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REPORT SUMMARY

In 1991, Medite of New Mexico requested a NIOSH health hazard evaluation (HHE) to evaluate employee exposures to formaldehyde during fiberboard manufacturing at its Las Vegas, New Mexico, facility. NIOSH investigators conducted two site visits at the facility, which included exposure monitoring, in 1991 and 1993. The objective of the NIOSH study was to assess occupational exposures to formaldehyde, formaldehyde on dust (FDust), inhalable dust and total dust (as soft wood dust) before and after process and engineering control changes implemented by the company to reduce worker formaldehyde exposures. The study was also designed to provide a comparison of two analytical methods for measuring formaldehyde on resin-treated wood dusts.

The range for 13 personal breathing zone (PBZ) exposures for formaldehyde (includes both site visits) was 0.029 - 0.48 milligrams per cubic meter (mg/m^3); wood dust (as total dust) exposures ranged from none detected to 21.03 mg/m^3; inhalable dust exposures ranged from 0.307 to 24.1 mg/m^3; and FDust exposures ranged from none detected to 0.09 mg/m^3. Workers in four job categories and five areas were sampled during both site visits, and results for formaldehyde, total dust (wood dust), and inhalable dust were compared (four additional job categories were sampled during the second visit). The mean formaldehyde concentration in PBZ and area air samples during the first site visit (0.38 mg/m^3) was significantly higher than the mean during the follow up visit (0.25 mg/m^3, p=0.002, paired t-test). No worker's exposure exceeded the Occupational Safety and Health Administration (OSHA) action level, 0.5 parts per million (ppm), although full-shift exposures greater than the American Conference of Governmental Industrial Hygienists Threshold Limit Value ceiling limit (ACGIH TLV-C) were measured for two of eight job categories, and it is quite likely that the ceiling limit was exceeded for three other job categories. The mean total dust (wood dust) concentration during the first site visit (3.77 mg/m^3) did not differ significantly from the mean during the second site visit (1.80 mg/m^3, p=0.30, paired t-test). Wood dust exposures exceeded the NIOSH REL of 1 mg/m^3 for one of four workers during the first visit, and for seven of nine workers sampled during the second site visit.

Paired FDust results for 28 air samples indicated that the results from NIOSH Method 5700 were significantly higher than those from another published method (Elia et al.), with means of 0.081 mg/m^3 and 0.012 mg/m^3 , respectively (p=0.01, paired t-test). The ratio of NIOSH/Elia results ranged from approximately 2 to 18 in individual air samples, however, the results from the two methods were highly correlated (r=0.98).

The results of this study indicated that formaldehyde and wood dust exposures at this fiberboard manufacturing facility were a health hazard. The company made a number of changes designed to reduce formaldehyde exposures during the study period, and the results indicate that they were effective in significantly reducing, but not eliminating, hazardous formaldehyde exposures. Wood dust exposures were not significantly reduced overall by the changes. The report provides a number of recommendations to help control hazardous formaldehyde and wood dust exposures through modifications of engineering controls and respiratory protection.

KEYWORDS: SIC 2493 (reconstituted wood products, medium density fiberboard [MDF] manufacturing) formaldehyde, formaldehyde on dust, wood dust, inhalable dust, urea-formaldehyde resins.

INTRODUCTION

In May 1991, Medite of New Mexico, Incorporated requested a NIOSH health hazard evaluation (HHE) to evaluate employee exposures to formaldehyde during fiberboard manufacturing at the company's facility in Las Vegas, New Mexico. Worker exposures to formaldehyde at this facility result from the use of urea-formaldehyde resins as the fiberboard binding materials. Previously (June-July 1990), the New Mexico Environmental Improvement Division of the Occupational Safety and Health Bureau (NMOSHA) had inspected the facility. NMOSHA had measured worker formaldehyde exposures above the Occupational Safety and Health Administration (OSHA) action level of 0.5 ppm and issued citations for violations of the OSHA formaldehyde standard (29 CFR 1910.1048). The company contested the citations, as the company's exposure monitoring had not revealed exposures above the OSHA Action Level. The company's HHE request was part of the settlement of these citations with NMOSHA.

On September 4, 1991, NIOSH investigators conducted an initial site visit at the facility, which included air sampling for formaldehyde, formaldehyde on dust (FDust), total dust and inhalable dust (both as wood dust), and informal employee interviews.[*] On June 2-3, 1993, after changes in the process, engineering controls, and work practices were carried out, NIOSH investigators returned for a second site visit, which included air sampling for the same contaminants. Some of the recommendations presented at the end of this report, which were based on observations during the site visits, were provided in a closing conference with company representatives on June 3, 1993.

OBJECTIVE

The objective of this study was to assess occupational exposures to formaldehyde, formaldehyde on dust, and total dust (wood dust) and inhalable dust (wood dust) before and after process and engineering control changes implemented by the company to reduce worker formaldehyde exposures. The study was also designed to provide a comparison of two analytical methods for measuring formaldehyde on resin-treated wood dusts, NIOSH Method 5700,[1] and the Elia et al. method.[2]

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* **To avoid duplication of an ongoing NMOSHA investigation, NIOSH did not investigate safety hazards associated with a flash fire that occurred at the facility a few days prior to the 1991 site visit.**

BACKGROUND

Fiberboard is a dense pressed wood product produced in boards of various thicknesses (3/16 to 1½ inch) for furniture, and in other shapes for interior applications such as baseboard moldings, cabinets, and picture frames.

This facility was reportedly constructed as a state-of-the-art fiberboard manufacturing plant in 1983, and began operations in 1984. After several changes of ownership, Medite of New Mexico began operations at the facility in 1989. At the time of the NIOSH site visits there were 133-135 hourly employees working over three shifts, seven days per week, and 20 administrative or office employees. The day shift operated between 7:00 a.m. and 3:00 p.m.

The highly automated manufacturing process consists of: preparing wood fibers, treating fibers with urea-formaldehyde resin and drying them, forming mats of resin-treated wood fibers, pressing the mats into fiberboard, and finishing the boards with sawing and sanding. Reportedly, there is currently no feasible substitute for urea-formaldehyde resin in fiberboard manufacturing. The urea-formaldehyde resin used in the process was manufactured at a separate facility, located across a public road about 200 yards away.

Raw materials used in the process are soft wood chips, sawdust, planer shavings, and recycled wood products (pine, spruce, and aspen) with about 50% water content. No hardwoods or western red cedar were reportedly used. The raw materials are moved by the front loader operator from large piles outside into a wood storage shed. The wood chips are softened with steam pressure in the digester and ground into fibrous material at the refiner. A refiner operator controls the process from an isolation booth. In an enclosed process, liquid urea-formaldehyde resin is injected into the fibrous material, and the fibers are then dried to about 10% water content. During the drying process, the resin is drawn into the porous fibers.

After drying, resin-treated fibers are conveyed to the former, which layers the fibers into a continuous 4-ft wide mat. The mat consists of two “face” layers on the top and bottom and two inner “core” layers; the face and core layers have resins of different composition. The continuous mat is fed onto a form line conveyer, where the mat is leveled to a specified thickness and cut into separate 8-ft mats by an automatic “flying” circular saw (form line saw). The mats are conveyed into a pre-compressor, where excess air is pressed out, and then are loaded into a 20-opening steam-heated hydraulic press. Mats are pressed at 1500-3000 pounds per square inch at 300-350 °F for specified times to cure the resin and bind the wood fibers together into a dense board. Steam and vapors are emitted when the hot press opens are exhausted through roof openings over the press. The boards are unloaded from the press onto an enclosed cooling wheel where they are cooled with outside air that is moved over the boards and then exhausted to the outside. The boards are then stacked and moved by forklift to a warehouse area, where they are allowed to continue cooling for a minimum of 24 hours.

Cooled fiberboards are cut to exact dimensions (usually 4 ft x 8 ft) by an automatic in-line saw, then moved to the sander, which removes the top and bottom surfaces to produce the finished fiberboard product.

Noise levels were reportedly 85-92 dBA in the production areas; the company had a hearing conservation program and provided appropriate hearing protection to workers. Workers were provided NIOSH-approved full-facepiece air-purifying respirators with formaldehyde/organic vapor cartridges and dust/mist filters for certain jobs associated with high formaldehyde exposures, such as press maintenance.

The former, form line, form line saw, press, cooling wheel, in-line saw, and sander were provided with local exhaust ventilation to remove airborne wood dust and formaldehyde vapors. The warehouse was provided with general dilution ventilation. The press and form station operators were in control rooms during most of their work shifts. These rooms were reportedly supplied with 100% air-conditioned outside air and maintained under positive pressure with respect to production areas. Workers had the option of turning the air conditioning off and operating the system on fan only. The air intakes for the control rooms were located on the roof of the facility. The sander operator spent most of his shift in an air-conditioned control booth, which was supplied with recirculated air from the sander area. The utilityman, when not performing duties in production areas, was in either the press or form station control room.

Previous air sampling for formaldehyde by the company had found that the jobs with the highest formaldehyde vapor exposures were press operator, former operator, sander operator, utilityman, and (production) laborer. The maximum personal exposure to formaldehyde, 2.8 parts per million (ppm), measured over a full shift, reportedly occurred during "stop changes" on the main press. A stop changes was a periodic maintenance activity to replace worn press parts, during which workers used full-face air-purifying respirators. The press was modified to eliminate the need for stop changes in late 1990.

Workers in the facility's fiberboard production areas are also exposed to untreated and resin-treated airborne wood dust. The source of the wood dust is primarily conveyors used to transport fibers from one production area to another. Although the conveyors are enclosed, they are not airtight, and visible fibers continuously escape into the air and fall to surfaces in production areas. The heaviest accumulations appeared to be in the blender room and form line areas. In these and other areas, a laborer periodically cleans moving equipment and the floors with compressed air and a broom (or shovel), respectively. Approximately every 10 days a general cleaning, or “blow down” of settled surface dust accumulations is conducted from the rafters to the floors using compressed air and brooms. A blow-down did not occur during the NIOSH site visits. Even outdoors, at the employee-of-the-month (EOM) sign in the parking lot in front of the building, a visible (but much reduced) fallout of wood dust from the process was observed.

Process and Engineering Control Changes

After the initial NIOSH site visit in September 1991, and prior to the second NIOSH site visit in June 1993, the company implemented the following changes which were designed to reduce worker formaldehyde exposures:

1. The molar ratio of formaldehyde to urea was reduced in the urea-formaldehyde resins used for binding both the “face” and “core” areas of the fiberboard.

2. Additional openings were installed in outside walls to provide for passive movement of make-up air.

3. Larger exhaust fans were installed on the board cooler to drop temperatures faster and produce more air movement in the plant.

4. Openings were installed in an interior wall to allow passive air flow from form line to exhaust fans located at the dryers.

5. The frequency of cleaning for main press exhaust fan shrouds was increased.

6. The use of compressed air for cleaning settled dust accumulations from surfaces was restricted to certain approved operations.

METHODS

Occupational exposure assessment-general

PBZ and area and air samples were collected with appropriate sampling media connected with flexible tubing to portable sampling pumps. The air sampling pumps (Gilian High Flow Sampler® HFS513A, Gilian Instrument Co., W. Caldwell, NJ) were calibrated before and after sampling on each day with a rotameter or with a Kurz Pocket Flow Calibrator® mass flowmeter, both of which had been previously calibrated in the laboratory using a primary standard (bubble flowmeter). The mean of the pre- and post-sampling flow rate measurements was used to calculate air sample volumes.
Sampling protocol and analytical methods used are summarized below. NIOSH analytical methods are described in the *NIOSH Manual of Analytical Methods, 4th Edition*.[1] Each laboratory method has a limit of detection (LOD) and limit of quantitation (LOQ), which are determined by the laboratory. The minimum detectable concentration (MDC) and minimum quantifiable concentration (MQC) for each sample were calculated from the LOD and LOQ, in conjunction with the sample volume. Sample values which fall between the MDC and the MQC

are approximate, these are reported in *italicized text*; none detected results are reported as MDC/2 for statistical purposes,[3] these values are in **bold text** in the results for statistical purposes.

Formaldehyde and Total Dust (Wood Dust)

Air samples were collected at a flow rate of 0.5 liters per minute (L/min) through (in series): a 37-millimeter (mm) cassette with tared 37-mm, 1-micron (µm) pore size polytetrafluoroethylene (PTFE) filter; followed by one or two midget impingers, each with 20 milliliters (mL) of 1% sodium bisulfite solution. During the first site visit, two impingers were used in series for the area samples, and one spill-proof impinger for the PBZ samples. Since the recoveries of HCHO in the first impingers were found to be 95% or more of the totals, only one impinger was used for all samples during the second site visit. The impinger samples were transferred to low-density polyethylene bottles before shipping. Impinger samples were analyzed for formaldehyde according to NIOSH Method 3500. The laboratory reported a LOD and LOQ for formaldehyde of 0.5 and 1.4 micrograms per sample (µg/sample), respectively, for the first site visit, and a LOD and LOQ of 0.7 and 2.3 µg/sample for the second site visit.

The tared PTFE filters were analyzed gravimetrically for total dust (wood dust), according to NIOSH Method 0500 for total particulate, not otherwise regulated (modified by using PTFE filters instead of PVC filters). The expected precision of weighing PTFE filters was 0.02 milligrams. In some cases sample weights were less than the mean field blank weight, in these cases the total dust result is reported as 0.00 mg/m^3.

Formaldehyde on Dust

Per NIOSH Method 5700, air samples of inhalable dust were collected at a flow rate of 2.0 L/min through: an Institute of Occupational Medicine (IOM) inhalable dust sampler (Personal Inhalable Dust Sampler, Air Quality Research, Berkeley, CA) with a 25-mm aluminum cassette containing a 25-mm, 5-µm pore size polyvinyl chloride (PVC) filter, or for the second site visit, a similar IOM sampler with plastic housing (SKC IOM Sampler®, SKC, Inc., Eighty Four, PA) with the 25-mm aluminum cassettes. After sampling, the aluminum cassettes with filters were placed in a 30-ml Nalgene® bottles, kept upright, for sample shipment. At this facility airborne wood dust included inhalable particles. The IOM sampler has a much larger inlet than the 37-mm closed faced cassette used for total dust sampling; it collects more mass than the total dust method (NIOSH Method 0500) when inhalable particles are present.

For comparison purposes, bulk samples of settled wood dust, consisting of resin-treated or untreated wood fibers, were collected from various horizontal surfaces in clean plastic bags and transferred to 20-ml glass vials (with no head space in the vial) for shipment. A weighed portion of each bulk samples was subsequently analyzed.

Air and bulk samples were analyzed for formaldehyde on dust according to NIOSH Method 5700, Formaldehyde on dust (textile or wood). The laboratory reported a LOD and LOQ for FDust of 0.4 and 1.1 µg/sample, respectively for the first site visit. The precision of weighing the IOM sampler filter cassettes has not been determined.

Laboratory testing after the first site visit indicated that, due to instability of the material and off gassing of formaldehyde at room temperature, holding time and temperatures were critical for air samples containing resin-treated wood fibers. For the second site visit the air and bulk samples were refrigerated (2-5 °C) immediately after sample collection, and kept refrigerated until analysis.

Samples collected during the second site visit were analyzed as soon as possible in by two methods, NIOSH Method 5700 (chromotropic acid procedure), and the Elia et al. method (acetylacetone procedure).[2] Both methods use extraction procedures and colorimetric analysis for formaldehyde on dust. The Elia et al. method measures "released" formaldehyde with a mild hydrolysis procedure, whereas the NIOSH method determines both "released" formaldehyde and formaldehyde equivalents (e.g., the small oligomeric pieces of formaldehyde-containing resin) present in more acidic hydrolysis solutions. The LOD and LOQ for NIOSH Method 5700 were 9.9 and 16.6 µg/sample, respectively; for the Elia et al. method the LOD and LOQ were 1.1 and 3.7 µg/sample, respectively.

Initial Site Visit, 1991

Full-shift personal breathing zone (PBZ) sampling for the above analytes was conducted during one day shift on four workers in four presumed maximum-exposure job categories: sander operator, press operator, laborer, and utilityman. Full-shift area air samples were collected in three locations of presumed highest exposure: blender room, form line, and in-line saw; and in two other areas to determine background levels: the form station control room and outside at the employee-of-the-month (EOM) sign in the parking lot.

Bulk samples of settled wood dust were collected in the blender room and form line areas. In these areas, visible wood dust particles were continually settling from the air, and depositing on surfaces.

Second Site Visit, 1993

Full-shift PBZ sampling was conducted during two consecutive day shifts on nine workers in eight job categories: sander grader, forklift driver (near sander), utilityman, sander operator, laborer (2 workers), form station operator, front loader operator (moving untreated wood chips), and press operator. Full-shift area air samples were collected during two consecutive day shifts in five locations: blender room, form line, form station control room, in-line saw, and outside at the EOM sign. Four of the preceding job titles (underlined) and the five area locations were also sampled during the first site visit.

Bulk samples of settled wood dust were collected in the following locations: catwalk railing in wood storage shed, wood chip pile outside, blender room, core line, form line, floor next to board cooler, and sander dust silo outside.

CRITERIA FOR EVALUATION OF OCCUPATIONAL EXPOSURES

A. General guidelines

To evaluate occupational exposures to potentially toxic agents, NIOSH investigators use NIOSH Criteria Documents and Recommended Exposure Limits (RELs),[4] the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs),[5] and the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[6] These criteria are designed to provide exposure levels to which most workers may be exposed over a working lifetime without experiencing significant adverse health effects. However, because of variations in individual susceptibility, a small percentage of workers may experience occupational illness even if exposures are maintained below these limits. The evaluation criteria do not take into account individual hypersensitivity, preexisting medical conditions, or possible interactions with other work place agents, medications being taken by the worker, or other environmental conditions.

The evaluation criteria for chemical substances are usually based on the personal breathing zone exposure to the airborne substance over an entire 8- to 10-hour workday, expressed as a time-weighted average (TWA). Personal exposures are usually expressed in units of parts per million (ppm), milligrams per cubic meter (mg/m^3), or micrograms per cubic meter ($\mu g/m^3$). To supplement the 8-hr TWA where there are recognized adverse health effects from short-term exposures, some substances have a short-term exposure limit (STEL) for 15-minute peak periods; or a ceiling limit (C), which is not to be exceeded at any time. Additionally, some chemicals have a "skin" notation to indicate that the substance may be absorbed through direct contact of the material with the skin and mucous membranes.

NIOSH RELs and ACGIH TLVs are based primarily on concerns related to the prevention of occupational disease. The OSHA PELs are legal standards in the U.S. In developing PELs, OSHA is required to consider the economic feasibility of controlling exposures in various industries, public notice and comment, and judicial review, in addition to prevention of occupational diseases and injury. NIOSH investigators recommend that exposures be reduced below the most protective of these criteria.

The OSHA PELs, as found in Tables Z-1 through Z-3 of the OSHA General Industry Air Contaminants Standard (29 CFR 1910.1000), that were effective on July 1, 1993 and which are currently enforced by OSHA are listed here unless otherwise noted. In 1992, a federal appeals court vacated the more protective PELs set by OSHA in 1989 for 212 substances, moving them back to PELs established in 1991 (*AFL-CIO v. OSHA*, 965 F.2d 962 [11th Cir., 1992]). The court also vacated new PELs for 164 substances not previously regulated.

B. Specific Substances

Formaldehyde

Formaldehyde gas (HCHO) is colorless, with a strong, pungent odor. Exposure to formaldehyde can occur through inhalation or skin absorption. It is an irritant of the eyes and respiratory tract; aqueous solutions of formaldehyde (typically formalin, 37-50% formaldehyde) can cause both primary irritation and sensitization dermatitis.[7]

The first symptoms associated with formaldehyde exposure, at concentrations ranging from 0.1 to 0.5 parts per million (ppm), are burning of the eyes, tearing, and general irritation of the upper respiratory tract. There is variation among individuals, in terms of their tolerance and susceptibility to acute exposures of the compound.[8]

In two separate studies, formaldehyde has induced a rare form of nasal cancer in rodents. Formaldehyde exposure has been identified as a possible causative factor in cancer of the upper respiratory tract in a proportionate mortality study of workers in the garment industry.[9,10]

As established in the OSHA formaldehyde standard (29 CFR 1910.1048), the PEL for occupational exposure to formaldehyde is 0.75 ppm (0.92 mg/m^3) as an 8-hour TWA, with an action level of 0.5 ppm (0.61 mg/m^3) and 2 ppm as a STEL.[11] OSHA designates formaldehyde as a probable human carcinogen. ACGIH has established a TLV-ceiling limit of 0.3 ppm (0.37 mg/m^3) for formaldehyde. ACGIH has designated formaldehyde as a suspected human carcinogen and recommends that exposures by all routes should be carefully controlled to levels "as low as reasonably achievable."

NIOSH considers formaldehyde to be a potential human carcinogen and as such recommends that exposures be maintained at the lowest feasible level.[12] The NIOSH REL is 0.016 ppm (0.019 mg/m^3) for up to a 10-hr TWA, and a 15-min ceiling limit of 0.1 ppm, both were based on the lowest reliably quantifiable concentration using NIOSH Method 3500.[13]

Formaldehyde on dust

Currently there are no criteria for occupational exposures to formaldehyde on dust. Previous studies have suggested an excess of cancers in the upper respiratory passages among workers exposed to formaldehyde and formaldehyde-containing dusts (garment manufacture).[10] It has been hypothesized that upper respiratory areas may be receiving additional formaldehyde exposure from the deposition of formaldehyde-containing particulate material in addition to the vapor phase formaldehyde which evolves from these materials.[14]

Much work remains to be done to better assess the effects of occupational exposure to formaldehyde-containing dusts, including epidemiologic study of upper respiratory tract cancers. As a first step in this process, analytical methods have been developed to measure formaldehyde that may be physically adsorbed or chemically bound on textile or wood dusts (NIOSH Method 5700 and Elia et al.).[1,2]

Wood Dust (measured as total dust)

Wood dust in this facility consisted of airborne particulate from soft woods and wood products. Wood dust may be inhaled and deposited in the nose and throat region, the upper bronchial region, or the lung, depending on the particle aerodynamic size. Formaldehyde and other gaseous compounds can be adsorbed on wood particles; the criteria below were established without regard to formaldehyde content.

Wood dust may cause respiratory irritation and sensitization among exposed workers. Chronic exposure to wood dust has been reported to have resulted in numerous health effects including allergic reactions, chronic non-allergenic respiratory disease, and nasal sinus cancer.[15,16,17] Obstructive respiratory effects, development of lung fibrosis, and impairment of the mucociliary clearance mechanism also have been reported.[18,19]

The criteria for wood dust exposure are based on sampling for total dust with 37-mm closed faced cassettes. The OSHA PEL for wood dust (as total dust) is 15 mg/m^3 as an 8-hour TWA. During the first site visit, before a federal court vacated the 1989 OSHA PELs, the PEL was 5 mg/m^3. The ACGIH TLVs for soft and hard wood dust are 5 mg/m^3 and 1 mg/m^3, respectively; both as 8-hour TWAs. ACGIH has established a STEL of 10 mg/m^3 for soft wood dust. NIOSH has designated wood dust as a potential occupational carcinogen and has established a numerical REL of 1 mg/m^3, but recommends that exposures for all potential occupational carcinogens be reduced to the lowest feasible level. NIOSH has indicated that it does not agree that soft wood dust should be considered separately from hard wood dust, the REL applies to all wood dusts.[20]

RESULTS

Initial Site Visit

The results of four PBZ and five area samples for formaldehyde and total dust (wood dust) are presented in Table 1. The intent was to conduct full-shift sampling; sample times ranged from 329 to 449 minutes. Formaldehyde concentrations are expressed in both mg/m^3 and the equivalent ppm; the former units will be used in this discussion.

The workers' formaldehyde exposures ranged from 0.23 to 0.48 mg/m^3; none exceeded the OSHA action level (0.61 mg/m^3) or the current OSHA PEL (0.92 mg/m^3). The highest exposures, for the sander operator and laborer, exceeded the current ACGIH TLV-C of 0.37 mg/m^3. All four PBZ formaldehyde exposures were in the range (0.1 - 0.6 mg/m^3) at which some individuals begin to experience eye or respiratory tract irritation. The company conducted side-by-side PBZ formaldehyde sampling of the four workers with 3M Diffusional Monitors (analyzed by 3M Analytical Service); the results are reported in Table 1. The means for personal formaldehyde exposures as measured by NIOSH (0.37 mg/m^3) and the company (0.44 mg/m^3) were not significantly different (p=0.31, paired t-test), but that may have been due to the small sample size.

The range for area formaldehyde concentrations was 0.05 - 0.56 mg/m^3. The highest area concentrations, in the blender room (0.56 mg/m^3) and the in-line saw (0.54 mg/m^3) approached, but did not exceed, the OSHA action level for personal exposures. The concentration of formaldehyde measured outside at the employee-of-the-month (EOM) sign, 0.05 mg/m^3, was notable in that it exceeded several other States' 8-hour limits for formaldehyde in ambient air (range: 0.012-0.018 mg/m^3).[21] This relatively high ambient level was probably due to formaldehyde emissions from the Medite facility, and/or the urea-formaldehyde resin manufacturing facility located about 200 yards away across the road. The concentration of formaldehyde in the form station control room, 0.35 mg/m^3, was lower than in production areas sampled, but seven times higher than the outdoor level in the parking lot. This indicates either that outside air supplied to the control room was being contaminated or that the air supply was insufficient.

The ranges for PBZ exposures and area concentrations of total dust (wood dust) were 0.07-21.03 mg/m^3 and 0.03-8.48 mg/m^3, respectively (see Table 1). One of four personal wood dust exposures (21.03 mg/m^3) exceeded the OSHA PEL (15 mg/m^3), the ACGIH TLV (5 mg/m^3), and the NIOSH REL (1 mg/m^3). The job category associated with this exposure was laborer; his duties included periodically cleaning wood dust from form line equipment with compressed air, and sweeping or shoveling wood dust in the form line and other areas. The laborer's full-shift exposure exceeded the ACGIH STEL of 10 mg/m^3; it is likely that this worker's actual peak (15-minute) exposure was much higher, as the work was not continuous. On the day of the survey, the laborer used a single-use dust/mist respirator, which was not adequate for protection against the measured wood dust exposure. The concentration of wood dust in the form station control room, 0.33 mg/m^3, was eleven times higher than the outdoor level measured, indicating either that outside air supplied to the control room was being contaminated or that the air supply was insufficient.

Four bulk samples of settled wood dust were analyzed for FDust; the pre-analysis weights of sample portions were 300 to 500 milligrams (mg). Two samples of resin-treated dust from the blender room were found to be 3.4% and 4.2% formaldehyde by weight, and two samples of resin-treated dust collected next to the form line were 5.8% and 5.3% formaldehyde.

A total of nine air samples collected for FDust contained 0.02 to 14.39 mg/sample of inhalable dust, corresponding to airborne inhalable dust concentrations of 0.21 - 24.14 mg/m^3. The trace amounts of formaldehyde (<2 µg/sample) measured in these nine air samples were not consistent with the expected quantities (up to hundreds of µg/sample), based on the formaldehyde concentrations measured in the bulk samples, which contained essentially the same material. For this reason, FDust results are not reported. The inconsistency between formaldehyde results for settled dust and FDust air samples indicated an unforeseen problem with NIOSH Method 5700. Subsequent laboratory testing indicated that, due to apparent off gassing of formaldehyde at room temperature within the sample containers, holding time and temperature were critical for FDust air samples of this resin-treated wood dust. The potential for off gasing of formaldehyde was much lower in the bulk samples, because the sample containers were full, with no head space above the wood fibers.

On the day of the survey, seven employees representing the highest exposure job categories (laborer, utilityman, press operator, form station operator, sander operator) were informally interviewed. The employees had worked at the facility from one to eight years (mean 3.6 years). None of the workers reported current health complaints. Two workers reported past respiratory or skin irritation due to cleaning, sweeping or shoveling settled wood dust from floors or equipment; the workers reported that wood dust exposures at that time were higher than at the present time.

Second Site Visit

The results of 18 PBZ and 10 area air samples collected for formaldehyde, total dust (wood dust), inhalable dust and FDust are presented in Table 2. Full-shift sampling was conducted of nine workers and in five areas over two consecutive days, sample times ranged from 453 to 509 minutes.

The mean PBZ formaldehyde exposure measured was 0.23 mg/m^3 (range: 0.029-0.40 mg/m^3). None of the workers' exposures exceeded the OSHA action level (equivalent to 0.61 mg/m^3), or the OSHA PEL. Of the eight job categories sampled, the highest personal exposures were for a utilityman and sander operator (both 0.40 mg/m^3), which on one of the two days sampled exceeded the ACGIH TLV-C (ceiling limit) of 0.37 mg/m^3. It is quite likely that the ACGIH TLV-C was exceeded for three other job categories: sander grader, forklift driver, and laborer; all of which had at least one full-shift exposure $\geq$0.28 mg/m^3, which equals 75% of the ceiling limit.

All of the workers' formaldehyde exposures, except for the front loader operator's, were in the range (0.1-0.6 mg/m^3) at which some individuals begin to experience eye or respiratory irritation.

The mean area formaldehyde concentration was 0.25 mg/m^3 (range: 0.007-0.53 mg/m^3). All of the area formaldehyde concentrations were less than the OSHA action level (0.61 mg/m^3); the highest concentrations were measured in the form line (0.53 mg/m^3) and in-line saw (0.38 mg/m^3) areas. Over the two days of sampling, the mean form station control room concentration (0.175 mg/m^3) was lower than all other production area concentrations, but more than an order of magnitude higher than the mean outside level at the EOM sign (0.010 mg/m^3). This indicates either that outside air supplied to the control room was being contaminated or that the air supply was insufficient.

In 14 paired PBZ and area results, formaldehyde concentrations were significantly higher on the first day of sampling than on the second day; the means were 0.27 mg/m^3 and 0.21 mg/m^3, respectively (p=0.01, paired t-test). No specific explanation for this difference was apparent; it is likely that the difference was due to day-to-day variations in production, weather, and ventilation conditions.

The mean PBZ exposure to total dust (wood dust), 2.32 mg/m^3, exceeded the NIOSH REL of 1 mg/m^3 (range: 0.0* - 12.31 mg/m^3). Seven of nine workers sampled, in the laborer, forklift driver (sander), utilityman, front loader operator, sander operator and press operator job categories, had wood dust exposures exceeding the NIOSH REL during at least one day of the survey. The two laborers and the front loader operator had wood dust exposures exceeding the NIOSH REL on both days of the survey. Three of 18 employees had wood dust exposures exceeding the ACGIH TLV of 5 mg/m^3; all were laborers. None of the wood dust exposures exceeded the current OSHA PEL of 15 mg/m^3. The mean wood dust concentration in area samples was 1.29 mg/m^3 (range: 0.0 - 6.62 mg/m^3). Unlike the first visit, the two-day mean area wood dust concentration for the form station control room (0.22 mg/m^3) was lower than the mean level measured outside at the EOM sign (0.41 mg/m^3). However, the relatively high concentration measured outside at the EOM on the first day (0.82 mg/m^3) is probably not representative of daily ambient levels; on this day the grass next to the sign was mowed with a power mower, which probably stirred up a considerable amount of wood dust settled on the lawn. On the second day of sampling no wood dust was detected outside. The mean total dust levels in PBZ and area samples did not differ significantly between the two days of sampling (p=0.65, paired t-test).

The mean PBZ exposure to inhalable dust (collected with IOM samplers) was 3.22 mg/m^3 , range: 0.43 -7.55 mg/m^3; the mean for area samples was 7.36, range: 0.31 -23.4 mg/m^3 (Table 2). Overall, the inhalable dust levels were significantly higher that the corresponding total dust levels in 28 paired area and PBZ samples (p=0.02, paired t-test). This was expected, because the IOM

***Zero values had a sample weight less than the mean blank weight.**

sampler is designed to collect larger airborne particles than the 37-mm closed-face cassette used for total dust sampling. Interestingly, the inhalable dust results were not well correlated with total dust results for the 28 paired air samples (r=0.098, Pearson correlation); this indicates that particle size distributions were not homogeneous throughout the facility. The mean inhalable dust levels in PBZ and area samples did not differ significantly between the two days of sampling (p=0.29, paired t-test). Times (noted in Table 2) for some of the PBZ inhalable dust/FDust samples were shortened due to pump faults. The IOM samplers seemed to be more susceptible than the closed face 37-mm cassettes to pump faults caused by accidental covering of the filter cassette opening by the worker.

The FDust results were relatively low compared to gaseous formaldehyde levels measured by NIOSH Method 3500 (above). The mean PBZ exposure to FDust was 0.03 mg/m^3 (range: 0.003 - 0.12 mg/m^3, NIOSH Method 5700). The highest levels were for utilityman and laborer job categories. The mean area concentration of FDust was 0.18 mg/m^3 (range: 0.001-0.61 mg/m^3, NIOSH Method 5700). The highest levels were in the blender room and form line areas, with concentrations about an order of magnitude above those in the other production areas. The mean FDust level in PBZ and area samples did not differ significantly between the two days of sampling (p=0.92, paired t-test), which is consistent with the total dust results, but not the formaldehyde results.

Paired FDust results for 28 air samples indicated that the concentrations determined by NIOSH Method 5700 were significantly higher than those determined by the Elia et al. method; means 0.081 mg/m^3 and 0.012 mg/m^3, respectively, p=0.01, paired t-test (Table 2). The ratio of NIOSH/Elia results ranged from approximately 2 to 18 in individual air samples. The ratios of means for area and PBZ results were seven and five, respectively. However, the results for the two methods were highly correlated (r=0.98), see Figure 1. Previously, Elia et al. reported that the NIOSH method produced results (bulk samples only) approximately 10 to 14 times greater than the Elia et al. method.[2]

Nine bulk samples of settled dust were collected and analyzed for FDust using NIOSH Method 5700 and the Elia et al. method, see Table 3. The formaldehyde content of the dust samples ranged from none detected (<0.09%) to 2.31% (NIOSH Method 5700, sample weights of 10-15 mg). The highest formaldehyde content was found in dust collected in the blender room (2.31%) and on the form line (2.16%); however, both of these bulk samples had lower formaldehyde concentrations than those collected on the first site visit. This result is consistent with reported reductions in the formaldehyde content of the resin made after the first site visit. No formaldehyde was detected in samples of untreated wood dusts collected in the wood storage shed, wood chip pile, or core line (< 0.09%, NIOSH Method 5700).

Paired results for FDust in nine bulk samples indicated that the formaldehyde concentrations determined by NIOSH Method 5700 were higher than those determined by the Elia et al. method (means: 0.77% and 0.16%, respectively). The ratio of NIOSH/Elia results for individual bulk dust samples ranged from approximately one to eight, and the mean ratio was five. In contrast to the paired air sample results, this difference was only borderline significant (p=0.055, paired t-test). Results for the two methods were less well correlated in the bulk dust samples than in the air samples, r=0.82, p=0.006 (Figure 2).

Other Observations--Second Site Visit

1. The audible alarm for transmission in reverse on the forklift was not working and could result in a worker being accidentally struck by the forklift when it is backing up.

2. The fiberboard used as flooring on the operator’s platform at the in-line saw was somewhat slippery and could result in slip and fall accidents.

3. The capture efficiency of the local exhaust ventilation at the “flying” automatic circular saw on the form line could be improved to prevent the escape of wood dust observed at each pass of the saw.

Comparison of Two Site Visits

Four job categories and five areas were sampled during both site visits (see Table 4) and results for formaldehyde, total dust (wood dust), and inhalable dust were compared (four additional job categories were sampled only during the second visit). Overall (personal breathing zone [PBZ] and area results), the mean formaldehyde concentration during the first site visit (0.38 mg/m^3) was significantly higher than the mean during the follow up visit (0.25 mg/m^3), p=0.002, paired t-test. The change in mean formaldehyde level between the site visits, 0.13 mg/m^3, was more than twice the difference between mean formaldehyde levels on two consecutive days (0.06 mg/m^3) during the second site visit. For all four job titles and five areas sampled, the formaldehyde concentrations were less during the second site visit. These results strongly suggest that changes made by the company were successful in reducing formaldehyde concentrations throughout the facility.

The mean total dust (wood dust) concentration during the first site visit (3.77 mg/m^3) did not differ significantly from the mean during the second site visit (1.80 mg/m^3), p=0.30, paired t-test. Total dust concentrations during the second site visit were higher for six of the paired samples, and lower for the laborer job category, and blender room and form station control room areas. The mean inhalable dust concentration for the first site visit (4.86 mg/m^3) did not differ significantly from the mean during the second site visit (5.43 mg/m^3), p=0.85, paired t-test. FDust concentrations from the first site were not reportable and could not be compared to the second site visit results.

DISCUSSION AND CONCLUSIONS

Formaldehyde exposures in this facility represented an occupational health hazard. Changes made by the company between the two NIOSH site visits significantly reduced, but did not eliminate, hazardous personal and area airborne formaldehyde levels. Formaldehyde exposures did not exceed the OSHA action level (0.5 ppm, or 0.6 mg/m^3) or the OSHA PEL on either site visit. Area formaldehyde concentrations did approach the OSHA action level (for personal exposures) in the blender room and in-line saw areas during the first site visit, and could have exceeded the action level previously due to process and environmental variations.

The NIOSH REL for formaldehyde of 0.019 mg/m^3 was established as the lowest reliably quantifiable concentration for a full-shift exposure (NIOSH Method 3500). NIOSH considers formaldehyde to be a potential occupational carcinogen and recommends that exposures be reduced to the lowest feasible level. All of the employees' exposures exceeded the numerical REL. Formaldehyde exposures greater than the ACGIH TLV-C (ceiling limit) were measured for two of eight job categories sampled, and it is quite likely that the ceiling limit was exceeded for three other job categories with full-shift exposures at least 75% of the limit.

Area sampling results suggested that the form station control room's ventilation system was not effective in isolating this area from process emissions, as the formaldehyde concentration in the form station control room was more than an order of magnitude higher than the mean outside level during the second site visit.

Wood dust exposures, irrespective of the formaldehyde content of the dust, represented a health hazard in this facility. Wood dust exposures for seven of nine workers sampled (in six job categories) exceeded the numerical REL on at least one day during the second site visit. NIOSH considers wood dust to be a potential occupational carcinogen and also recommends that exposures be reduced to the lowest feasible level. The average personal and area air concentrations of total and inhalable dust (wood dust) for the first and second NIOSH site visits were not significantly different. This indicates that changes made by the company following the first site visit were not generally effective in reducing wood dust exposures, although they may have reduced exposures for certain activities.

Air sampling results for formaldehyde on dust (FDust) during the first site visit demonstrated that sample time and temperature are critical for assessing the formaldehyde content of these treated wood dusts. Air samples should be refrigerated at 2-5 °C immediately after sampling until analysis is performed with 14 days. FDust exposures measured during the second site visit represent a potential source of worker formaldehyde exposure. The health significance of the FDust exposures measured is not known, but it would be prudent to minimize the exposures to the extent feasible. This study has characterized FDust exposures at a fiberboard manufacturing facility and demonstrated the need for special sample handling procedures to measure formaldehyde on dust for this type of material.

The study compared two analytical methods for FDust air samples and determined that formaldehyde concentrations determined by NIOSH Method 5700 were significantly higher than those determined by the Elia et al. method. This result was consistent with a previous published comparison.[2] The air sample results for the two analytical methods were highly correlated, although the ratio of NIOSH/Elia results ranged from approximately 2 to 18 in individual samples. At this time it is unknown which FDust method is more useful for occupational exposure characterization; more epidemiologic data are needed to relate health outcomes to FDust exposure levels. The difference between the results obtained with the two methods represents the amount of oligomeric formaldehyde, or formaldehyde equivalents, in the dust sampled.

RECOMMENDATIONS

The following recommendations are offered to assist the company in minimizing employee exposures to formaldehyde and wood dust at this facility.

1. The company should continue its program to reduce worker formaldehyde exposures to the lowest feasible level. The company's program of reducing the formaldehyde content of the resin and implementing other technological changes was effective in reducing formaldehyde exposures significantly during the study period. Increased attention is needed to the reduction of hazardous wood dust exposures throughout the facility.

2. Until all formaldehyde and wood dust exposures can be reduced below their respective NIOSH RELs, respirators should be provided to exposed workers. Both substances are identified by NIOSH as potential occupational carcinogens. NIOSH recommends that only the most protective respirators be used for protection against occupational carcinogens, either a supplied-air respirator that has a full-facepiece, operated in pressure-demand or other positive-pressure mode, or self-contained breathing apparatus (SCBA) that has a full-facepiece and is operated in positive-pressure mode. The next best alternative would be to provide workers with NIOSH-approved full-facepiece powered air-purifying respirators (PAPRs) equipped with combined cartridges for toxic dusts and organic vapors (formaldehyde). PAPRs are more comfortable to wear than air-purifying respirators in hot conditions, and result in less cardiovascular stress. At minimum, a PAPR should be provided to any worker who requests one, and the respirator program should meet OSHA requirements (29 CFR 1910.134).

3. The ventilation system for the form station control room should be modified to provide more effective isolation from process emissions of formaldehyde and wood dust. A separate rooftop heating, ventilation and air-conditioning system should supply 100% outside air to the control room through ventilation ducts. The air intake for this system should be located to ensure that contaminants exhausted from the plant are not entrained in the outside air supply. Due to the presence of wood dust outside the building, filtration of the outside air supply may be necessary. The supply ducts, and the control room itself, should be maintained under positive air pressure with respective to surroundings to maintain airflow from "clean" to "less clean" areas. Pressure differentials are more easily maintained in closed rooms; therefore, it is important that the control room door(s) close tightly and be kept closed as much as possible. The ventilation for the press control room should also be modified in this manner.

4. To reduce hazardous exposures to wood dust, open belts and conveyors which release airborne dust should be enclosed. A wider shroud should be installed on the automatic saw on the form line to improve capture efficiency of the local exhaust ventilation.

5. To reduce hazardous exposures to wood dust, the use of compressed air for cleaning settled dust from surfaces during “blow down” should be avoided. Wherever possible, workers should use vacuums with medium- to high-efficiency filters for cleaning dust from surfaces. Shoveling, dry or wet sweeping, and brushing should only be used for cleaning where vacuuming has been found to be infeasible. Compressed air should not be used to clean up floors or other surfaces unless it is used in conjunction with a local exhaust ventilation system which captures the airborne dust created by the compressed air. This may require one worker to move the compressed air supply while another worker moves a portable exhaust ventilation system. Exposure monitoring during blow-down should be conducted.

6. The front loader should be provided with an enclosed, air-conditioned cab to control the front loader operator’s wood dust exposures. A supply-air fan should be provided, with coarse and high-efficiency filters in series, to provide clean outside air to the enclosed cab. The filters should be changed as necessary to maintain air flow and positive pressure in the cab.

7. The ventilation systems for the sander operator’s booth, and other similar control booths located on the plant floor, should be modified to more effectively isolate employees from process emissions. Instead of filtered, recirculated air from the production areas, these booths should be supplied with clean outside air and maintained under positive pressure with respect to the surroundings.

8. The company should continue to periodically monitor employee exposures, test the efficiency of local exhaust and general dilution ventilation systems, and keep records of the results. System airflows, capture, and velocities should be periodically be compared to original design specifications and applicable criteria for industrial ventilation. Unless carefully maintained, the efficiency of ventilation systems tends to decrease with time due to worn parts, trapped dust and debris, and unauthorized modifications.

9. To prevent injuries, a non-skid surface should be installed on the platform at the in-line saw, and the audible alarm for transmission in reverse should be repaired on the forklift.

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Table 1. Air Sampling Results--First Site Visit
Medite of New Mexico, HETA 91-239
September 4, 1991

Job Title or Location	Sample Time (min)	Formaldehyde (mg/m³)		Formaldehyde (ppm)	Total Dust[1] (mg/m³)	Inhalable Dust[1]** (mg/m3)
AREA SAMPLES						
Form Line	422	0.47		0.39	2.39	2.85
Blender Room	404	0.56		0.46	8.48	10.39
Form Station Control Rm	395	0.35		0.28	0.33	0.40
In-line Saw	376	0.54		0.44	0.13	0.21
Outdoors at EOM sign	329	0.05		0.04	0.03	0.55
PBZ SAMPLES						
Sander Operator	438	0.45	[0.44][2]	0.37	0.89	1.39
Press Operator	419	0.23	[0.42]	0.19	0.07	0.47
Utilityman	432	0.31	[0.45]	0.25	0.62	3.36
Laborer	449	0.48	[0.44]	0.39	21.0	24.1
OSHA PEL		0.92		0.75	15	
NIOSH REL		0.019		0.016	1	
ACGIH TLV		0.37 C		0.3 C	5	

[1]Resin-treated and untreated wood dust (soft woods).

[2][ ] = formaldehyde sampling result from side-by-side sampling conducted by Medite with 3M Diffusional Monitors.

** Formaldehyde on dust results are not reported (see text).

C = ceiling limit

Table 2. Air Sampling Results--Second Site Visit (page 1 of 2)
Medite of New Mexico, HETA 91-239

Date	Location/Job Title	Sample Time (min)	HCHO[1] (mg/m³)	Total Dust[2] (mg/m³)	Inhalable Dust (mg/m³)	FDust[3] NIOSH 5700 (mg/m³)	FDust[3] Elia et al. (mg/m³)	FDust[3] Ratio NIOSH/Elia
	AREA SAMPLES							
6/2/93	Blender room	453	0.29	1.41	23.4	0.61	0.094	6
6/3/93	Blender room	461	0.21	1.39	20.5	0.55	0.064	9
6/2/93	Form line	450	0.53	6.62	10.9	0.33	0.050	7
6/3/93	Form line	462	0.32	1.04	9.50	0.26	0.039	7
6/2/93	Form station control rm	472	0.20	**0.00**	0.31	**0.016**	0.003	6
6/3/93	Form station control rm	460	0.15	0.43	1.12	0.020	0.003	8
6/2/93	In-line saw	450	0.38	0.84	1.58	0.007	0.002	4
6/3/93	In-line saw	468	0.37	0.34	3.40	0.019	0.001	13
6/2/93	Outside (at EOM sign)	462	0.013	0.82	1.98	**0.0005**	**0.0003**	2
6/3/93	Outside (at EOM sign)	509	0.007	**0.00**	0.92	0.003	**0.0003**	10
	Mean		0.25	1.29	7.36	0.18	0.026	7
	Minimum		0.007	0.000	0.31	0.0005	0.0003	
	Maximum		0.53	6.62	23.4	0.61	0.09	

Bold = none detected, MDC/2 is reported for statistical purposes.

Italics = approximate value, between MDC and MQC.

[1]Formaldehyde, NIOSH Method 3500.

[2]Zero values had sample wt less than mean blank wt.

[3]FDust = formaldehyde on dust (inhalable), see references 1 and 2.

Table 3. Formaldehyde in Bulk Samples of Settled Dust--Second Site Visit
Medite of New Mexico, HETA 91-239

	Formaldehyde on dust		
Sample Location	**NIOSH 5700 (% by wt)**	**Elia et al. (% by wt)**	**Ratio NIOSH/Elia**
Wood storage shed--dust on catwalk railing	**0.04**	*0.009*	5
Wood chip pile outside	**0.03**	**0.004**	8
Blender room--next to area air sample	2.31	0.431	5
Core line--untreated dried wood fibers	**0.05**	**0.006**	8
Form line--next to area air sample	2.16	0.321	7
Sander operator station--dust on catwalk	*0.12*	0.120	1
Form line--fibers face mat on line	*0.15*	0.275	1
Board cooler--dust on floor next to machine	1.13	0.145	8
Sander dust--from silo outside building	**0.91**	0.167	5
Mean	0.77	0.16	5
MDC*	0.09	0.010	
MQC*	0.15	0.034	

Bold = none detected, MDC/2 is reported for statistical purposes.
Italics = approximate value, between MDC and MQC.
*MDC/MQC for average sample wt of 11 mg.

Table 4. Comparison of Paired Air Sampling Results for Two Site Visits
Medite of New Mexico, HETA 91-239
Sept 1991 and June 1993

Sample Type	Job Title/Location	Formaldehyde^ Jun-93[A]	Formaldehyde^ Sep-1991[B]	Total dust^* Jun-93	Total dust^* Sep-91	Inhalable dust^* Jun-93	Inhalable dust^* Sep-91
PBZ	Laborer[C]	0.255	0.48	6.39	21.03	3.17	24.14
PBZ	Press operator	0.122	0.23	1.14	0.07	1.26	0.47
PBZ	Sander operator	0.346	0.45	0.97	0.89	3.62	1.39
PBZ	Utility	0.260	0.31	1.22	0.62	3.99	3.36
Area	Blender room	0.247	0.56	1.40	8.48	21.97	10.39
Area	Form line	0.424	0.47	3.83	2.39	10.20	2.85
Area	Form station control room	0.175	0.35	0.22	0.33	0.71	0.40
Area	In-line saw	0.374	0.54	0.59	0.13	2.49	0.21
Area	Outside (at EOM sign)	0.010	0.05	0.41	0.03	1.45	0.55
	Mean	0.25	0.38	1.80	3.77	5.43	4.86

^Results in mg/m^3.

*Resin-treated and untreated wood dust (soft woods).

[A]Average of two full-shift samples 6/2/93 and 6/3/93 (day shift)

[B]One full-shift sample collected on 9/4/91 (day shift).

[C]Average for 2 workers sampled 6/93; single worker 9/91.

Figure 1 Air Sampling Results for FDust, Correlation of Two Methods.
Medite of New Mexico, HETA 91-239
June 2-3, 1993

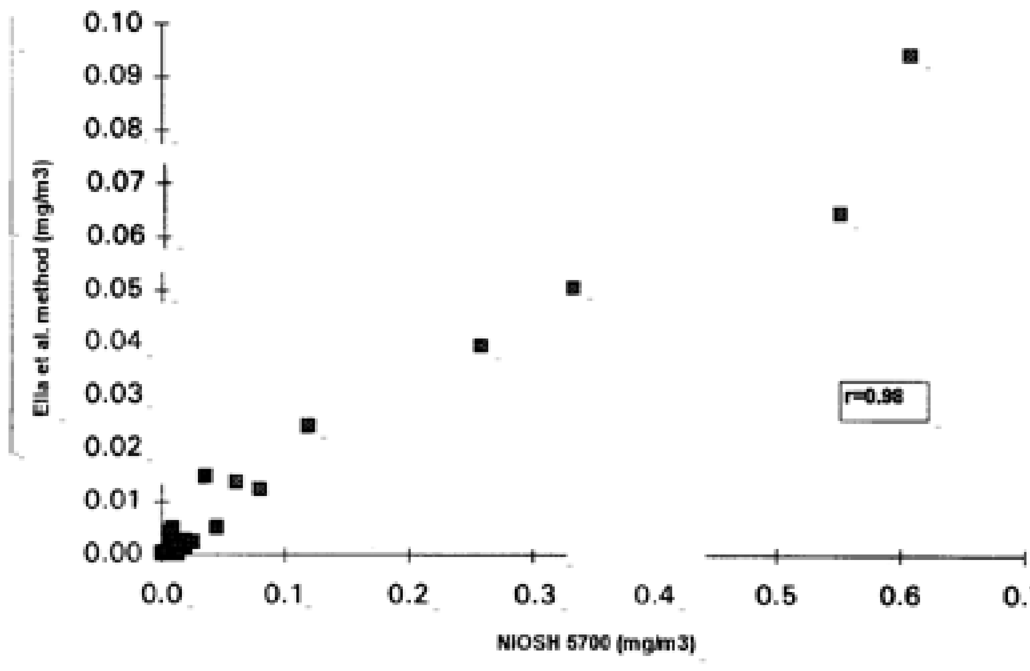

Figure 2. Bulk Sampling Results for FDust, Correlation of Two Methods
Medite of New Mexico, HETA 91-239
June 2-3, 1993