IN-DEPTH SURVEY REPORT

EVALUATION OF A VENTILATION SYSTEM TO CONTROL FORMALDEHYDE EXPOSURES DURING EMBALMING

AT

CINCINNATI COLLEGE OF MORTUARY SCIENCE
CINCINNATI, OHIO

REPORT WRITTEN BY
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INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency engaged in occupational safety and health research Located in the Department of Health and Human Services (formerly the Department of Health, Education, and Welfare), it was established by the Occupational Safety and Health Act of 1970 This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions conducted by the Occupational Safety and Health Administration (OSHA) in the Department of Labor An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards The Engineering Control Technology Branch (ECTB) of the Division of Physical Sciences and Engineering (DPSE) has been given the lead within NIOSH to study the engineering aspects of hazard control

Since 1976, ECTB has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques The objective of each of these studies has been to document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures

Formaldehyde containing solutions are the predominant embalming agents in use in most mortuaries In the gaseous state, formaldehyde is colorless, flammable, and has a pungent odor NIOSH has classified formaldehyde as a potential carcinogen, with the Recommended Exposure Limit (REL) of 0 1 ppm, 15-minute ceiling [1] The OSHA Permissible Exposure Limit (PEL) and the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV,) are both 1 ppm for 8-hour time weighted-average (TWA) and 2 ppm for a 15-minute interval [2,3] The ACGIH also recognizes formaldehyde as a suspected human carcinogen

Mortuaries are typically small businesses Currently, there are just over 20,000 establishments, 68% of which employ 10 or fewer employees More than 75,000 people are employed in the industry [4] As small businesses, mortuaries typically do not have access to occupational health and safety expertise that larger companies do Also, because they are small businesses, mortuaries are infrequently inspected by OSHA

Several studies have been conducted to evaluate the formaldehyde exposures in autopsy and gross anatomy laboratories and mortuaries Two studies in mortuaries reported TWA exposures during the embalming procedures to have ranges of 0 09 to 5 3 ppm and 0 18 to 2 1 ppm [5,6] These studies found that room ventilation had a significant effect upon concentrations of formaldehyde as determined by area sampling Another study, conducted in gross anatomy laboratories, reported exposures ranged from 0 24 to 6 8 ppm over a 1 to 2 hour period [7] In addition, two other studies have been conducted at the

Cincinnati College of Mortuary Science (CCMS) in Cincinnati, Ohio The first study at CCMS reported formaldehyde concentrations during the embalming procedure ranged from 0 3 to 8 7 ppm, and that ventilation rates significantly affected exposures [8] The second study found personal exposures in the isolation room ranged from 1 24 ppm to 3 64 ppm [9] The study reported here was conducted in the isolation room at CCMS

The goal of this study was to develop and evaluate local exhaust ventilation controls which will reduce the embalmer's exposure to formaldehyde Since earlier studies indicated that ventilation rates affect the exposures, the general room ventilation could be increased to reduce exposures However, this solution would result in increased heating and cooling costs, since, for every cubic foot of air exhausted, another cubic foot must be brought into the building as makeup air This makeup air must be heated or cooled depending upon the season A potentially more effective system, both in terms of operating costs and performance, would utilize local exhaust ventilation near the source of formaldehyde emissions A local exhaust ventilation system, described later in this report, was evaluated at the Cincinnati College of Mortuary Science

FACILITY AND PROCESS DESCRIPTION

The Cincinnati College of Mortuary Science has three tables set up for conducting embalmings Two of the tables are in a large room which serves as a laboratory for the students, and the third is located in an isolation room This latter table is typically used for suspected infectious cases (AIDS, hepatitis) However, all embalmings observed during this study were conducted in the isolation room, and only non-infectious cases were included for the sampling

A diagram of the CCMS mortuary laboratory is shown in Figure 1, while Figure 2 shows a detailed diagram of the isolation room The embalming table is of porcelain on steel construction, with the top of the table having a slight slope The body is placed on the table so that the head is higher than the feet A drain is located at the foot of the table A short length of rubber hose leads from the drain to a urinal located below the table Blood and embalming fluid flow down the table, through the drain, and into the urinal The table can be rotated and the height and slope also can be adjusted Located near the foot of the table is a hot and cold water supply, an aspirator, and a pump for injecting the embalming solution

Prior to the installation of the local exhaust ventilation system, the only control for formaldehyde emissions was the general ventilation system The exhaust and supply locations are shown in Figure 2 The supply was located in the ceiling above the embalming table The exhaust was located approximately 2 feet off the floor in one corner of the room The supply system was designed to provide 215 cubic feet per minute (cfm) to the room, while the exhaust system removed the same amount The general ventilation system remained in operation during the evaluation of the local exhaust ventilation system

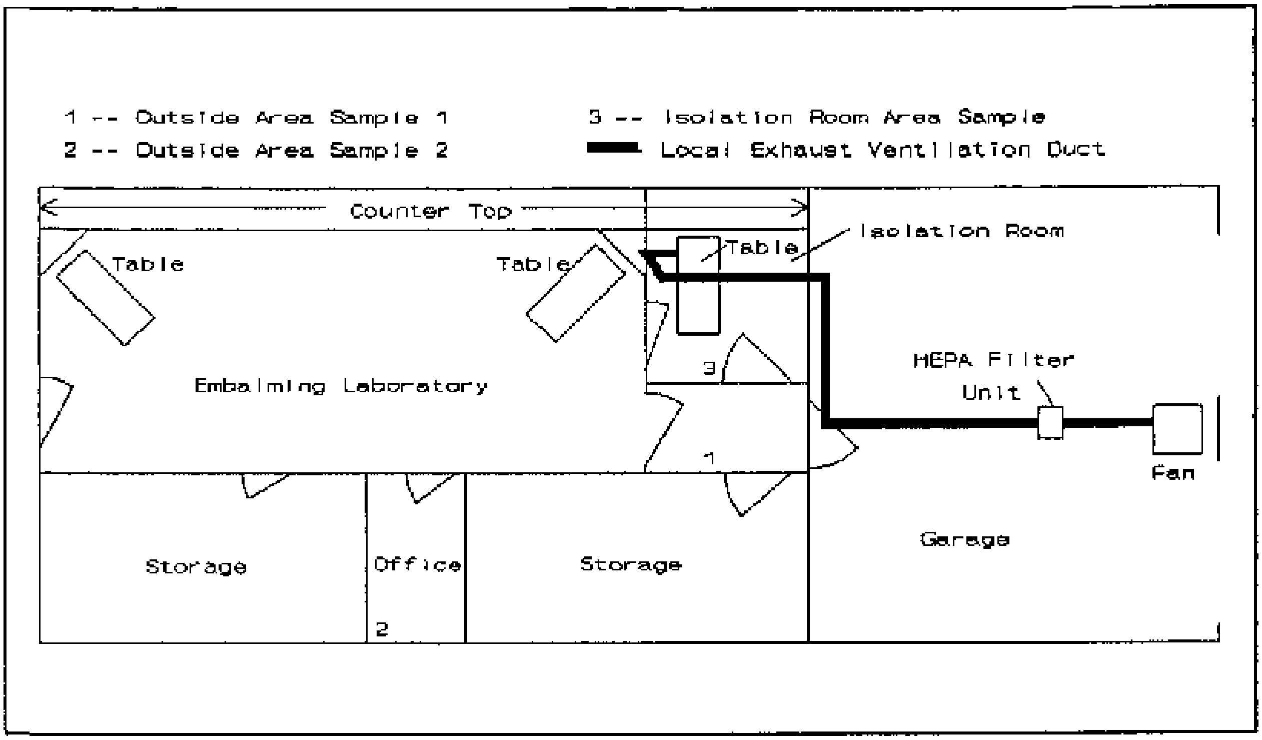

Figure 1 Diagram of mortuary laboratory area

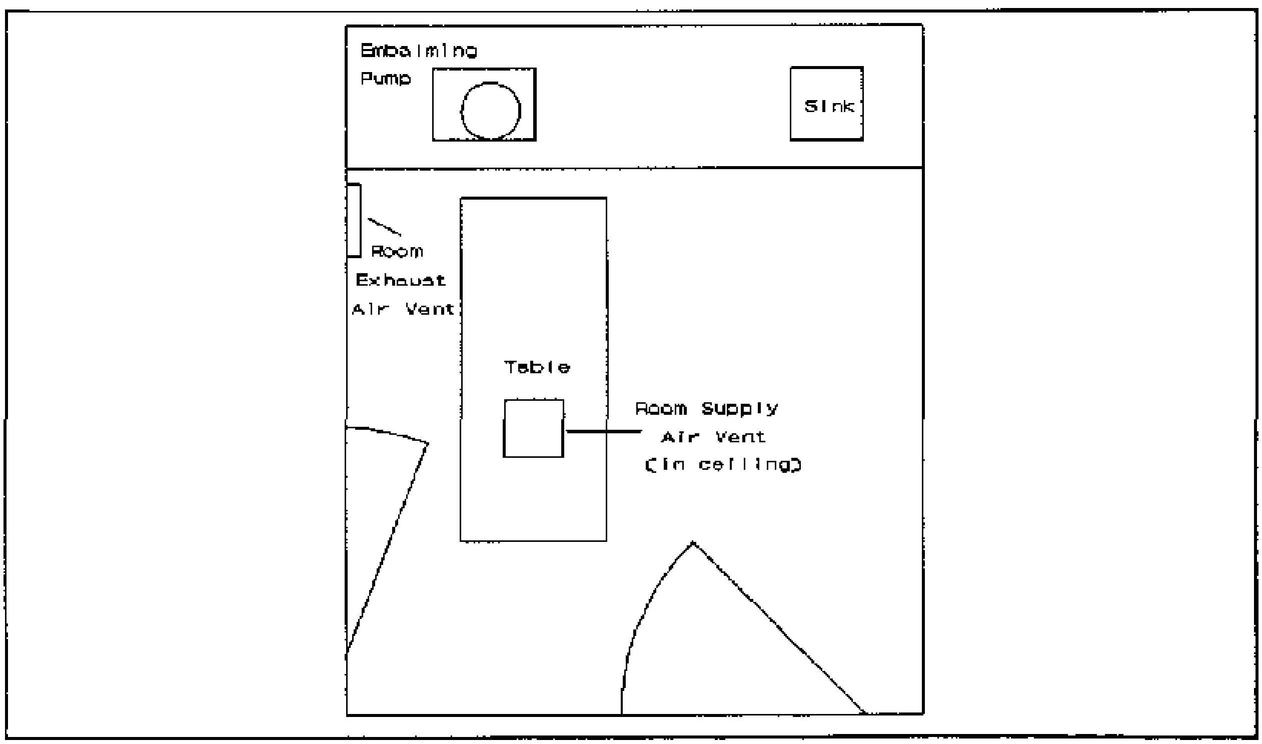

Figure 2 Diagram of isolation room

LOCAL EXHAUST VENTILATION DESIGN

The local exhaust ventilation system developed for the mortuary consisted of local exhaust ventilation in the form of slot hoods on either side of the embalming table. The design of the slot hood is shown in Figure 3. As an initial approximation, it was assumed that the constant velocity contours would take the shape of a quarter cylinder, as shown in Figure 4. While a quarter cylinder may not have been the precise shape of the velocity contour, it did serve as a initial approximation. The exhaust volume for slots, Q, was estimated by the equation[10]

$$Q = 2\pi F r L V \tag{1}$$

where,
- Q = volumetric flow of the hood, cfm
- F = fraction of a whole cylinder
- r = control distance, ft
- L = length of slot hood, ft
- V = control velocity at distance r from the hood, ft/min

For the quarter cylinder, F = 0.25, therefore this equation reduces to

$$Q = 1.57 r L V \tag{2}$$

The slot hood installed at the college consisted of two 6 foot sections, one on each side of the table. From equation (2), for a volumetric flow of 800 cfm, the resultant control velocity at the center of the table (r = 1.2 ft) would be 35 ft/min. For a 1-inch slot, the slot velocity (velocity at r = 0) would be 800 ft/min. While the 35 ft/min control velocity may seem low in comparison with the ACGIH Ventilation Manual recommendation of 50 ft/min minimum,[11] it was anticipated that this low velocity might be sufficient since the isolation room is small with few crossdrafts.

The actual exhaust volume required for control was determined experimentally in the NIOSH ventilation laboratory. The slot hoods were set up in a fashion similar to the proposed installation at CCMS. The ducts were connected to an exhaust system and the flow was controlled through adjustment of a blast gate. Flows ranging from 600 cfm to 1200 cfm were evaluated in 100 cfm increments. A mannequin was placed on the table and a tracer gas, nitrous oxide, was released at a known generation rate at the chest area of the mannequin. A Miran 1A (Foxboro, Co., East Bridgewater, MA), an infrared monitor, measured the nitrous oxide concentrations in the duct, indicating the amount of nitrous oxide captured by the ventilation system. These concentrations ranged from 30 to 70 ppm, depending upon the exhaust flow rate. This series of tests indicated the minimum flow rate for effective capture was around 700 cfm. Therefore, the exhaust system installed at CCMS was sized to exhaust 700 cfm.

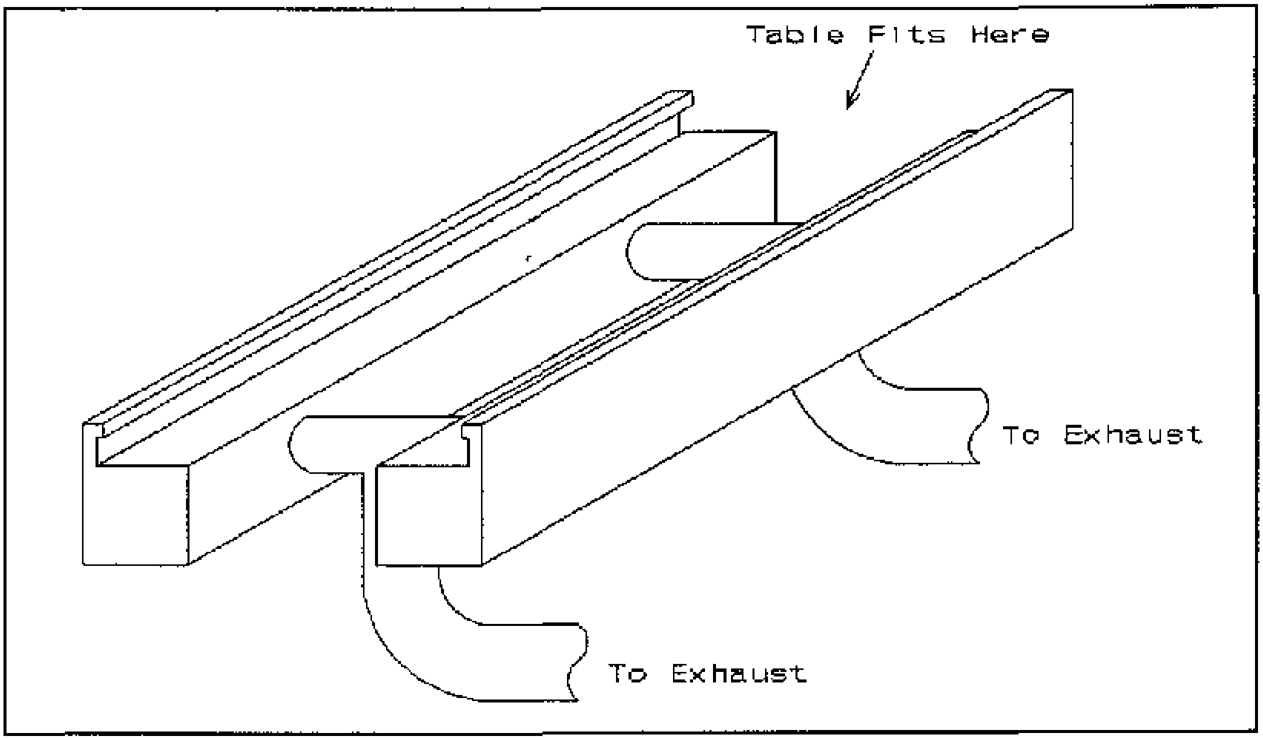

Figure 3 Diagram of local exhaust ventilation hood

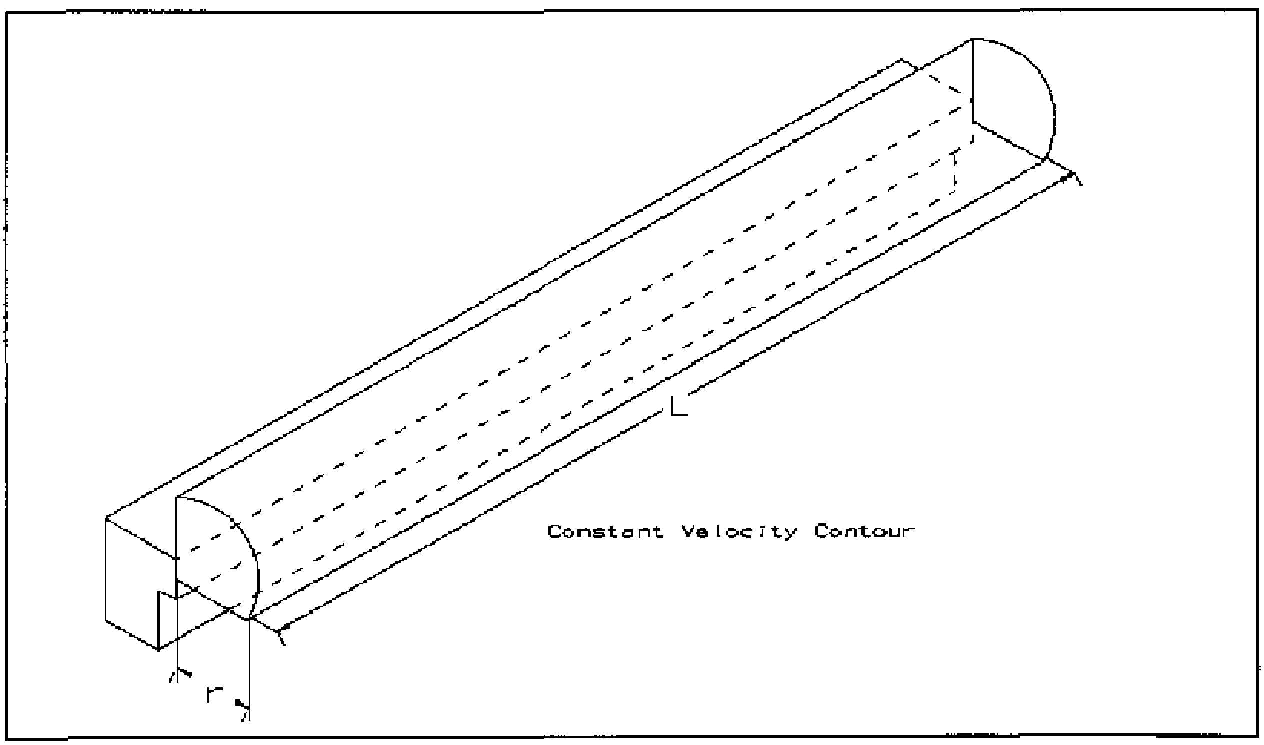

Figure 4 Constant velocity contour

The use of an air shower also was investigated The rationale for the air shower was that it would push the contaminated air down and toward the slot hoods, thereby reducing the exhaust volume required to achieve control In this series of tests, it was determined that the air shower did not improve the capture efficiency of the slot hoods at the flow rates (600-1200 cfm) evaluated Therefore, the air shower was not installed for the field evaluation at CCMS

The pressure drop for the hood also was measured in the laboratory for the different flows evaluated For the 700 cfm flow used in the installation at CCMS, the static pressure for the hood was found to be 0 8 inches of water A plot of the exhaust flow versus pressure drop is listed in Appendix A

A metal ramp was fabricated to fit across the slot hood on one side of the table This ramp was used to make it easier to move the bodies over the slot hood and to protect the bodies from damage by the front edge of the hood The ramp was removed after the body was moved onto the table, before the embalming procedure was started

METHODOLOGY

SAMPLING

Area and personal exposure monitoring was used to determine the effectiveness of the local exhaust ventilation system Sampling and analysis was performed in accordance with NIOSH Method 2502 [12] This method calls for the use of solid sorbent tubes (2-(benzylamino)ethanol on Chromosorb 102 or XAD-2, 120 mg/60 mg) with a maximum flow rate of 0 05 l/min For this study, all sampling pumps were calibrated at approximately 0 05 l/min The estimated limit of detection for the method is 1 μg

For each run, personal samples were collected in the breathing zone of two of the embalmers conducting the procedure in the isolation room Three area samples were collected for each run one area sample was collected in the isolation room, one in the hallway just outside the isolation room, and one in the laboratory office. These sampling locations are shown in Figure 1 Both the personal and the area samples were collected during the entire time required for the embalming procedure, which varied from run to run

EXPERIMENTAL DESIGN

The original study design intended to evaluate the effectiveness of the local exhaust ventilation system for both autopsied and nonautopsied bodies In an earlier study at CCMS, approximately half of the procedures sampled were for autopsied bodies In that study, autopsy was found to be a significant factor in the effecting exposures, possibly due to the slightly different methods used on autopsied bodies [8] However, for the study reported here, CCMS was not able to provide an equal number of autopsied and nonautopsied bodies Therefore, the local exhaust ventilation system evaluation was based on the types of embalming cases available to CCMS

The study was conducted with the local exhaust ventilation system in place and operating for all runs The study was designed to determine if the local ventilation system could control personal formaldehyde exposures to 1 ppm or less This 1 ppm level was chosen for two reasons First, in order to determine the number of repetitions needed, a target value for the exposure was needed The 1 ppm level was as low a concentration possible without requiring an unreasonable number of samples For this study, sixteen embalming procedures were sampled Second, the 1 ppm level is also the OSHA PEL level and the ACGIH TLV level If the local exhaust ventilation system could not control personal formaldehyde concentrations to 1 ppm or less, its value as a control system would be minimal The overall goal was to reduce the formaldehyde concentrations to as low a level as possible

EMBALMING PROCEDURES

Of the 16 runs sampled, only two were with bodies that were autopsied Of the remaining 14 runs, 12 of the bodies were anatomical preparations for a local medical college Anatomical procedures differed from the normal embalming procedures in that a final high pressure injection of approximately 5 gallons of a mixture of phenol, ethanol, glycerol, formaldehyde, and a disinfectant is made This mixture contains 2% formaldehyde Also, a formaldehyde containing gel is routinely applied to the face, hands, and feet of the anatomical bodies The analysis of the data was done without breaking out the type of procedure since there were only two each of the normal and autopsied embalmings

RESULTS

Of the 32 personal samples, (2 samples for each of 16 runs) the formaldehyde concentration of 5 samples were found to be higher than 1 ppm Run number 8, personal sample number 2 showed a concentration of 1 9 ppm, highest of all measurements However, the slot hood was obstructed by the ramp used to slide the bodies on and off the table The worker with this sample was positioned on the side of the table with the obstructed slot Because of the obstructed slot, this sample was not included in the analysis of the data Of the 94 personal, area and duct samples collected, 37 were found to be below the limit of detection For the purpose of the data analysis, these samples were assigned a sample mass of 0 71 μg, the limit of detection divided by the square root of 2 [13]

The means and standard deviations for the formaldehyde sampling are listed in Table 1 A full listing of the data from this study is in Appendix B A calculation of the upper confidence limit of the mean of the personal samples showed that the local exhaust ventilation system controlled formaldehyde exposures to 0 73 ppm (95% confidence) Similarly, a calculation of the upper confidence limit for the area location inside the isolation room indicated that local exhaust system controlled concentrations inside the room to 0 31 ppm There were two other area sample locations, one in the hallway just outside the embalming room and the other located in the embalming laboratory office An analysis of variance comparing these two outside area locations with the area location inside the embalming room showed no statistically significant differences in concentration [14]

Table 1 Summary of formaldehyde sampling results

Sample	n	Mean (ppm)	Standard Deviation (ppm)
Personal	32	0 60	0 41
Area, Isolation Room	16	0 24	0 14
Area, Hallway	16	0 21	0 12
Area, Laboratory Office	16	0 18	0 07
Exhaust Duct Outlet	13	0 81	0 42

DILUTION VENTILATION COMPARISON

A calculation was made to estimate the dilution ventilation rate needed to achieve the same control over the formaldehyde emissions as the local exhaust ventilation system Table 1 shows the mean formaldehyde concentration and standard deviation for the exhaust duct samples A t-test showed that the mean for this location is not significantly different than 1 ppm The mean duct concentration was used to calculate an average generation rate and the dilution ventilation rate needed to control formaldehyde emissions to the same level as the local exhaust ventilation system First, the mean concentration of the isolation room area samples was used as an estimate of the isolation room formaldehyde concentration after completion of the embalming procedure Multiplying this concentration (0 24 ppm) by the room volume (864 ft^3), resulted in a mass 7 34 mg of formaldehyde remaining in the isolation room Next, the mass of formaldehyde removed from the room was calculated by multiplying the mean exhaust duct concentration by the mean time of the procedure, yielding a mass of 1669 mg of formaldehyde The total mass of formaldehyde released, 1676 mg, is the sum of these two masses Dividing the mass release by the average time for a procedure yields a generation rate of 1183 mg/hr The dilution ventilation flow rate was calculated from the following equation [15]

$$Q = \frac{KG}{C} \tag{3}$$

where Q = exhaust volume (cfm)
K = mixing factor (3 to 10)
G = generation rate (mg/hr)
C = concentration (mg/m^3)

To determine the dilution ventilation flow rate, Q, which results in equivalent control of the formaldehyde emissions, C is taken to be the mean concentration of the personal samples, 0 60 ppm, and G is 1183 mg/hr, as calculated above The mixing factor, K, takes into account the degree of mixing within the room For K equals 3 (a well mixed room), the required dilution ventilation rate, Q, is 2800 cfm, while for a K of 10 (little or no mixing in the room), the ventilation rate would be 9300 cfm A detailed calculation of these exhaust volumes is given in Appendix C

CONCLUSIONS AND RECOMMENDATIONS

Based upon this study, the local exhaust ventilation system presented in this report controlled personal formaldehyde exposure concentrations to 0 73 ppm (95% confidence) The statistical analysis of the area samples results showed that the concentration in the isolation room was controlled to a level that was not significantly different than the concentrations measured outside the room From these results, it is recommended that a local exhaust ventilation system similar to the design tested here, should be installed permanently in the isolation room and on the other tables in the main embalming laboratory

The calculation of the dilution ventilation flow rate required to control formaldehyde emissions to the same level as the local ventilation system shows how effective ventilation can be when applied locally Even if a well mixed room is assumed, it would require up to 4 times the exhaust volume to reduce formaldehyde concentrations to the same level as the local exhaust ventilation system If the room is assumed to be poorly mixed, more than 10 times the exhaust volume is required The reduced exhaust volume for the local system will result in lower operating costs, due mainly to the reduction in the amount of make-up air required

It should be noted that the design tested in this study was merely a prototype For a permanent installation, additional work should be performed to design a more efficient plenum to reduce the pressure drop in the system This will reduce the fan size, thereby reducing the system purchase price and operating costs

REFERENCES

1 National Institute for Occupational Safety and Health Pocket Guide to Chemical Hazards Cincinnati, Ohio DHHS (NIOSH) Publication No 85-114, 1985

2 Title 29, Code of Federal Regulations Part 1910 1000 Air Contaminants (July 1, 1980)

3 American Conference of Governmental Industrial Hygienists Threshold Limit Values and Biological Exposure Indices for 1988-1989 Cincinnati, Ohio 1988

4 Dunn and Bradstreet Electronic Yellow Pages.

5 Kerfoot, Edward J and Thomas F Mooney "Formaldehyde and Paraformaldehyde Study in Funeral Homes " Am. Ind Hyg. Assoc. J (36[7] 533-537 1975)

6 Williams, Ted M , Richard J Levine and Patricia B Blunden. "Exposure of Embalmers to Formaldehyde and Other Chemicals " Am. Ind Hyg Assoc. J (45[3] 172-176 1984)

7 Perkins, Jimmy L and James D Kimbrough "Formaldehyde Exposure in a Gross Anatomy Laboratory " J Occup Med (27[11] 813-815 1985)

8. Herrick, Robert National Institute for Occupational Safety and Health Personal communication January 1989

9. Boeniger, Mark F Biological Markers for Formaldehyde Exposure in Mortician Students, Report II, Extent of Exposure U S Department of Health and Human Services (National Institute for Occupational Safety and Health) Report No IWSB 125 27 Cincinnati, Ohio (1990)

10 Hemeon, W C L Plant and Process Ventilation New York Industrial Press Inc , 1962

11 American Conference of Governmental Industrial Hygienists Industrial Ventilation--A Manual of Recommended Practice 19th edition Cincinnati, Ohio 1986

12 National Institute for Occupational Safety and Health NIOSH Manual of Analytical Methods Cincinnati, Ohio DHHS (NIOSH) Publication No 84-100, 1984

13 Horning, Richard W and Laurence D Reed "Estimation of Average Concentration in the Presence of Nondetectable Values " App Occup & Env Hyg 5, 1 (1990) 46-51

14 SAS Institute SAS Language Guide for Personal Computers, Version 6 Pages 72, 85, Cary, NC, 1985

15 National Institute for Occupational Safety and Health The Industrial Environment -- Its Evaluation and Control Cincinnati, Ohio DHHS (NIOSH), 1973

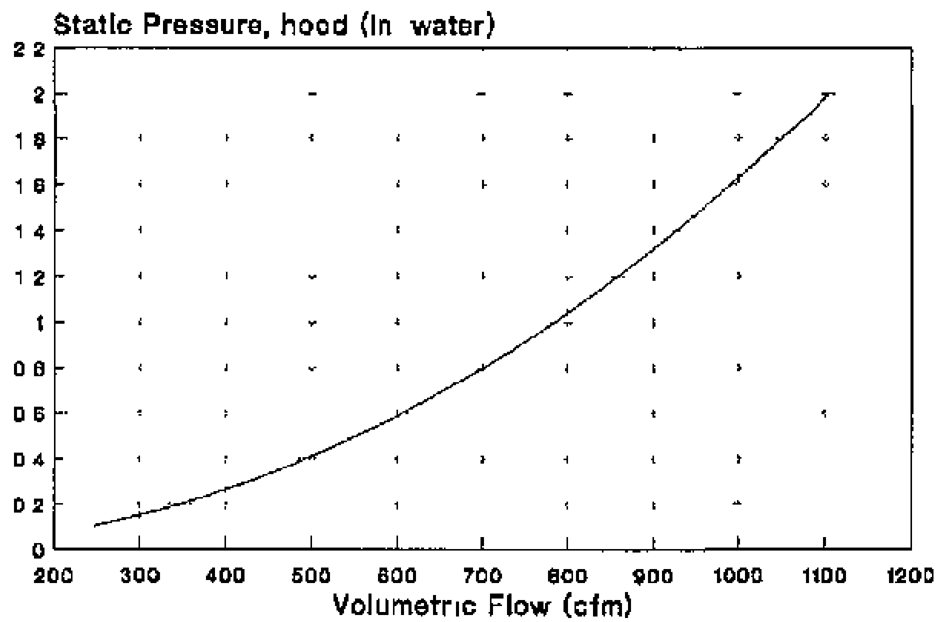

Figure A1 Plot of pressure drop versus exhaust volume for local exhaust ventilation hood

Appendix B

Listing of sampling data (*) indicates nondetected sample

Run No	Sample Location	Sample Time	Sample Mass	Non Detected	Formaldehyde Conc (ppm)
1	OUT AREA 1	146	0 71	*	0 08
1	OUT AREA 2	147	0 71	*	0 09
1	IN AREA 1	146	1		0 13
1	PERSONAL 1	134	3		0 39
1	PERSONAL 2	133	3		0 43
2	OUT AREA 1	54	0 71	*	0 22
2	OUT AREA 2	54	0 71	*	0 22
2	IN AREA 1	54	0 71	*	0 21
2	PERSONAL 1	53	0 71	*	0 25
2	PERSONAL 2	54	1		0 36
3	OUT AREA 1	137	0 71	*	0 09
3	OUT AREA 2	137	0 71	*	0 09
3	IN AREA 1	135	0 71	*	0 10
3	PERSONAL 1	136	0 71	*	0 10
3	PERSONAL 2	136	0 71	*	0 09
3	EXHAUST	137	1		0 12
4	OUT AREA 1	47	0 71	*	0 27
4	OUT AREA 2	48	0 71	*	0 28
4	IN AREA 1	47	1		0 37
4	PERSONAL 1	48	4		1 43
4	PERSONAL 2	48	3		1 04
4	EXHAUST	48	3		1 17
5	OUT AREA 1	69	0 71	*	0 17
5	OUT AREA 2	70	0 71	*	0 17
5	IN AREA 1	71	1		0 23
5	PERSONAL 1	69	2		0 46
5	PERSONAL 2	69	3		0 69
5	EXHAUST	71	5		1 32
6	OUT AREA 1	73	0 71	*	0 17
6	OUT AREA 2	73	0 71	*	0 17
6	IN AREA 1	73	0 71	*	0 17
6	PERSONAL 1	70	0 71	*	0 18
6	PERSONAL 2	73	0 71	*	0 18
6	EXHAUST	71	1		0 24
7	OUT AREA 1	71	0 71	*	0 15
7	OUT AREA 2	71	0 71	*	0 16
7	IN AREA 1	70	0 71	*	0 17
7	PERSONAL 1	72	2		0 53
7	PERSONAL 2	72	1		0 25
7	EXHAUST	69	1		0 25
8	OUT AREA 1	127	0 71	*	0 10
8	OUT AREA 2	128	1		0 13
8	IN AREA 1	127	0 71	*	0 09
8	PERSONAL 1	128	3		0 43
8	PERSONAL 2	127	14		1 91

8	EXHAUST	127	3		0 40
9	OUT AREA 1	93	2		0 36
9	OUT AREA 2	92	2		0 37
9	IN AREA 1	91	0 71	*	0 13
9	PERSONAL 1	92	4		0 74
9	PERSONAL 2	93	4		0 75
9	EXHAUST	94	7		1 16
10	OUT AREA 1	56	0 71	*	0 23
10	OUT AREA 2	57	0 71	*	0 20
10	IN AREA 1	57	1		0 30
10	PERSONAL 1	55	2		0 56
10	PERSONAL 2	56	3		0 99
10	EXHAUST	57	4		1 15
11	OUT AREA 1	80	2		0 42
11	OUT AREA 2	80	0 71	*	0 17
11	IN AREA 1	80	2		0 39
11	PERSONAL 1	80	2		0 42
11	PERSONAL 2	80	3		0 63
11	EXHAUST	79	5		1 04
12	OUT AREA 1	47	1		0 37
12	OUT AREA 2	47	0 71	*	0 29
12	IN AREA 1	47	2		0 66
12	PERSONAL 1	48	3		1 09
12	PERSONAL 2	47	4		1 44
12	EXHAUST	44	4		1 37
13	OUT AREA 1	81	0 71	*	0 14
13	OUT AREA 2	81	0 71	*	0 17
13	IN AREA 1	81	1		0 21
13	PERSONAL 1	81	4		0 80
13	PERSONAL 2	81	2		0 42
13	EXHAUST	81	4		0 86
14	OUT AREA 1	122	0 71	*	0 11
14	OUT AREA 2	123	0 71	*	0 11
14	IN AREA 1	121	1		0 14
14	PERSONAL 1	123	3		0 43
14	PERSONAL 2	123	1		0 15
14	EXHAUST	124	3		0 42
15	OUT AREA 1	68	2		0 50
15	OUT AREA 2	68	0 71	*	0 17
15	IN AREA 1	68	1		0 26
15	PERSONAL 1	67	2		0 58
15	PERSONAL 2	66	2		0 52
15	EXHAUST	68	3		0 82
16	OUT AREA 1	101	0 71	*	0 12
16	OUT AREA 2	102	0 71	*	0 13
16	IN AREA 1	101	2		0 34
16	PERSONAL 1	102	4		0 74
16	PERSONAL 2	102	2		0 36
16	EXHAUST	100	5		0 99

18 blanks were analyzed, all were nondetected

Appendix C

Dilution ventilation flow rate calculation

Mass in isolation room, inside concentration = 0 244 ppm room volume = 864 ft^3

$$0\ 244\ ppm \times 1\ 23\ \frac{\left(\frac{mg}{m^3}\right)}{ppm} = 0\ 30\ \frac{mg}{m^3}$$

$$0\ 30\ \frac{mg}{m^3} \times 864\ ft^3 \times \frac{m^3}{35\ ft^3} = 7\ 34\ mg$$

Mass exhausted, Concentration in duct = 0 807 ppm exhaust flow = 700 cfm average time of procedure = 85 minutes

$$0\ 807\ ppm \times 1\ 23\ \frac{\left(\frac{mg}{m^3}\right)}{ppm} = 0\ 99\ \frac{mg}{m^3}$$

$$0\ 99\ \frac{mg}{m^3} \times 700\ \frac{ft^3}{\text{min}} \times \frac{m^3}{35\ ft^3} \times 85\ \text{min} = 1669\ mg$$

Total mass emitted from procedure

$$1669\ mg + 7\ 34\ mg = 1676\ mg$$

Calculation of generation rate

$$1676\ mg \times \frac{1}{85\ \text{min}} \times \frac{60\ \text{min}}{1\ hr} = 1183\ \frac{mg}{hr} = G$$

Calculation of Q, C = 0 605 ppm

$$0\ 605\ ppm \times 1\ 23\ \frac{\left(\frac{mg}{m^3}\right)}{ppm} = 0\ 744\ \frac{mg}{m^3}$$

$$Q = \frac{KG}{C}$$

For K = 3

$$Q = \frac{(1183)\ (3)}{0\ 744} = 4770\ \frac{m^3}{hr}$$

$$4770\ \frac{m^3}{hr} \times \frac{35\ ft^3}{1\ m^3} \times \frac{1\ hr}{60\ \text{min}} = 2783\ \frac{ft^3}{\text{min}}$$

For K = 10

$$Q = \frac{(1183)\ (10)}{0\ 744} = 15900\ \frac{m^3}{hr}$$

$$15900\ \frac{m^3}{hr} \times \frac{35\ ft^3}{1\ m^3} \times \frac{1\ hr}{60\ \text{min}} = 9275\ \frac{ft^3}{\text{min}}$$