposures to workers have changed over time. However, the increased awareness of asbestos as a health hazard and active asbestos abatement in the Hawaii sugarcane mills probably has led to a decrease in asbestos exposures over time. Classification of asbestos exposure relied on a review of job titles and an industrial hygiene walk-through survey. A second limitation was the cross-sectional study design that prevented us from examining the risk of illness over time. In addition, we could not study workers who may have left employment prior to retirement or workers who had died, and this may have created a selection bias. Participation varied by job status and by type of work, and this may have resulted in a slight bias in the study results. Finally, BSF concentrations may have been too low to have caused illness in this population.

The study had various strengths. Exposures to BSF were well documented, and we used detailed job history records to identify all sugarcane jobs worked over the past 40 years. We included workers with the greatest potential for exposure, who had worked in the industry for the longest period of time. A comparison group of other long-term workers allowed us to control for time-related factors such as age, duration of employment, and ethnicity. We presented an analysis where only the most heavily BSF-exposed jobs were considered as exposed. We have also analyzed these data by considering BSF exposures in all four BSF exposure categories. BSF-years was calculated by weighting each BSF exposure category by its mean BSF concentration, multiplying this weight by the duration of employment in each category, and summing across all four categories. Our results did not differ when we analyzed the data using this cumulative measurement of BSF exposure.

3. Mesothelioma study

We identified a total of 104 cases of mesothelioma through the 1960-1987 Hawaii Tumor Registry. We excluded 11 cases because they did not reside in Hawaii when their illness was diagnosed. According to tumor registry records, a histologic diagnosis was consistent for mesothelioma for 92 of the 93 remaining cases. We obtained death certificates for 85 of the 88 cases known to have died.

Data on 281 controls were included in the analysis; 30 persons were excluded because they resided outside of Hawaii at the time of their diagnosis. Since controls were selected from persons with any cancer, most had common types of cancer (Table 10). Microscopic examination confirmed the histologic diagnosis for 258 of the controls included in the analysis. Because of the high case fatality rate associated with mesothelioma, more cases (95%) than controls (67%) had died. We obtained death certificates for 175 of the 189 controls known to have died. As expected, the distribution of cases and controls by decade at diagnosis, age at diagnosis, and sex was similar (Table 11). In addition, the mean age at diagnosis for cases [62.5, standard deviation (s.d.)=13.6 years] was the same as that of controls (62.5, s.d.=13.9 years).

The estimated risk for mesothelioma associated with having worked in the sugarcane industry varied depending on the source of occupational data (Table 12). The odds ratios ranged from 1.1 to 2.3, but in all cases the confidence intervals were wide. We identified 7 cases and 19 controls as once having worked in the sugarcane industry (OR=1.1, 95% CI: 0.4=2.9). From union records we identified four cases and nine controls as sugarcane workers (OR=1.4, 95% CI: 0.5=5.0). This odds ratio increased to 2.3 (95% CI: 0.4=12.5) when controls with cancers of the trachea, bronchus, lung, or stomach were excluded. Removing these controls did not substantially alter the association between employment in the sugarcane industry and mesothelioma when data from death certificates or the 1942 population census was used to establish occupation (Table 12).

We obtained detailed job histories for two cases and seven controls who had worked in the sugarcane industry (Table 13). Both cases had worked in jobs with potential for asbestos exposure. One case worked as a mechanic on sugarcane trucks for 36 years where he could have been exposed to asbestos brake pads. The second case worked as a plumber in the sugarcane industry for two years before becoming a sugarcane truck driver. None of the cases or controls operated a harvesting tractor, the job considered to have the highest exposure to BSF.

We did observe a statistically significant association between occupational asbestos exposure and mesothelioma (OR=1.8, 95% CI: 1.6-3.2) (Table 12). Of the 26 cases and 50 controls who were considered occupationally exposed to asbestos, the cases were more likely than controls to have worked at the Pearl Harbor Shipyard (OR=8.2, 95% CI: 2.6-30.3). The exclusion of controls with diagnosed cancers of the larynx, trachea, bronchus, lung, or stomach increased the estimated risk associated with asbestos exposure (OR=2.2, 95% CI: 1.2-4.2) and work at the Pearl Harbor Shipyard (OR=10.1, 95% CI: 2.6-56.6).

The risk of mesothelioma was significantly increased among people employed in construction (OR=2.7, 95% CI: 1.3-5.7), machinery (OR = 7.1, 95% CI: 1.2-72,4), or transportation industries (OR=2.3, 95% CI: 1.2-4.7). These industries include many occupations that create a potential for asbestos exposure. None of these industries seem to involve BSF exposure. We also noted that people who had worked in medical- or science-related jobs had an elevated, but statistically nonsignificant, risk of mesothelioma (OR=3.4, 95% CI: 0.8-17.7). This finding was based on only six cases (three nurses, two physicians, and one office worker) and four controls. We know of no exposure peculiar to the medical field that would influence the risk of mesothelioma.

The multivariate analysis included the following variables: sex, any employment in the sugarcane industry, any occupational asbestos exposure, work in the medical field, age at diagnosis, and decade at diagnosis. Age at diagnosis, decade at diagnosis, and sex were dropped from the regression model because the inclusion of these factors did not alter the regression coefficients for employment in the sugarcane industry or asbestos exposure. The odds ratio for work in the sugarcane industry did not change after adjustment for the other variables, including exposure to asbestos. The model that best predicted mesothelioma included exposure to asbestos (OR=2.4, 95% CI: 1.3-4.3) and employment in the medical industry (OR=4.2, 95% CI: 1.2-15.5).

Discussion

In this study, we found a small elevated risk of mesothelioma associated with employment in the Hawaii sugarcane industry. The estimated risk varied according to the source of the employment information. The confidence intervals surrounding the parameter estimates for this association were broad and included the null value. The slight elevation in risk may be the result of chance or may be due to asbestos exposures in certain jobs within the sugarcane industry. Data in personnel records of the two cases who were sugarcane workers suggest that the two had been exposed to asbestos rather than BSF. We consider none of the cases employed in the sugarcane industry to have held jobs with a high potential for BSF exposure.

Although the results of earlier studies suggested an increased risk of mesothelioma for workers in the sugar industry, those studies were not designed to test the BSF-mesothelioma hypothesis. Researchers who reported the case-series from India[19] did not attempt to measure BSF exposure, did not use a comparison group, and did not consider the risks associated with zeolite. The two reports from Sweden[21,22] involved refinery workers who may never have been exposed to BSF.

In this study, we documented that Hawaii sugarcane workers are exposed to BSFs and that such exposures are greatest during cane harvesting, a process that continues daily for 10 months each year. Unionization has encouraged sugarcane workers to remain in their jobs for decades. Thus, some sugarcane workers are exposed to reasonably high levels of BSF for long periods. Even so, we believe that none of the people diagnosed with mesothelioma in Hawaii between 1960 and 1987 worked at jobs that create the greatest opportunity for BSF exposure. We could not, however, document the past exposures of each person in the study and there exists the potential for misclassification of exposure. Any conclusions based on these data should be made with consideration of the inherent limitations to this study.

One limitation is the quality of the occupational data we used. The death certificate and special census data were subject to non-differential misclassification of BSF exposure and may have biased the odds ratio toward the null value. Occupational data from death certificates usually reflect the decedent's most recent job and previously held jobs cannot be determined by using death certificates alone. On the other hand, the jobs of people who did not live in the Hawaiian Islands in 1942 could not have been identified by the special census of that year. The job-exposure matrix that we used to classify asbestos exposure may also have led to misclassification. Not everyone with the same job title had the same potential for exposure to asbestos. In addition, the accuracy of any job-exposure matrix is questionable, since the matrix is based on numerous assumptions that are generally not well tested.

With the exception of a few subjects identified as sugarcane workers through union records, detailed job histories were unavailable. We chose not to contact the next-of-kin to obtain additional detailed occupational histories. The cost of collecting such data would have been beyond the means of this study. In addition, data collected from next-of-kin are not necessarily accurate and are subject to both recall and interviewer biases.

For efficiency, we used controls with cancer.[39,40] The use of such persons may have introduced a possible selection bias. If the controls were more likely to have been employed in the sugarcane industry or in an asbestos-related job than were members of the general population, our results would be biased towards the null. To reduce the possibility of such selection bias, we randomly selected controls from all persons with cancer listed in the tumor registry. We further reduced the potential for selection bias by reanalyzing the data after excluding cancers known to be associated with exposure to asbestos.

Mesothelioma seems to have a long latency period, typically longer than 20 years[41]. Sugarcane workers who began their employment in the late 1960s may not yet have developed mesothelioma. Even so, this fact should not have prevented us from finding an association between sugarcane work and mesothelioma if one exists. In 1946 in Hawaii, 26,000 sugarcane workers were active. By 1961, from 15 to 42 years had passed since those persons identified as sugarcane workers in 1946 were first employed, enough time for them to have developed mesothelioma and thus to be identified in this study.

Some researchers have postulated that the carcinogenic potential of asbestos fibers is a function of length and diameter.[36] They believe that fibers longer than 5 um and less than 0.15 um in diameter pose the greatest risk for mesothelioma. We found that all BSF from Hawaii had a diameter greater than 0.15 um. Perhaps the size of these fibers accounts for the lack of an association between mesothelioma and employment in the sugarcane industry.

Our mesothelioma study had several strengths. Access to ILWU records enabled us to identify active and retired sugarcane workers from 1961 through 1988. We could identify those persons who had worked at the Pearl Harbor Naval Shipyard where they may have been exposed to asbestos. Cases were identified through one of the oldest state wide population-based tumor registries in the country and were not constrained by an ill-defined catchment area, as is sometimes the case with hospital-based tumor registries. BSF exposures in the Hawaii sugarcane industry were documented by personal breathing zone sampling. The power of this study to detect an association between mesothelioma and employment in the sugarcane industry was adequate for detecting a relatively large odds ratio (for example, a power of 89% to detect an odds ratio of 3.0, two-sided alpha test) but probably inadequate for detecting an odds ratio of 2.0 (power = 44%) or less. The study's power to determine a relationship between harvest tractor drivers, the sugarcane workers most heavily exposed to BSF, and mesothelioma is substantially less, since less than 10% of sugarcane workers are involved in these jobs.

VII. CONCLUSION

Respirable amorphous silica fibers, ranging in size from 0.25 to 2.0 um in diameter and 5-80 um in length, were found in sugarcane smoke samples, bulk samples of bagasse dust and sugarcane leaf, and personal breathing zone samples of workers involved in harvesting and processing of sugarcane. Three of seven area samples located near burning sugarcane fields had detectable amorphous silica fibers (range 680-6200 fibers/m^3). These fibers were found in the samples closest to the smoke plume. Fibers were also detected in 17 of 22 personal breathing zone samples, in concentrations ranging from 620 to 56,280 fibers/m^3. With the exception of operators inside the Paia Sugar Mill, fiber counts appeared to correlate with the dustiness of the job, as measured by respirable particulates. Amorphous silica fibers were not found in background samples or on personal breathing zone samples of bagasse dozer operators.

A slight decrease in the FEV_1/FVC ratio was associated with BSF exposure of more than ten years' duration. This may be due to BSF exposure, to other factors related to harvesting burned sugarcane, or to chance. Chest X-ray pleural abnormalities were present in several workers and were associated with decreased pulmonary function; three workers with pleural abnormalities had worked in heavily exposed jobs for ten or more years. However, most respiratory symptoms and conditions did not appear to be associated with BSF exposure.

We found no clear evidence that exposure to BSF, as determined by employment in the sugarcane industry, is a risk factor for mesothelioma. We found a slight increased risk for sugarcane workers, but the risk appears more likely to be the result of exposure to asbestos or chance than of exposure to BSF. Our negative findings may be explained by the differences in the physical characteristics between BSF and asbestos or the small number of sugarcane workers who are highly exposed to BSF.

VIII. RECOMMENDATIONS

Asbestos exposures among machinists, mechanics, and mill employees, as indicated by the presence of asbestos fibers on a portion of air samples collected from these workers, warrants continued surveillance of these jobs/operations. Where the predominant source of exposure is asbestos-containing building materials (mill workers), the Environmental Protection Agency's publications, "Managing Asbestos in Place[42] and "Asbestos/NESHAP Regulated Asbestos Containing Materials Guidance,"[43] provide guidelines, procedures, and decision logic for managing asbestos-containing materials. For machinists and mechanics, where the primary source of exposure is asbestos-containing brake shoes and drums, the NIOSH publication, "Control of Asbestos Exposure During Brake Drum Service," offers specific guidelines and recommendations.[44]

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1. Hawaii Department of Health
2. International Longshoremen's and Warehousemen's Union Local 142
3. Hawaiian Commercial & Sugar Company
4. Hamakua Sugar Plantation
5. Hawaiian Sugar Planters Association
6. OSHA Region IX
7. EPA Region IX

Table 1
Information Abstracted from the Clinic Records of Current
and Retired Sugarcane Workers
Hawaiian Commercial & Sugar Company
Puunene, Hawaii
March 1988
HETA 89-119

Date of last visit
Presenting complaint
Mention of the following specific medical conditions

- Chronic cough or shortness of breath
- Asthma
- Emphysema
- Chronic obstructive pulmonary disease
- Pneumoconiosis
- Cancer
- Allergic alveolitis (bagassosis)

Date of diagnosis and date of last visit for any of these conditions
Smoking history
History of hospitalization for any of these conditions
Pulmonary function testing and results
Chest x-rays and results
Other significant diagnoses (e.g., Tuberculosis)

Table 2
Air Sample Results, Sugarcane Burning Operations
Hawaiian Commercial & Sugarcane Company
Puunene, Hawaii
March 5-9, 1988
HETA 89-119

Sample Set No.	Sample Minutes	Particulate Mass (mg/m^3)[1]	Organic Carbon (ug/m^3)[2]	Metal[3] Fe	Al	Fibers (f/m^3)	Location/Description
1	420	<0.01	ND[4]	<0.5	<0.5	ND	"Clean air sample at Reservoir #34, upwind of harvesting operations.
2	380	0.01	ND	<0.5	<0.5	ND	"Clean" air sample at Reservoir #90, distant from harvesting operations.
3	29	0.5	123	<11	<11	ND	Stationary sample 50' from burning field but only in smoke about 5 minutes
4	100	0.7	430	5	--	680	Stationary sample 50' from field 3012 but in smoke only 5-10 minutes. Winds 2-9 mph (Tuesday a.m.).
5	70	<0.2	--	20	18	ND	Stationary sample 3000' downwind from burning field 3012 (Tuesday a.m.)
6	35	<0.4	73	35	29	ND	Mobil truck station (Tuesday p.m.)
7	57	--	29	20	11	2140	Mobil truck station (Tuesday p.m.)
8	60	0.5	92	39	30	2140	Mobile truck station near highway about 25 minutes in direct smoke (Wednesday a.m.)
9	60	0.3	73	14	12	ND	Mobil truck station near highway about 15 minutes in direct smoke (Wednesday a.m.)

1. Blank corrected based on a 5-blank average of 0.05 mg/sample.
2. Blank corrected based on a 2-blank average of 2.18 ug/sample.
3. Results expressed as ug/m^3.
4. Sample value below the blank value.
5. Sample voided for technical reasons.

Table 3
Air Sampling Results: Total Particulate Mass and Inorganic Silicate Fibers, Field Harvesting Crews
Hawaiian Commercial & Sugar Company
Puunene, Hawaii
March 8-10, 1988
HETA 89-119

Sample Set Number	Sample Number	Duration (minutes)	Location and Description	Particulate Conc. (mg/m^3)	Fiber Conc.[1] (fibers/m^3)
1	F10/BSF16	88	Burner	ND	ND
2	F9	378	Burner and Rake Operator	0.6	-
3	BSF11	103	Burner and Rake Operator	-	56,280
4	BSF7	85	Water Wagon Driver	-	3,220
5	BSF15	87	Supervisor During Burn	-	4,480
6	F31	475	Utility Worker	3.2	-
7	F38/BSF13	474	Small Rake Operator	2.1	1,250
8	F35/BSF34	--	Small Rake Operator	Voided	Voided
9	BSF39	361	Rake Operator	-	3,720
10	BSF28	360	Rake Operator	-	3,970
11	F4/BSF30	100	Rake Operator	3.4	30,270
12	F34/BSF41	88	Rake Operator	Voided	-
13	BSF8	75	Field Supervisor	-	5,950
14	BSF5	302	Dozer Operator (Part-time)	-	4,560
15	BSF4	161	Dozer Operator	-	10,250
16	F42/BSF29	435	Crane Operator	0.2	1,390

Table 4
Air Sampling Results: Total Particulate Mass and Inorganic Silicate Fibers, Paia Sugar Mill
Hawaiian Commercial & Sugar Company
Puunene, Hawaii
March 10, 1988
HETA 88-119

Sample Set Number	Sample Number	Duration (minutes)	Location/ Description	Particulate Conc. (mg/m^3)	Fiber Conc.[1] ($fibers/m^3$)
1	F21/BSF43	410	Crane Operator	0.4	2,490
2	F28/BSF36	220	Crane Operator	1.5	8,350
3	F36/BSF26	380	Cane Cleaner Operator	0.3	1,410
4	F11/BSF35	409	Cane Cleaner Operator	0.2	1,200
5	F29/BSF23	410	Trash Truck Operator	0.1	620
6	F26/BSF31	195	Bagasse Dozer Operator	Sample voided	-
7	F20/BSF42	147	Bagasse Dozer Operator	1.2	ND
8	F02/BSF40	404	Bagasse Dozer Operator	2.1	ND
9	F44/BSF25	401	Utility Operator	Sample voided	1,340
10	F01/BSF38	422	Cane Hauler	0.9	ND
11	F27/BSF37	470	Cane Hauler	1.7	ND

1. Only fibers with a diameter of greater than 0.25 microns but less than 3.0 microns and with a length of at least 5 microns with an aspect ratio of 3:1 greater were included.

Table 5
Biogenic Silica Fiber Exposures (fiber/cc) among Hawaiian Sugarcane Workers by Job Category and Plantation
Hawaiian Commercial & Sugar Company
Puunene, Hawaii
Hamakua Sugar Plantation
Honakaa, Hawaii
August 16 - September 1, 1989
HETA 88-119

	Maui Plantation				Hawaii Plantation			
	N[1]	mean	sd[2]	median	N	mean	sd	median
Planting								
Machinery	17	.016	.015	.011	14	.029	.099	.003
Field Work	9	.060	.006	.004	0			
Other	2	.018	.022	.018	3	.002	.003	.002
Harvesting								
Rake Operator	22	.045	.099	.011	13	.164	.210	.098
Others	6	.016	.019	.007	6	.007	.009	.004
Drivers	5	.001	.001	0	3	.006	.008	.002
Mill Operations								
Unloading	8	.004	.005	.002	5	.002	.002	.002
Power House	7	.004	.007	0	10	.001	.002	0
Others	12	0	0	0	5	0	0	0
Total	88	0.17	.052	.003	59	.045	.125	.002

1. N - number of participants in group
2. sd - standard deviation

Table 6
Notes from Clinic Records Indicating Abnormal Chest X-Rays
Hawaiian Commercial & Sugar Company
Puunene, Hawaii
March 1988
HETA 88-119

Clinical note
Job title, age, years of employment

Current Workers:

A. Interstitial infiltrates, subsegmental atelectasis, cardiomegaly with prominent right hilium.

welder second class, 58 years old, 10.3 years of service

B. Slight prominence of bronchovascular markings bilaterally, difficult to assess.

ice mechanic third class, 58 years old, 6.3 years of service

C. Generalized increased lung markings.

bagasse fuel controller, 52 years old, 9.0 years of service

D. Generalized increase in interstitial markings (fibrosis).

radio operator, 40 years old, 13.4 years of service

E. Diffuse prominence of interstitial markings, may represent chronic interstitial fibrosis (12/83); increased interstitial markings in the lung bases persist, unchanged since 12/83 (10/87).

utility truck driver, 62 years old, 41 years of service

F. Increased bronchial and interstitial markings.

cultivation irrigation maintenance, 35 years old, 17.5 years of service

G. Minimal scarring since 1/81.

mud system operator, 58 years old, 7.8 years of service

H. Evidence of pneumoparenchymal scarring and left interstitial infiltrate.

welder second class, 51 years old, 7 years of service

I. Slight increased density in the lingula and minimal interstitial prominence of right lower lobe on the PA projection, persists on lateral view, lung bases remain clear.

blanket replant crew worker, 42 years old, 10.4 years of service

Table 6: Continued

J. Old scarring, increased density left costrophrenic angle.

chemical mixer-janitor, 59 years old, 13.0 years of service

K. Minimal linear scarring versus atelectasis.

utility tractor driver, 45 years old, 16.7 years of service

L. Some generalized increased interstitial densities.

irrigator (mobile), 59 years old, 13 years of service

M. A curvilinear density superimposed on the right hemidiaphram on lateral view, could represent an area of pleural calcification. This is of doubtful significance, clinical correlations as to prior asbestos exposure is suggestive. Also a linear density adjacent to the left heart border likely representing an area of fibrosis.

mason, 62 years old, 21.6 years of service

Retired workers:

N. Prominent interstitial markings in the lung bases. Density in the upper lobes and right lateral wall.

O. Pleural thickening in both apices and left hemithorax.

P. Pleuroparenchymal scarring left base. Haziness in both lung bases.

Q. Increased markings on lower lungs bilaterally.

R. Several densities left base, biapical pleural thickening, hyperaerated.

S. Bilateral pleural thickening, ? asbestosis.

T. Haziness both bases.

U. Cardiomegaly, haziness in both bases.

V. Increased interstitial markings both bases.

W. Pleural thickening lateral chest wall, left diaphragm. Fibrotic changes left base.

X. Increased parenchymal density bilaterally, lower lobes (pneumonitis).

Y. Extensive pleural thickening, left hemithorax. Increased interstitial markings in both lung bases.

Z. Densities in lateral left base.

Table 7
Work Status and Demographic Characteristics of Hawaii Sugarcane
Workers by Plantation and Having Worked in Harvesting-related Jobs
Hawaiian Commercial & Sugar Company
Puunene, Hawaii
Hamakua Sugar Plantation
Honakaa, Hawaii
August 16 - September 1, 1989
HETA 88-119

	Maui Plantation				Hawaii Plantation			
	Harvesting		Nonharvesting		Harvesting		Nonharvesting	
A. Years of age, education, and duration of employment.								
	mean	sd[2]	mean	sd	mean	sd	mean	sd
Age	56.7	13.2	55.9	13.3	51.9	11.4	53.4	9.3
Education	9.2	3.6	9.4	4.5	9.9	3.4	11.2	3.0
Employment	31.9	12.6	30.4	12.7	29.3	11.4	28.3	11.0
B. Work Status and Ethnicity								
	N[3]	(%)	N	(%)	N	(%)	N	(%)
Work Status								
Current	49	(48)	37	(48)	82	(73)	41	(75)
Retired	50	(49)	39	(51)	28	(25)	12	(22)
Other	3	(3)	1	(1)	2	(2)	2	(4)
Ethnicity								
Filipino	46	(45)	37	(48)	42	(38)	18	(33)
White	24	(23)	14	(18)	21	(19)	4	(7)
Japanese	21	(21)	21	(27)	18	(16)	22	(40)
Pacific Islander	11	(11)	4	(5)	29	(26)	10	(18)
Other	0	(0)	1	(1)	2	(2)	1	(2)
Total	102	(100)	77	(100)	112	(100)	55	(100)

1. Work status (current/retired) or harvesting/non-harvesting status not known for 5 persons.
2. sd - standard deviation
3. N - number of participants in group

Table 8
Exposure to Biogenic Silica Fibers (BSF), Exposure to Asbestos, and Smoking Status by the Prevalence of Respiratory Symptoms and Conditions in 340 Hawaii Sugarcane Workers
Hawaiian Commercial & Sugar Company
Puunene, Hawaii
Hamakua Sugar Plantation
Honakaa, Hawaii
August 16 - September 1, 1989
HETA 88-119

	BSF exposure: Years in heavily exposed jobs		Asbestos exposure: Years in exposed jobs		Smoking Status	
	1-9 yrs (N[1]=59)	10+ yrs (N=37)	1-9 yrs (N=34)	10+ yrs (N=55)	Current (N=106)	Former (N=128)
Chronic cough	2	1	1	3	9	6
(N=16) RR[2]	0.6	0.5	0.6	1.1	8.8	4.9
95% CI[3]	0.2, 2.7	0.1, 3.6	0.1, 4.6	0.4, 3.9	1.1, 68.5	0.6, 39.9
SOB[4] grade 1	14	10	8	14	34	28
(N=83) RR	1.0	1.1	1.0	1.0	1.6	1.1
95% CI	0.6, 1.7	0.6, 1.7	0.5, 1.8	0.6, 1.7	1.0, 2.6	0.6, 1.8
SOB grade 2	7	3	1	8	13	14
(N=31) RR	1.4	0.9	0.3	1.6	3.2	2.8
95% CI	0.6, 3.2	0.3, 2.8	0.0, 2.4	0.8, 3.5	1.1, 9.5	1.0, 8.4
Wheeze	3	2	1	2	7	12
(N=23) RR	0.7	0.7	0.4	0.4	1.7	2.4
95% CI	0.2, 2.3	0.2, 2.9	0.0, 2.6	0.1, 1.9	0.5, 5.7	0.8, 7.3
Restriction	5	1	4	2	9	4
(N=16) RR	2.0	0.6	2.9	0.9	3.0	1.1
95% CI	0.7, 5.8	0.1, 5.0	1.0, 8.9	0.2, 4.1	0.8, 10.7	0.2, 4.8
Obstruction	9	10	3	12	25	26
(N=65) RR	0.8	1.4	0.4	1.1	1.8	1.5
95% CI	0.4, 1.6	0.8, 2.5	0.2, 1.4	0.6, 1.9	1.0, 3.2	0.8, 2.7
Pleural plaques	0	3	0	5	2	9
(N=15) RR	0.0	1.6	0.0	2.2	0.5	1.8
95% CI	---	0.5, 5.6	---	0.8, 6.2	0.1, 2.8	0.6, 5.8

1. N - number of participants in group (columns) or total number of participants with symptom or condition (rows)
2. The relative rates (RR) compare (a) persons in exposed jobs by years of work in exposed jobs (BSF and asbestos) to persons never working in exposed jobs, and (b) current and ex-smokers to never smokers. Chronic bronchitis (N=7), wheezing with shortness of breath (N=10), and interstitial fibrosis (N=2) not included. The number of workers with complete job histories and chest readable chest radiographs was 331.
3. CI - confidence interval
4. SOB - shortness of breath

Table 9
Percent of Predicted Forced Vital Capacity (FVC%) and Ratio of One-second For
Expiratory Volume to FVC (FEV_1/FVC) by Exposure to Biogenic Silica Fibers (BS
Asbestos, and Pack-years of Cigarettes Smoked
Hawaiian Commercial & Sugar Company
Puunene, Hawaii
Hamakua Sugar Plantation
Honakaa, Hawaii
August 16 - September 1, 1989
HETA 88-119

	FVC%			FEV_1/FVC		
	Mean	sd[1]	p[2]	Mean	sd	p
BSF-exposed jobs in years						
O (N[3]=243)	109.2	18.1		75.4	8.4	
1-9 yrs (N=59)	105.8	16.9		<u>77.3</u>	8.3	
10+ yrs (N=37)	103.3	17.5	0.10	<u>72.4</u>	13.0	0.04
Asbestos-exposed jobs in years						
O (N=250)	107.4	17.8		75.5	9.2	
1-9 yrs (N=34)	105.3	18.5		77.8	6.2	
10+ yrs (N=53)	112.5	17.7	0.11	73.4	9.6	0.08
Pack-years smoked						
O (N=109)	108.7	16.2		77.2	7.7	
1-15.2 yrs (N=60)	110.8	17.1		77.4	9.4	
15.3-30.9 yrs (N=84)	108.5	18.2		76.5	8.2	
31+ yrs (N=83)	104.7	20.5	0.22	<u>70.9</u>	10.1	<0.01

1. sd - standard deviation
2. p - values calculated from F-score based on 1-way analysis of varian
   Underlined means differ statistically from each other.
3. N - number of participants

Table 10
Distribution of Control Subjects by Tumor Type
Hawaii
1988
HETA 88-119

ICD* code	Cancer Type	Number	Percent
140-149	Lip, oral cavity, and pharynx	8	3
150, 152-159	Digestive organs (excluding stomach)	70	25
151	Stomach	21	7
161	Larynx	5	2
162	Trachea, bronchus, and lung	48	17
174-175	Breast	21	7
180-189	Genitourinary tract	72	26
191-192	Brain and central nervous system	4	1
	Other sites and primaries	32	11
	Total	281	99**

* International Classification of Diseases
** Sum of percentages is less than 100% because of rounding

Table 11
Distribution of Case and Control Subjects by Sex (M/F),
Decade of Diagnosis, and Age at Diagnosis
Hawaii
1988
HETA 88-119

Decade of Diagnosis	20-29		30-39		40-49		50-59		60-69		≥70		TOTAL	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F
1960-1969														
Cases	0	0	0	0	3	3	4	1	0	0	3	1	10	5
Controls	0	0	0	0	9	9	13	3	0	0	7	3	29	15
Subset*	0	0	0	0	7	8	10	3	0	0	6	3	23	14
1970-1979														
Cases	0	1	0	0	4	0	6	1	12	2	5	5	27	9
Controls	0	3	0	2	13	0	16	6	34	4	23	15	86	30
Subset*	0	3	0	2	10	0	9	5	29	3	17	14	65	27
1980-1988														
Cases	0	0	0	0	2	0	12	1	5	4	13	3	32	10
Controls	0	0	0	0	4	0	35	3	17	12	37	7	93	28
Subset*	0	0	0	0	4	0	22	2	6	11	23	6	55	25

Age at diagnosis (years)

* A subset of control subjects that does not include the 48 with cancer of the trachea, bronchus, or lung; the 5 with cancer of the larynx; or the 21 with cancer of the stomach.

Table 12
The Risk of Mesothelioma Related to Having Worked in the Sugarcane Industry and to Occupational Exposure to Asbestos
Hawaii
1988
HETA 88-119

Type of worker and source of data	Cases ($N^1 = 93$)	Controls (N = 281)	Control Subset[2] (N = 207)	Odds Ratio	95% Confidence interval
Sugarcane workers					
Union records	4	9		1.4	0.3, 5.0
			4	2.3	0.4, 12.5
1942 census	4	10		1.2	0.3, 4.4
			7	1.3	0.3, 5.2
Death certificates	4	6		2.1	0.4, 8.9
			5	1.8	0.4, 8.6
Any Sugarcane worker	7	19		1.1	0.4, 2.9
			12	1.3	0.4, 3.8
Asbestos workers					
Shipyard[3]	12	5		8.2	2.6, 30.3
			3	10.1	2.6, 56.6
1942 census	8	21		1.2	0.5, 2.9
			10	1.8	0.6, 5.3
Death certificates	16	30		1.7	0.8, 3.5
			19	2.9	1.3, 6.2
Any asbestos exposure	26	50		1.8	1.6, 3.2
			31	2.2	1.2, 4.2

1. N - number of subjects in group
2. Excludes subjects with cancer of the larynx, trachea, bronchus, lung, or stomach
3. Member of the Pearl Harbor Shipyard Cohort

Table 13
Summary of Work Histories of Hawaiian Sugarcane Workers Identified by
International Longshoremen's and Warehousemen's Union
Hawaii
1988
HETA 88-119

Worker	Study Status	Years Employed	Years Exposed to: BSF[2] (level)	Years Exposed to: Asbestos	Primary Job
A	case	44	3 (moderate)	36	Truck Mechanic
B	control	27	27 (low)	27	Steam generator or operator
C	case	46	37 (low)	27	Steam generator or operator
D	control	37	0	0	Tractor-trailer driver
E	control	40	2 (low)	25	Plumber
F	control	22	0	0	Engine mechanic
G	control	8	0	0	Laboratory technician
H	control	31	0	0	Garage serviceman
I	control	6	2 (low)	0	Cane truck driver

1. Assessment of probability of exposure to biogenic silica fibers and asbestos is based on the findings of this health hazard evaluation.
2. Biogenic silica fibers