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NIOSH INVESTIGATORS:
Michael S. Crandall, M.S, CIH
Robert T. Hughes, Ph.D., PE
Teresa M. Buchta, M.S.

I. SUMMARY

On June 16, 1992, the National Institute for Occupational Safety and Health (NIOSH) received a request for a technical assistance from the National Center for Infectious Diseases and the National Center for Prevention Services, Centers for Disease Control, Atlanta, Georgia. The request was for NIOSH to determine whether ventilation requirements for the isolation of TB patients were being met at the Veterans Administration Medical Center (VAMC) in East Orange, New Jersey.

On June 18, 1992, NIOSH investigators made ventilation measurements on VAMC Ward 5B, an infectious diseases ward housing AIDS patients, to determine the status of the systems serving the area. At the time of the investigation there were two patients with infectious TB in isolation on 5B. This ward had 12 single-bed (two being used for isolation of TB patients during this evaluation) and four three-bed patient rooms. One single pass (100% outdoor air) heating, ventilating, and air-conditioning (HVAC) system served the patient rooms. A separate system served the corridors. The patient rooms were designed to be neutrally pressurized (equal supply and exhaust airflow). FlowHood® measurements showed that in all the single-patient rooms, exhaust airflow was essentially zero. The average supply airflow varied above and below the designed value. These rooms were all positively pressurized, which would not be recommended for the isolation of infectious patients. Most single-bed rooms shared a bathroom which allowed room to room airflow depending on open and closed doors. The three-patient room measurements also varied from the design airflow. The most remarkable feature in these rooms was that the exhaust airflows in all rooms were measured to be positive, that is, the exhausts were supplying air to the rooms.

Smoke tube traces were used to determine room to corridor pressure relationships, and the pressure relationship of Ward 5B to the core areas of the hospital. There was a general flow of air out of 5B and into the core area. In fact, the air flowed through the core area and into an adjacent wing of the hospital (Ward 5C). This condition could cause the circulation of infectious agents to other wards and floors of the hospital because of shared HVAC systems.

Based on the measurements made during this evaluation, it was obvious that there was no isolation of infectious patients on Ward 5B. It is recommended that a separate isolation facility be constructed in the hospital to house infectious patients. Interim corrective measures for the systems in place are also recommended.

Key Words: SIC 8062 (General Medical and Surgical Hospitals); tuberculosis, ventilation.

II. INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) received a request on June 16, 1992, for technical assistance from the National Center for Infectious Diseases (NCID) and the National Center for Prevention Services (NCPS), Centers for Disease Control (CDC), in Atlanta, Georgia. The request was for technical support during their EPI-AID investigation of nosocomial transmission of tuberculosis (TB) at the Veterans Administration (VA) Medical Center in East Orange, New Jersey . The request was explicitly for NIOSH help to determine whether ventilation requirements expected of TB patient isolation facilities were being met.

On June 17-18, 1992, NIOSH investigators made a site visit to the VA Medical Center to conduct a ventilation system evaluation. This report contains the results of that evaluation and resulting recommendations.

The CDC investigators provided preliminary tuberculin skin test (TST) information for the VA Medical Center (VAMC). Of the 1768 VA staff who had been tested, 514 (29%) are TST positive. A prevalence of 20 to 25% was expected due to the large number of foreign born staff (mainly the Philippines), and the fact that many staff come from the Newark/New York City area where the prevalence is high. Of approximately 270-300 medical doctors on staff, 105 are TST positive (35-39%). Many have not been tested, so this prevalence rate may be low. Of 604 nursing staff, 476 have been tested and 239 (50.2%) are positive. For the Infectious Disease ward (5B), 24 staff were tested in the summer of 1991. Eleven (46%) were positive then, and 13 were negative. Ten of the 13 testing negative in 1991 have been retested since then, and 5 (50%) have converted to a positive TST.

Areas of concern in the hospital were the wards where TB patients were potentially admitted to, and diagnostic and treatment rooms. These areas included wards 5B, 5D, 7B, the Pentamidine administration room (5-196A, on 5B), and the Pulmonary Lab (7-101, on 7A). Following discussions with VAMC engineering staff representatives, and CDC and New Jersey Department of Health investigators, the decision was made to focus the ventilation investigation on Ward 5B. Ward 5B is a residence ward for AIDS patients. During the investigation there were two patients with infectious TB in isolation on 5B.

A walk-through tour was conducted through Ward 5B, the Pentamidine Room, and the Pulmonary Lab on Ward 7A. We observed that patient rooms on 5B which were marked by signs as isolation rooms did not have closed doors and that respiratory protection, other than surgical masks, was not being used. It was reported that the first orinasal, single-use (disposable) dust and mist respirators had just arrived on the afternoon of the walk-through tour. In fact, we witnessed two of the 5B nurses attempting to don respirators for the first time (without prior instruction). Neither of them were successful in correctly using the respirators. We then showed them how to don them correctly and briefly discussed these respirators with them. One nurse disliked the respirator because it chafed her face. We did not see anyone using these respirators at any other time.

III. BACKGROUND

The East Orange VAMC was constructed in 1953. The hospital has nearly 640 beds and a staff of about 2200 workers. The hospital's heating, ventilating, and air-conditioning (HVAC) systems underwent extensive renovation in the late 1980's.

WARD 5B

Ward 5B is an infectious diseases ward having a capacity of approximately 24 beds. There are 12 single-bed patient rooms and four three-bed patient rooms.

The HVAC system serving the patient rooms on 5B also served rooms on A-level (below the first floor) and on floors one through 13 (system 1-AC1). This system supplied tempered, 100% outdoor air through 85% efficient filters (ASHRAE dust-spot efficiency) via supply fan 1-SF1. The main air supply duct traverses the length of Ward 5B's main corridors. Smaller branch ducts feed off the main supply and provide outside air to each patient room through wall mounted rectangular diffusers. Air was exhausted from the patient rooms on 5B through a system which serves floors 1,2,4,5, and 6 (1-EF4). The exhaust air travels through bathroom exhaust grilles (one bathroom for two adjoining patient rooms) to a large duct branch above the main corridor and then to a rooftop stack. This single-pass supply and exhaust system was designed (according to the plans) to provide an equal amount of supply and exhaust airflow for the patient rooms. A fan-coil unit was mounted near the ceiling over the door to each room which recirculated within the room and tempered the air.

One patient room (5-190) on this ward was designed to be an isolation room, using a variable supply airflow (20 to 80 cubic feet per minute (cfm)) and a fixed amount of exhaust (50 cfm). In this fashion, a negative pressure or positive pressure isolation environment could be accomplished. We did not evaluate the ability of this system to work as designed, however, it was reported by the VAMC engineering staff that it did not function properly. This room did have a fan-coil unit for air tempering. The Pentamidine Room had supply air delivered through the fan-coil unit and exhausted through a dedicated system to the outside. We did not evaluate the operation of the Pentamidine Room system because of maintenance being performed on the fan-coil unit on the day of the survey.

The corridors for the ward were supplied air from a different HVAC system (1-AC4) which served floor 2 and floors 4-12. This system supplied a mixture of outdoor air and return air from the central core area.

IV. EVALUATION CRITERIA

Hierarchy of Ventilation Control Strategies

In the hospital setting, primary importance should be placed on early identification, treatment, and isolation of infectious TB patients, and correct application of principles of ventilation (both local and general). The use of germicidal ultraviolet radiation and personal protective equipment (respirators) should be viewed as ancillary control measures.

The risk of TB transmission in any setting is proportional to the number of viable TB bacilli in the air. All suggested control measures may reduce a worker's exposure to TB to some extent; however, there are no currently-available methods to quantify the degree of reduction that may be achieved by each control measure. Although ventilation is frequently relied upon to control TB in the health-care setting, ventilation systems sometimes can be complex and difficult to evaluate. Satisfactory performance of ventilation systems requires oversight by engineers or industrial hygienists. Incorrect design applications or inadequate maintenance can, in fact, increase the risk of TB transmission.[1,2] Consensus guidelines for ventilation and ancillary measures of worker protection have been formulated and are based on what are believed to be the most effective combination of feasible control strategies.[4,5]

Ventilation Considerations

There are two types of ventilation used for control of airborne transmission of TB; general dilution ventilation and local exhaust ventilation. General dilution ventilation provides an exchange of contaminated indoor air with uncontaminated air thereby diluting the airborne

concentration of the infectious agent and reducing potential exposures for workers and other susceptible persons (i.e., patients and visitors). Each of these types of ventilation is explained more fully below.

General Dilution Ventilation

General dilution ventilation performs two functions. The first is to provide sufficient outside air to maintain comfort. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) recommends for hospitals a range of 15 to 30 cubic feet per minute (cfm) per person of outdoor air.[3] The second function of general dilution ventilation is to provide sufficient exchange of potentially contaminated air with clean air to minimize the risk of infection. ASHRAE and the American Institute of Architects (AIA) suggest airflow ranging from 4 to 25 air changes per hour (ACH), depending on the functional area of the hospital.[4,5] These guidelines are provided in terms of pressure relationships to adjacent areas, minimum outdoor air and total air changes, exhaust location, and recirculation restrictions.

In addition to supplying the specified airflow, ventilation systems should also provide satisfactory airflow patterns both from area to area and within each room. Air flow should be from "clean" to "less clean" areas, such as from hallways to treatment rooms. This can be accomplished by creating negative (lower) pressure in the area into which flow is desired relative to adjacent areas. Negative pressure is attained by exhausting more air from the area than is being supplied. For large areas this will require careful balancing of the ventilation system.

Within a room or small area, a ventilation system should be designed to: 1) circulate air to all areas of the room (prevent stagnation of the air), 2) prevent short circuiting of the supply to the exhaust (i.e., passage of air directly from the supply site to the exhaust point without mixing of room air), and 3) direct the clean air past the worker without recirculation within the room. These conditions are not always achievable but should be attempted to the fullest extent feasible. One way to accomplish this is to supply low velocity air at one end of a room and exhaust it from the opposite end. Another method is to supply low velocity air near the ceiling and exhaust it near the floor. However, air flow patterns are also affected by air temperature, the precise location of supply vents and exhaust vents, diffuser design, the location of furniture, movement of workers, and the physical configuration of the space. Each room or space must be evaluated individually.

Ideally, ventilation systems used in areas where *Mycobacterium tuberculosis* may be present should supply non-contaminated air (a portion should be outside air), discharge exhaust air to the outside, and should not recirculate air back into the facility. Where TB may be present, an area of the hospital should be selected where the ventilation can be optimized or simply rebalanced to provide the desired ventilation parameters. Where this is not possible, less desirable alternative approaches may be used. Rooms connected to recirculating ventilation systems could utilize high efficiency particulate air (HEPA) filtration in the room exhaust or filter the air before it is recirculated. In cases where a room has no ventilation, a HEPA-filtered recirculating duct system for that room might be considered. In no case should a room or area without mechanical exhaust ventilation be used for patients with *M. tuberculosis*.

Recommended ventilation rates in hospitals are frequently expressed in terms of air changes per hour (ACH). An ACH is defined by the theoretical number of times that the air volume of a given space will be replaced in a one-hour period. Assuming perfect mixing, a rate of six ACH would require 46 minutes to remove 99.0% of contaminants from a room.[6] Hence, the air is not actually "changed" six times per hour. The amount of air required to maintain six ACH in a smaller room will be less than a larger room.

For purposes of general ventilation, all supplied air does not have to be outside air. For example, AIA recommends that operating rooms be ventilated with a minimum of three ACH outside air

with a minimum total of fifteen ACH. The remaining twelve air changes only need be "clean" air (often referred to as "transfer air"), not necessarily outside air. It is always advisable, however, to use the most stringent and protective alternative possible.

The AIA ventilation recommendations are presented in Table 1 (see next page). Hospital isolation rooms should provide six ACH with all air exhausted directly to the

outside. Exhaust locations should not be near areas that may be populated (e.g., sidewalks or windows that may be opened). Exhaust points should also be away from air intakes, so that exhaust air is not recirculated into the facility. The rooms should be under negative pressure with respect to adjacent areas.[4,7] For isolation rooms, ASHRAE has similar recommendations, except that a recommendation that two of the six ACH should be outside air is included.[5] ASHRAE also recommends a minimum of 25 cubic feet per minute/person (CFM/person) of outside air for patient rooms.[3]

Table 1

Ventilation Evaluation Criteria[1,2]
VA Medical Center
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Area Designation	Air movement relationship to adjacent area	Minimum air changes per hour outside air	Minimum total air changes per hour	Recirc-ulated by means of room units[3]	All air exhausted directly to outside
Operating room	Out	3	15	No	--
Delivery room	Out	3	15	No	--
Newborn nursery	--	1	6	No	--
Recovery room	--	2	6	No	--
Intensive care	--	2	6	No	--
Isolation room	In	--	6	No	Yes
Isolation anteroom	Out	--	10	No	Yes
Patient room	--	--	2	--	--
Examination room	--	--	6	--	
ER trauma room	Out	3	15	No	--
Autopsy room	In	--	12	No	Yes

1 Selected ventilation guidelines adapted from the American Institute of Architects Guidelines for Construction and Equipment of Hospital and Medical Facilities (reference #4).

2 This table covers ventilation for comfort, as well as for asepsis and odor control in areas of acute care hospitals that directly affect patient care. Areas where specific standards are not given shall be ventilated in accordance with ASHRAE Standard 62-1989, "Ventilation for Acceptable Indoor Air Quality Including Requirements for Outside Air."

3 Because of cleaning difficulty and potential for buildup of contamination, recirculating room units shall not be used in areas marked "No." Isolation and intensive care unit rooms may be ventilated by reheat induction units in which the primary air supplied from a central system passes through the reheat unit.

Local Exhaust Ventilation

Local exhaust ventilation captures the infectious agent in the immediate field of an infectious patient (i.e., scavenging booths or tents) without exposing other persons in the area. It is the preferred type of ventilation because the TB organisms are removed before they can disperse throughout the work area. Local exhaust ventilation is used most effectively in a fixed location. The hood portion of a local exhaust system may be of exterior design, where the infection source is near but outside the hood, or enclosing, where the infectious source is within the hood. Enclosures (booths) are available for aerosol-generating activities, such as sputum collection and aerosol therapy. These devices may be exhausted directly to the outside, or they can exhaust through a HEPA filter back into the room.

V. METHODS

On June 18, 1992, a walk-through tour was conducted of the main mechanical unit (1-AC1) supplying air to Ward 5B. The outside air dampers, filters, and heat transfer coils in the supply systems were visually inspected. The exhaust system (1-EF4) serving 5B was evaluated from a design standpoint using the mechanical plans.

Ward 5B

Ten rooms were evaluated on June 18, 1992, seven single-patient, two three-patient rooms, and the day room (5-172). The evaluation consisted of making airflow measurements using a Shortridge Instruments, Inc. FlowHood® Model CFM 88. Using this instrument, airflow through a supply diffuser or exhaust grille can be read directly in cfm. The measured airflows were compared to the design specifications on the mechanical plans and to the AIA and ASHRAE guidelines.

Airflow measurements were obtained under the following four conditions: 1) door to hallway open and door to bathroom closed; 2) door to hallway closed and door to bathroom closed; 3) door to hallway closed and door to bathroom open; and 4) both doors open.

Smoke tests were conducted to subjectively evaluate (by visual observation) the relative pressures of the rooms with respect to the main ward corridor, and the main corridor with the core area of the 5th floor. For each of the patient rooms on the ward the direction of smoke was observed at the gap between the floor and the bottom of the door, with the door closed.

Pulmonary Laboratory (7-101)

The direction of airflow was observed using smoke tubes to qualitatively determine the pressure relationships of the room with respect to the adjacent corridor. The direction of smoke was observed at the gap between the floor and the bottom of the door, with the door closed.

VI. RESULTS AND DISCUSSION

During the inspection of HVAC system 1-AC1, we observed that the outdoor air dampers were closed. This situation was reportedly corrected.

Ward 5B

The results of the ventilation measurements are presented in Table 2. For each of the rooms, measurements made under each condition, the average of these measurements, the design airflow, and the pressure relationship of the room with the corridor (+/-) are shown.

The single-patient rooms are grouped in the table according to the shared bathroom exhaust. The design plans indicated that the rooms should be neutrally pressurized (equal supply and exhaust airflow). The measurements made under the different conditions in the rooms were quite variable. From the single-patient rooms, exhaust airflow was essentially zero. The average supply airflow also varied above and below that specified in the design. These rooms were all positively pressurized, which would not be recommended for the isolation of infectious patients. Based on an average volume of 1250 cubic feet for these rooms the number of ACH ranged from one to three and one-half.

Most of the single patient rooms had a shared bathroom. If the HVAC system were operating as designed a patient using the bathroom would be exposed to any infectious agent from the other room. In the current state of operation there will be room to room flow depending on open and closed doors.

The three-patient room measurements were similarly variable with regard to the design specifications. The most remarkable feature in these rooms was that the exhaust airflows in all rooms were measured to be positive, that is, the exhausts were actually supplying air to the rooms. Room 5-171D received nearly two ACH (1.75 ACH using only the airflow through the supply diffuser), while 5-171B received about two ACH (2.3 ACH). These ACH figures should be compared to the six recommended by ASHRAE and the AIA. These guidelines (ASHRAE) also suggest a minimum of 15 ACH if the patient is immunocompromised.

While this discussion focuses on the issue of housing TB patients in the rooms on 5B, a secondary issue is the adequacy of room ventilation otherwise. If the exhaust ventilation is repaired and functioning as designed in concert with the supply system, providing at least 2 ACH with a neutrally pressurized room, the AIA and ASHRAE guidelines will be met for "normal" patient rooms.

Table 2
VA Medical Center
Ventilation Measurements Results
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Room/Area		Condition a[1]	b[2]	c[3]	d[4]	Average (cfm)	Design (cfm)	PR[5] +/-
189[6]	supply	54	19	48	47	42	20	+
	exhaust	0	0	0	0	0	-40	
188	supply	20[7]	--	--	--	20	20	
186	supply	59	50	87	90	72	30	+
	exhaust	0	0	0	0	0	-50	
187	supply	--	--	--	--	--	20	
180	supply	28	25	22	28	26	40	+
	exhaust	0	0	0	0	0	-70	
179	supply	30	28	24	34	29	30	+
176	supply	--	--	--	--	--	30	+
	exhaust	0	0	0	0	0	-60	
175	supply	36	59	33	35	41	30	

Three-Patient Rooms		Door Open	Door Closed			
172	supply	37	27	32	50	+
Day Room	exhaust	+25	+48	+37	-50	
171D	supply	88	68	78	50	+
	exhaust	0	+43	+22	-50	
171B	supply	120	140	130	80	+
	exhaust	+45	+16	+30	-80	

1 - Main door opened, bathroom door closed
2 - Both doors opened
3 - Main door closed, bathroom door opened
4 - Both doors closed
5 - Pressure relationship between patient room and corridor
6 - Single-patient rooms are grouped according to a shared bathroom exhaust
7 - Estimated airflow, based upon air velocity and diffuser area

Corridor supply air measurements were also made but not included in the table. In the single-patient room wing, a total of 280 cfm was measured from two supply diffusers. This figure is within the range of the design specification of 260-320 cfm. The supply diffuser in the three-patient room wing measured 364 cfm (260 cfm design).

Smoke tube traces, which were used to determine room-to-corridor pressure relationships, were also used to judge the relationship of Ward 5B to the core areas of the hospital. There was a general flow of air from 5B to the core area. In fact, the air flowed through the core area and into the adjacent wing of the hospital (Ward 5C). This condition could cause the circulation of infectious agents to the other floors of the hospital served by HVAC 1-AC4 . It was observed that 5C also had no exhaust flow as indicated by smoke tube tests at the exhaust grilles. The flow of air into 5C was apparently caused by several open windows in the ward.

In addition to the obvious non-isolation environment present on Ward 5B, other practices were observed which were compromising to worker's health. As mentioned from the walk-through the previous day, doors to marked isolation rooms were left open. We observed staff using surgical masks for respiratory protection and visitors to the isolation rooms without any type of protection.

Pulmonary Laboratory

The Pulmonary Laboratory evaluation consisted only of determining the pressure relationship between it and the corridor. It was strongly positively pressurized. This is indicative of an exhaust flow deficiency similar to 5B. Since bronchoscopy, endotracheal suctioning, sputum induction and other procedures which could generate droplet nuclei take place here, it should be under negative pressure with respect to adjacent areas and the room air should be exhausted directly to the outside.

VII. RECOMMENDATIONS

HVAC Systems

The ideal solution is to construct correctly configured and operating isolation rooms on a dedicated hospital wing or floor. A second solution would be to locate an area in the hospital which has properly operating ventilation systems and room configurations to permit effective isolation. The short-term solution will be to minimize the problems which now exist in 5B and in other areas housing TB patients.

1. The first, and mandatory step, is to correct the faulty exhaust system. A systematic inspection of all exhausts connected to 1-EF4 should be conducted. Ideally, the flow rate should be brought up to design specifications or even somewhat higher in all areas. As a minimum it should be increased to a flow rate which provides room negative pressure in all areas with TB patients. Supply air flow should also be increased to the extent possible, so that a sufficient quantity of outdoor air (the ASHRAE guideline is an example) is supplied to each room, or that an adequate number of total ACH are provided.

2. Once negative pressure is established by correcting the exhaust system, a directional check on corridor air flow should be made. Some quantity of corridor supply air should be exhausted through the negative pressure rooms, however, some will still flow out of the wing. Installing doors at the ward entrance may be helpful in containing the flow and will provide some pressurization of the corridor to assist airflow into the negative pressure rooms.

3. If negative pressure cannot be established using the 1-EF4 system, then the use of individual centrifugal-type window fans with HEPA filters may be a possibility. This alternative must be carefully considered since this will affect the overall HVAC system balance.

Other Issues

1. VAMC should use the services of the industrial hygiene staff of the VA, who were present at the closing meeting on June 18, 1992, to respond to the variety of health and safety problems encountered in the hospital environment. The size and mission of the hospital, regulatory requirements, and the importance of a high quality employee health an medical surveillance program are justification for their involvement. They should routinely interact with local infection control program coordinators and assist in resolving nosocomial infections and exposures to health care workers.

2. VAMC should review current work practices and procedures to assure that they are consistent with current CDC, and other (ASHRAE, AIA, etc.) guidelines regarding isolation procedures, infection control, and medical surveillance of staff and patients. Specifically, isolation room doors should remain closed and health care workers should always wear respiratory protection when entering TB isolation areas. Patients with infectious TB should not be allowed to directly interact with immunocompromised persons (HIV ward patients) or general community environments (day room, corridor areas, or patient visiting lounges). HVAC systems supplying air to rooms occupied by AIDS patients should be HEPA filtered.[5]

3. Pentamidine administration, sputum induction, and other aerosol producing procedures should be conducted in properly ventilated and designed settings. Ultra-violet lights used in Pentamindine administration rooms should remain on at all times. Patients being administered Pentamindine should remain in the room until all coughing subsides, and only one patient at a time should be treated.

4. VAMC should have a policy for health care workers regarding the use of respiratory protection against potential inhalation hazards when working with known or suspected TB infected patients. Respirators which meet the requirements specified by NIOSH in 30 CFR 11, Respiratory Protective Devices should be worn, and a respirator program which meets the OSHA requirements (29 CFR 1910.134) should be in place at the facility. Surgical masks do not meet these guidelines and may not provide adequate protection to the wearer due to poor face fit characteristics or leakage of small particles through the filter media. For exposure to aerosols containing TB organisms, the respirator offering the highest level of protection should be selected that is consistent and feasible with the tasks to be performed by the workers.

   In 1990, the CDC published *Guidelines for Preventing the Transmission of Tuberculosis in Health-Care Settings, with Special Focus on HIV-Related Issues*.[6] In this document, CDC recommended that disposable particulate respirators be used by workers exposed to tuberculosis patients in certain sistuations. NIOSH is presently updating the guidance for respiratory protection of health-care-facility workers. The use of repiratory protection is required to help minimize the risk of exposure to droplet nuclei for health-care-facility workers performing certain high-risk procedures or entering specific areas in hospitals, correctional facilities, and other environments where there are persons with infectious TB or potential TB transmitters. NIOSH and CDC are also currently in the process of updating guidelines for the use of ventilation and UV lamps in the prevention of TB transmission.

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IX. AUTHORSHIP AND ACKNOWLEDGEMENTS

Report Prepared by:

Michael S. Crandall, M.S., CIH
Industrial Hygiene Engineer
Industrial Hygiene Section
Hazard Evaluations and Technical Assistance Branch

Robert T. Hughes, Ph.D., PE
Research Mechanical Engineer
Control Section 3
Engineering Control Technology Branch
Division of Physical Sciences and Engineering

Field Assistance:

Teresa Buchta, M.S.
Industrial Hygienist
Industrial Hygiene Section
Hazard Evaluations and Technical Assistance Branch

Originating Office:

Hazard Evaluations and Technical Assistance Branch
Division of Surveillance, Hazard Evaluations, and Field Studies

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