HETA 95–0328–2630
OshKosh B'Gosh
Byrdstown, Tennessee

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PREFACE

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ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Teresa Seitz and Vincent Mortimer of the Hazard Evaluations and Technical Assistance Branch, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Field assistance was provided by Ken Martinez of DSHEFS. Desktop publishing was performed by Ellen Blythe of DSHEFS.

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March 1997

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SUMMARY

In May 1995, an employee at the OshKosh B'Gosh plant in Byrdstown, Tennessee, was diagnosed with cavitary tuberculosis (TB). Based on an initial contact investigation which found a large number of persons with positive tuberculin skin tests, the Division of Tuberculosis Elimination (DTBE), National Center for HIV, STD, and TB Prevention (NCHSTP) asked the National Institute for Occupational Safety and Health (NIOSH) to evaluate the ventilation system at this sewing plant. The epidemiologic evaluation conducted by the Kentucky and Tennessee Health Departments and DTBE later documented positive skin tests among 75% of the workers (174 of 233 workers tested).

NIOSH investigators performed an initial evaluation to measure air flow rates and assess air movement within the plant. Because of the unusually high number of positive skin tests found among the employees, a more in–depth ventilation assessment was made to document conditions that likely occurred during the period of time the employee with TB was infectious. This involved a tracer gas evaluation to quantify the extent and speed of contaminant dispersion and contaminant removal rate. Sulfur hexafluoride was used as the tracer.

The tracer gas evaluation showed that the plant had excellent air mixing and a low air change rate (typically less than 0.4 air changes per hour [ACH] in production areas). When the tracer gas was released in the middle of the plant, it was detected at the furthest points in the production area (approximately 100 feet away) within 11 minutes. The tracer gas was also detected in the engineering and main office areas, the cafeteria, and the conference room.

The NIOSH evaluation determined that ventilation conditions were favorable for TB transmission based on a low air change rate (<0.4 ACH) and excellent air mixing within the plant. Thus, TB bacteria would have spread quickly and uniformly throughout the plant, and remained suspended for hours before being removed from the air. It is impossible to predict, however, to what extent ventilation played a role in TB transmission. Other factors that may have influenced TB transmission include prolonged infectiousness of the individual, virulence of the organism, and TB exposure outside the workplace. These factors were not evaluated in the NIOSH study, but are being examined by the health departments and other groups within the Centers for Disease Control and Prevention (CDC). Recommendations for improving general ventilation are made in the report.

Keywords: SIC 2361 (Girls', Children's, and Infants' Outerwear), Tuberculosis, TB, sewing, ventilation, tracer gas, sulfur hexafluoride.

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INTRODUCTION

In May 1995, an employee at the OshKosh B'Gosh plant in Byrdstown, Tennessee, was diagnosed with cavitary, drug-susceptible tuberculosis (TB). Because the initial contact investigation of family and friends identified a large number of persons with positive tuberculin skin tests (indicating infection with *Mycobacterium tuberculosis*, the bacteria which causes TB), the investigation was extended to all coworkers at the OshKosh plant. In June 1995, the Division of Tuberculosis Elimination (DTBE), National Center for HIV, STD, and TB Prevention (NCHSTP), Centers for Disease Control and Prevention (CDC), was asked to assist the Tennessee and Kentucky State and local Health Departments with the investigation. Tuberculin skin test (TST) screening identified positive skin tests among 75% of the workforce (174 of 233 workers tested), with documented TST conversions among 30 (17%) workers.[1]

In July 1995, the DTBE, NCHSTP, requested assistance from NIOSH in evaluating the ventilation system at the OshKosh plant. NIOSH personnel conducted an environmental evaluation on August 23–25, 1995, and a more detailed ventilation assessment on January 29–February 1, 1996. At the request of OshKosh management, formaldehyde monitoring was performed on the initial visit. This report presents the results of the ventilation assessment only; results of the formaldehyde exposure assessment and preliminary ventilation evaluation were reported in December 1995.

BACKGROUND

Tuberculosis is an infectious disease caused by *Mycobacterium tuberculosis*. The bacteria are carried in airborne particles known as droplet nuclei, that can be generated when persons with pulmonary or laryngeal TB cough, sneeze, or vocalize.[2] Because of their small size (1–5 microns [µm]), the droplet nuclei can be suspended in the air for long periods of time, probably hours. Infection occurs when a susceptible person inhales infectious droplet nuclei and the particles become established in the alveoli of the lungs and spread throughout the body. Within 2–10 weeks, the body's immune system is usually able to prevent further multiplication and spread of bacteria; however, some of the organisms remain dormant, but viable, for many years. People with this condition, referred to as latent TB infection, will usually test positive on a purified protein derivative (PPD)–tuberculin skin test, but do not have symptoms of active TB, and are not infectious. Individuals with latent TB infection have approximately a 10% risk of developing active TB in their lifetimes, with the risk being greater for persons who are immunocomprised.[3] To decrease the chance of developing active disease, CDC recommends that persons with positive TSTs be evaluated for preventive drug therapy.[4]

The probability that a person exposed to *M. tuberculosis* will become infected depends primarily on the concentration of infectious droplet nuclei in the air and the duration of exposure. The actual dose required to initiate infection is not known. The probability of tuberculosis transmission is affected by the number of infectious persons and their level of infectiousness, the susceptibility and proximity of uninfected individuals, and the building ventilation.

Ventilation guidelines for the prevention of tuberculosis transmission in industrial environments do not exist. Ventilation is present in most buildings to maintain a comfortable environment by providing a supply of air which may be heated or cooled, and humidified or dehumidified. Another function of ventilation is to bring in "fresh" air and exhaust airborne contaminants. Usually, the flow of supplied air also creates air currents which substantially mix the air in an enclosed space before it is exhausted. Because TB is spread by airborne bacteria, ventilation is a factor in the spread of this infection. Both the extent and rapidity of the spread of contaminants and their rate of removal are important. In this evaluation, we assessed the spread and removal of a tracer gas that was used as a surrogate for the contaminant, *M. tuberculosis*.

Process Description

At the time of the NIOSH evaluation there were approximately 263 workers at the Byrdstown OshKosh plant. This included 238 sewers and 25 staff personnel, 7 of whom worked directly in the warehouse. The plant hours are from 7:00 a.m. to 4:30 p.m. Monday through Thursday, and 7:00 a.m. to 11:00 a.m. on Friday. Additional hours are scheduled on Friday and Saturday as needed to meet production demands. About 75,000 knit jerseys are produced each week at this facility from pre–cut cotton and polyester/cotton blended fabrics. A Gerber fabric mover system is used to facilitate garment manufacture.

METHODS

Preliminary Ventilation Assessment

NIOSH investigators performed a walk–through survey and a preliminary ventilation system evaluation to assess the potential for dissemination of airborne *M. Tuberculosis*. The ventilation system evaluation included discussions with persons responsible for operation and maintenance of the system, and performance of air flow measurements.

Air flow measurements were made at the outside air intakes, and exhaust and return air locations using either a TSI model 8360 VelociCalc Plus Thermoanemometer, or TSI model 8370 AccuBalance Flow Measuring Hood (TSI Inc., St. Paul, MN). The choice of instrument was dependant on the inlet or outlet configuration. The flow hood provides air flow rate data directly in cubic feet per minute (CFM). When the thermoanemometer was used, a traverse was made and multiple air velocity measurements were taken at the face of the grille. The average air velocity was then used to calculate the air flow rate by multiplying the air velocity by the area of the opening.

Tracer Gas Evaluation

A tracer gas evaluation was conducted to quantify the extent and speed of contaminant dispersion and contaminant removal rate. Sulfur hexafluoride (SF_6), a colorless, odorless gas was used as the tracer because it is chemically and toxicologically inert,[5,6] and there would be no other sources in the plant. Target concentrations of this tracer gas are typically in the range of 1 to 10 parts per million (ppm), well below the time–weighted average exposure limits for SF_6 of 1000 ppm.[7,8,9] SF_6 has been shown to be an acceptable surrogate for the movement of *M. tuberculosis* bacteria in air.[10] Taking into account normal room air currents and size distribution, the droplet nuclei and tracer gas will remain suspended and follow essentially the same path in moving air.[11]

Pure SF_6 was released at a controlled rate from a location in the middle of the production area (see Figure 1). The release time was 7 minutes, and the target concentration of SF_6 was 3 ppm. SF_6 was then detected at selected locations in the plant using one of two instruments, an infrared monitor or a photoacoustic analyzer. Five infrared monitors were used. All were MIRAN–203 continuous flow, infrared gas analyzers with interchangeable filters (The Foxboro Company, East Bridgewater, MA). The filter used for SF_6 selectively passed infrared light with a wavelength of 10.6 µm. At a pathlength of 12.5 meters, SF_6 could be monitored in the range of 0–4 ppm. Although the system was factory calibrated, the voltage output of each instrument was correlated with actual test–room concentrations of SF_6, as measured with one of the photoacoustic analyzers, prior to the survey.

Three photoacoustic analyzers were also used to determine the concentration of SF_6 at selected locations in the plant. All were B&K–1302 periodic sampling, gas analyzers (Brüel & Kjaer Instruments, Inc., Marlborough, MA). Each instrument was fitted with a narrow bandwidth, 10.6 µm filter for SF_6, and a separate filter to measure and/or correct for the effect of water vapor (relative humidity) in the sampled air. The B&K instruments were calibrated by the manufacturer.

The instruments were placed in selected locations for the duration of a test, which lasted about 5 hours. Tests were conducted during January 30–31, 1996. SF_6 injections were made in the morning and afternoon. The SF_6 concentrations measured by the instruments were stored in computer memory and analyzed after the survey. Plots of the natural log of concentration versus time were made, and a straight line that best fit the data was generated using mathematical regression analysis. The slope of the line is equivalent to the air change rate.

General Ventilation Evaluation

To evaluate general ventilation in the office areas, a GasTech Model RI-411A, portable carbon dioxide (CO_2) indicator (GasTech Inc., Newark, CA) was used to measure CO_2 concentrations. CO_2 is a normal constituent of exhaled breath and, if monitored, can be used as a screening technique to evaluate whether adequate quantities of outside air are being introduced into an occupied space. Instrument zeroing and calibration of the GasTech monitor were performed prior to use with a zero filter and a known concentration of CO_2 span gas.

RESULTS

Preliminary Ventilation Assessment

A floor plan of the Byrdstown facility is shown in Figure 1. The main section of the plant is approximately 140 by 200 feet, and the shipping area is about 40 by 80 feet. The locations of the ceiling fans, heaters, air handling units (AHUs), and associated ductwork are shown on the figure. There are no return air ducts for these AHUs; return air enters the AHUs through the front of the units after passing through aluminum and/or polyester/fiberglass particulate filters. The AHUs provide cooling only. Heating is provided by gas–fired heaters suspended from the ceiling. The AHU fans remain on during the heating season to improve air circulation within the plant. To provide optimum conditions for sewing knit fabrics, the relative humidity is maintained between 50–55% through the use of a misting system located above the workstations. During the cooling season, inside temperatures are maintained around 72 to 73$^{\mathrm{N}}$F, and during the heating season at 68–70$^{\mathrm{N}}$F. The four, ceiling–mounted fans were not consistently used during our evaluation.

Table 1
Airflow Measurements

Source	Supply Air (CFM)	Outside Air (CFM)	Exhaust Air (CFM)
AHU 6	4353	2655	
AHU 7	3086	1260	
AHU 8	8740	none	
Exhaust Fan (near conf rm)			1690
Compressor Room			465†
Women's Lav			87
Men's Lav			105
Handicap lav			70
First Aid Room			50
Utility Room			60
Canopy Hood (welding area)			365
Cafeteria (3 supplemental exhaust fans, combined)			310
Cleaning Stations (3 stations combined)			588

† Indirect measurement of air entering through doorway.

Air mixing between the office and plant areas occurs due to their close proximity and the frequent opening of doors. AHUs 6 and 7 have the capability of supplying outside air, while AHU 8 does not. On the
days of the NIOSH evaluation, the outside air intake for AHU 7 was open. As shown in Table 1, 1260 CFM of outside air was supplied by this unit. The damper for AHU 6 was not open during the survey because it was connected to the energy management system which reportedly would only bring in outside air when outdoor temperatures (during the cooling season) were below 74NF. However, we were able to manually override the system to make airflow measurements. With the damper fully open, the unit was bringing in 2655 CFM of outside air. The energy management system also controls an exhaust fan located on the outer wall behind the upstairs conference room. This exhaust fan operates in conjunction with the outside air damper for AHU 6. With the system in the override mode, this fan was exhausting approximately 1690 CFM of air. Assuming that outside air dampers for AHUs 6 and 7 are fully open, bringing in a total of 3915 CFM of outside air (approximately 15 CFM of outside air per person), and a plant volume of 650,00 cubic feet (ft^3), this equates to an air change rate of approximately 0.36 air changes per hour (ACH).

Tracer Gas Evaluation

As shown in Table 2, the tracer gas spread quickly throughout the plant, never requiring more than 11 minutes to reach even the furthest locations from the release point (approximately 100 feet away). On one occasion, SF_6 reached the intake to AHU 6 in less than 2 minutes. The response times varied considerably between tests for any given location. This may be due to a number of factors that were not evaluated, including production line operation, temperature gradients in the plant, and heating unit operation.

Table 2
Response Times for Detection of the SF_6 Tracer Gas

Day/ Conditions	Response Time (min:sec)							
	AHU #6	AHU #7	AHU #8	Cafeteria	Loading Dock	Corner Outside Office/ Lobby	Between Mover 1 and 2	Between Mover 2 and 3
1/30/96 injection @ 6:51 a.m. circulating fans off AHU#6 no outside air	01:40	—	03:00	N/A[†]	07:10	—	02:51	03:11
1/30/96 injection @12:00 p.m. circulating fans on at 12:10 p.m./ AHU #6 no outside air	02:35	—	08:00	07:35	10:55	—	03:01	06:35
1/31/96 injection @ 7:03 a.m. circulating fans on AHU #6 open for outside air	03:00	04:55	03:30	—	—	03:15	02:17	02:55
1/31/96 injection @ 12:10 p.m. circulating fans on AHU #6 open for outside air	07:40	10:25	08:10	—	—	08:05	06:23	07:19

† N/A = not available; equipment failure.

SF_6 was spread uniformly throughout the plant. The concentration of SF_6 measured at stationary sampling locations equilibrated within about 30 minutes, with the exception of the cafeteria and the loading dock, which took about 1 hour. SF_6 was also detected in non–production areas such as the engineering office, main office, and cafeteria; however, in the main office, the concentrations rose much more slowly. For example, on the first day of measurement, the SF_6 concentration in the main office was 1.1 ppm approximately 50 minutes after the injection, while the concentration in the adjacent lobby area was 2.4 ppm.

SF_6 was slowly removed from the plant. When the production line was operating, more than 2 hours were required for the SF_6 concentration to be reduced by one–half. Figure 2 shows a typical contaminant decay curve. The slope of the line, noted on the graph as the ACH (air changes per hour) value, is representative of the ventilation rate. To calculate the actual flow rate in CFM, the ACH value is multiplied by the volume of the plant (approximately 650,000 ft^3) and divided by 60 to convert the time units from hours to minutes.

In the cafeteria, over 4 hours would have been required to halve the SF_6 concentration if there hadn't been an exodus outside during break times. Figure 3 shows that when people were moving through the cafeteria to and from the area outside the building, the effective rate of ventilation in the cafeteria was increased so that the SF_6 concentration was halved in about 30 minutes. A similar, although less dramatic change occurred in the main area of the plant during the beginning–of–day (see Figure 4), lunch, and end–of–day movement into and out of the plant, when the effective rate of ventilation was increased so that the SF_6 concentration was halved in less than 1 hour.

Figure 5 shows that the ventilation rate changes four times during the period between 5:00 and 9:00 in the evening. The early change is due to workers leaving the plant at the end of the shift. Ventilation rate changes later in the evening are likely due to the opening and closing of doors by cleaning staff, use of compressed air by cleaning staff to blow–down sewing machines, and the shutting down of air handling units.

Table 3 lists the air change rates that were determined from the concentration decay plots. The air change rates in the production area ranged from 0.23 to 0.29 ACH on the first day of measurement, and from 0.30 to 0.34 ACH on the second day. The ACH rates on the first day are indicative of worst case conditions, since the outside air damper for AHU 6 was not open. The use of ceiling fans did not appear to affect air change rates. A small increase in the ACH rates was observed when the outside air damper for AHU 6 was open. The similarity in air change rates in the main production area indicates good air mixing in these areas. Though we suspected that there might be dead space in the corner by the office and lobby, this did not prove to be the case.

General Ventilation Evaluation

On the afternoon of January 30, 1995, CO_2 concentrations of 1825 and 1830 ppm were measured in the main office and engineering office, respectively. These concentrations exceed the American Society for Heating, Refrigerating and Air–Conditioning Engineers (ASHRAE) recommendation of 1000 ppm and the level of 800 ppm that NIOSH recommends should trigger further evaluation of the ventilation system. While these CO_2 concentrations do not represent a health hazard, they suggest that insufficient outside air is provided to dilute normal contaminants and odors. It was not surprising to find elevated CO_2 levels in the engineering office because it does not have mechanical ventilation. Using smoke tube traces, we observed that the direction of air flow was from the door closest to the cafeteria to the door at the opposite end of the office. The main office has its own HVAC system. On the days of the evaluation, the ventilation system in the main office was set on "automatic," thus, when the temperature was satisfied, there was no air supply to the office. In addition, there was no supply of air to the personnel manager's office because the ventilation duct had been capped–off since the time this office was used as a computer area.

Table 3
Air Change Rates in Production Areas During Work Hours

Day and Time‡	Conditions	Air Change Rates (ACH)† AHU #6	AHU #7	AHU #8	Corner Outside Office/ Lobby	Between Mover 1 and 2	Between Mover 2 and 3
1/30/96							
Morning (7:00 – 11:15 a.m.)	Injection @ 6:51 a.m. circulating fans off AHU#6 no outside air	0.27	——	0.29	——	0.28	0.28
Afternoon (12:30–5:00 p.m.)	Injection @12:00 p.m. circulating fans on at 12:10 pm / AHU #6 no outside air	0.27	0.23*	0.27	——	0.29	0.28
1/31/96							
Morning (7:30–11:30 a.m.)	Injection @ 7:03 a.m. circulating fans on AHU #6 open for outside air	0.33	0.34	0.33	0.32	0.34#	0.34#
Afternoon (12:30–4:30 p.m.)	Injection @ 12:10 p.m. circulating fans on AHU #6 open for outside air	0.32	0.30	0.32	0.32	0.32	0.31

† ACH = air changes per hour.
‡ The times listed in the table represent the approximate time range during which the air change rate was calculated. Exceptions noted in the table.
* Time range during which the air change rate was calculated was 3:52 to 5:21 p.m.
# Time range during which the air change rate was calculated was 8:00 to 11:30 a.m.

DISCUSSION AND CONCLUSIONS

The ventilation configuration and related factors for this plant were favorable to the spread of airborne contaminants. Taking air from the plant floor into the air handlers located on the perimeter of the building, mixing some of this recirculated air with some outside air, and redistributing this air throughout the overhead region of the plant, quickly and uniformly spread the tracer gas throughout the plant. The movement of the assembly lines, workers, raw materials and finished products in the plant greatly contributed to the mixing, as did the thermal buoyancy due to numerous heat sources in the plant.

Minimizing the intake of outdoor air in such a large structure limits the removal rate of any contaminant. Since between three and four hours were needed to exhaust a volume of air equal to the volume of the plant, it is suspected that some of the *M. tuberculosis* organisms discharged into the workplace in the morning would still have been somewhere in the plant at the end of the shift.

Brief periods of higher contaminant removal rates occurred during breaks, at the beginning and end of the work–day, and when raw materials were being received or finished products were being shipped. These periods of increased contaminant removal were probably due to the outside air brought into the building when the doors were opened and workers were entering and leaving the building. Similar reductions of contaminant concentrations occurred when the plant was being cleaned, presumably due to the use of compressed air from an outside source.

It is interesting to note that the air change rates determined from the tracer gas study (0.30 to 0.34 ACH) are very similar to the rate calculated based on the air flow measurements (0.36 ACH), given similar conditions (outside air damper for AHU 6 is open). Because the tracer gas analysis accounts for all ventilation sources, including natural ventilation and infiltration, the similarity in rates indicates that there is very little infiltration of outside air through the building envelope, and further supports the conclusion that the air is well mixed. If significant sources of air infiltration existed, or there was poor air mixing, then a greater discrepancy in air change rates would be seen.

Based on the results of this evaluation, it is concluded that *M. tuberculosis* present in droplet nuclei would have spread quickly and uniformly throughout the plant, and remained for hours before being removed from the air. Removal of *M. tuberculosis* would have been increased when the doors were opened, when workers were entering or leaving the plant, when raw materials or finished products were being loaded/unloaded on the loading dock, and during the evening cleaning. Other factors that may have influenced TB transmission include prolonged infectiousness of the individual, virulence of the organism, and TB exposure outside the workplace. These factors were not evaluated in the NIOSH study, but are being examined by state and local health departments and other groups within CDC.

RECOMMENDATIONS

Recommendations are made below for improving general ventilation at this facility. It should be noted, however, that there are no ventilation guidelines for preventing infectious disease transmission in manufacturing settings such as this. Although increases in the amount of outside air supplied to the plant will aid in dilution of any contaminants, it is impossible to predict what, if any, impact the addition of modest amounts of outside air would have had on TB transmission at this facility.

1. To increase the amount of outside air supplied to the plant, the damper to AHU 6 should remain open at all times. This would provide approximately 15 CFM of outside air per person, a rate that is recommended by ASHRAE for office environments. (Guidelines for outside air supply in manufacturing settings are not available.) The damper is currently coupled to the energy management system and is open only when outside air temperatures are optimum. The present system allows for only 1260 CFM of outside air to be supplied under most conditions, or approximately 5 CFM of outside air per person.

2. The fan to the office heating, ventilating, and air–conditioning system should run continuously to prevent stagnation of air, and the ventilation duct that supplies air to the manager's office should be uncapped. Additionally, filtered air from the plant could be supplied to the office to improve ventilation.

3. The engineering office has no mechanical ventilation with the exception of two window air conditioning units used during summer months. Louvers should be placed in both doors and a small

exhaust fan installed to improve the natural flow of air (from the cafeteria side to the office side).

4. The cafeteria exhaust fans should be operated when this area is occupied.

5. The fan behind the conference room is not well seated. Repairing the gap between the fan and the wall would allow it to operate more efficiently.

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