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University of Medicine and Dentistry of New Jersey, University Hospital Newark, New Jersey

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PREFACE

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ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

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SUMMARY

In July 1995, the National Institute for Occupational Safety and Health (NIOSH) conducted a health hazard evaluation (HHE) at University Hospital of the University of Medicine and Dentistry of New Jersey. The HHE was conducted in response to a management request for assistance in evaluating a supplemental high efficiency particulate air (HEPA) filtration system installed in one of University Hospital's new ambulances. The purpose of the HEPA filtration system is to reduce the potential for tuberculosis (TB) transmission during transport of patients with active TB by filtering the vehicle's air through a HEPA filter before returning it to the ambulance. HEPA filters are capable of removing at least 99.97% of particles $\geq$ 0.3 microns (µm) in diameter (the most penetrating particle size), thus they are believed to be highly efficient in removing *Mycobacterium tuberculosis*–containing droplet nuclei which are approximately 1–5 µm in size.

NIOSH investigators conducted a field evaluation of particle clearance in an ambulance equipped with a supplemental HEPA filtration system. A similar ambulance without the HEPA filtration system was also evaluated for comparison. A polystyrene aerosol tracer was nebulized in the ambulances, and the decay in particle counts was measured at four locations using laser particle counters. Using this data, effective air change rates in the ambulance were calculated under varying conditions of operation.

The results indicated that the ambulance with the supplemental HEPA filtration system cleared particles faster than the ambulance without the supplemental system, when tested under similar conditions. The effective air change rates ranged from about 43 to 46 air changes per hour (ACH) in the HEPA–equipped ambulance, and from 26 to 32 ACH in the non–HEPA–equipped ambulance. These comparisons were made using two different ambulances (the HEPA ambulance was a 1995 model and the non–HEPA ambulance was a 1994 model, same manufacturer). Undefined operational or design factors could have biased the effective ACH rates for both ambulances. This evaluation also showed that particle clearance could be improved by the use of the rear vent fan (when positioned on the "high" setting) in conjunction with the provision of outside air through the vehicle's main HVAC systems. For vehicles that do not have supplemental HEPA filtration systems, using the vent fan and providing outside air through the vehicle's main HVAC system improves aerosol clearance and thus reduces the potential risk of TB transmission. A recommendation concerning the use of respiratory protection by workers during transport of known or suspected infectious TB patients is included in the report along with a recommendation for the performance of regular preventive maintenance and leak testing of the HEPA unit.

Keywords: SIC 4119 (Ambulance service, road), tuberculosis, TB, ambulance, emergency medical services, EMS, health care, HEPA filtration.

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INTRODUCTION

In October 1994, a management representative at University Hospital/University of Medicine and Dentistry of New Jersey (UMDNJ) requested assistance from the National Institute for Occupational Safety and Health (NIOSH) in evaluating a high efficiency particulate air (HEPA) filtration system in an ambulance, and in the utilization of two portable HEPA filtration units in the hospital. These engineering controls were being considered for use as supplemental methods to reduce the risk of tuberculosis (TB) transmission. NIOSH investigators conducted a site visit in July 1995 to evaluate the HEPA filtration units. However, the portable HEPA filtration units in the hospital were not in use at the time of the site visit, and the units were not evaluated. This report summarizes the findings and recommendations from the NIOSH evaluation of the HEPA filtration system in the ambulance.

BACKGROUND

Because of the potential for exposure to airborne *Mycobacterium tuberculosis* from patients with known or unrecognized active tuberculosis, a recirculating HEPA filtration system was installed in a new ambulance to reduce the risk of airborne TB transmission during patient transport. Seven hospitals in the Newark area are served by University Hospital's ambulance service. Employees reported that approximately 80% of the ambulance runs are for non–emergency transport, and that many of these patients are in high–risk categories for active tuberculosis.

METHODS

On July 26–27, 1995, NIOSH investigators conducted a site visit at University Hospital. To evaluate the HEPA filtration system in the ambulance, NIOSH investigators released a polystyrene aerosol tracer and measured its decay under varying field conditions. This allowed assessment of the ability of the system to clear particles from the air and to determine the effective air change rate in the ambulance. To evaluate the positioning and integrity of the HEPA filter, the aerosol was also released at the exhaust grille, and the particulate concentration was measured at the return air diffuser. Monodisperse polystyrene spheres (Duke Scientific, Palo Alto, CA, lot 13172) were diluted with deionized, filtered water and aerosolized in a Collison 6–jet nebulizer (BGI Inc., Waltham, MA). The aerosol was generated at a flowrate of 20 liters per minute. The resulting monodisperse aerosol had an aerodynamic diameter of 3.004 microns (μm) and standard deviation of 0.029 μm.

The conditions used during successive runs included: engine status (on or off), heating, ventilating and air–conditioning (HVAC) system status (recirculation mode or outside air provision), vent fan status (on or off), and ambulance status (stationary or mobile). Two emergency transport vehicles were included in the field study. The first was a 1995 Type III ambulance (unit 113) that had been in service less than one month, and the second was a 1994 Type III ambulance (unit 109) that had been in service for over one year. Both were manufactured by Excellance of Allentown, PA. Only the 1995 model was equipped with the supplemental HEPA filtration system. The HEPA filtration system in the 1995 ambulance could not be turned off while the ambulance was running. Unfortunately, a comparable 1995 model without a HEPA filtration system was not available. Instead, we measured aerosol clearance for comparison purposes in a 1994 model which reportedly was nearly identical to the 1995 ambulance with respect to its layout and HVAC system design. Both had separate HVAC units for the cab and rear compartments and a vent fan in the rear of the ambulance capable of exhausting air directly to the outside. A bulkhead door separates the front and rear compartments, but is typically open allowing free access between the cab and rear sections of the ambulance.

The Vehiculaire™ recirculating HEPA filtration system (Biological Controls, Eatontown, NJ) in ambulance 113 operates independently from the vehicle's HVAC system. The HEPA unit contains a pre–filter followed by a HEPA filter. The air intake is at floor level directly behind the area where a patient's head would be positioned on the gurney. Supply air is delivered to the area behind the middle to rear portion of the gurney (see Figure 1). The volume of supply and return air was measured with a model 8370 AccuBalance® airflow–measuring hood (TSI Inc., St. Paul, MN). A model 8360 Velocicalc Plus air velocity meter (TSI Inc., St. Paul, MN) was used to determine the velocity of air exhausted by the vent fan in the rear of the ambulance. The airflow was calculated by multiplying the air velocity by the area of the vent. As shown in Figure 1, the aerosol was released in the rear of the ambulance, on the driver's side. To improve initial mixing, a small circulation fan was used during the aerosol release period. After a few minutes, the nebulizer was turned off and particle counts were continuously recorded using four Met One model 227B laser particle counters (Met One Inc., Grants Pass, OR). Three or four persons were present in the ambulance during the aerosol clearance evaluation. Efforts were made to restrict movement within the ambulance to minimize the disruption of airflow patterns. The particle counters were positioned on the attendant seat, family member seat, gurney, and on the background driver's seat. The particle counters were operated in the automatic mode with a sample time of 10 seconds and a hold time of one second. When the particle counts returned to baseline, the run was ended. The logarithmic rate of decline in particle counts 3.0 μm and greater (natural log of particle count versus elapsed time) was plotted and the least squares method[a] used to calculate a straight line that best fit the data. In the resulting equation which describes the line (y = mx + b), "m" represents the slope of the line and is equal to the air change rate. The decline in particle counts may be due to removal mechanisms other than the vehicle's HEPA filtration system. These unquantified mechanisms probably include dilution with outside air leaking into the ambulance, impaction of particles on surfaces, and removal by the vehicle's main ventilation system.

RESULTS

Figure 2 shows a typical plot of particle counts vs. time for ambulance 113. The plot begins when the aerosol release period has ended. When the engine is turned on and the HEPA filtration system and HVAC systems are operating, particle clearance is accelerated. Note the change in the slopes of the lines. Effective air change rates increased dramatically from 3.5 to 39.1 air changes per hour (ACH) when the ambulance ventilation system and HEPA filtration system were activated. The data in this example are from a particle counter positioned on a gurney inside a stationary ambulance (unit 113).

Air change rates for runs conducted under varying field conditions are shown in Table 1. As shown in the table, some particle clearance occurs when the engine is not running; however, this clearance equates to a mean air change rate for the four sampling locations of only 2.9 ACH. This clearance may be due to settling/impaction of the aerosol on surfaces inside the ambulance and infiltration of outside air. For the HEPA ambulance, air change rates were determined with the ambulance stationary and mobile. There was little difference in air change rates when all other conditions were held constant (HEPA sys = on; vent fan = off; cab and rear A/C = recirc), as evidenced by mean ACHs of 43.0 and 46.6 during stationary runs, and 45.0 and 46.4 during mobile runs. While there were differences in air change rates at the four sampling locations within a given run, there were no apparent trends in terms of some locations being consistently higher or lower than others.

The mean air change rate was considerably higher in the HEPA ambulance when the HVAC units were

[a] The least squares method is a statistical method of estimation that minimizes the sum of the squared differences between the observed values and the values predicted by the model.

allowed to bring in outside air and the rear vent fan was positioned on "high" (ACH = 55.9, as compared with 45.0 and 46.4, when recirculation mode was used and the vent fan was off). Air flow measurements indicated that the vent fan was exhausting 91 cubic feet of air per minute (CFM) directly to the outside when positioned on "high."

For the non–HEPA ambulance, air change rates were lower than in the HEPA ambulance when all other conditions were the same (ambulance = mobile; cab and rear HVAC = recirc; vent fan = off). The mean ACHs for three separate runs were 25.8, 27.6 and 32.0 for the non–HEPA ambulance, as compared to 45.0 and 46.4 for two runs with the HEPA ambulance. Unlike with the HEPA ambulance, the mean ACHs were not appreciably higher when the HVAC units were positioned to bring in outside air and the vent fan was turned on. However, this may be due to the fact that the vent fan was inadvertently placed on the "medium" setting rather than the "high" setting as had been done for the HEPA ambulance.

The HEPA filtration system supply and exhaust air flow rates ranged from 105 to 110 CFM. Ambulance status (stationary or mobile) did not affect the measured air flow rates. The positioning and integrity of the HEPA filter was checked by releasing the polystyrene aerosol at the unit's exhaust (intake) grille and measuring particle counts at the face of the supply diffuser. This brief evaluation revealed that the filter was effective in removing the polystyrene aerosol as evidenced by very low or non–detectable values for particles 3.0 µm or greater in size. Leak testing of the HEPA filter was not performed. Modifications to the system may be necessary to allow such testing to be done.

DISCUSSION AND CONCLUSIONS

NIOSH investigators conducted a field evaluation to assess the performance of two Type III ambulances in clearing particles from the air. One ambulance had been retrofitted with a supplemental HEPA filtration system to enhance particle clearance and thus reduce the risk of airborne TB transmission. A tracer aerosol with an aerodynamic diameter of approximately 3 µm was used for the evaluation. This aerosol is in the size range of *Mycobacterium tuberculosis* (Mtb)– containing droplet nuclei (1–5 µm), and is also in the range where HEPA filters remove nearly 100% of particles. The NIOSH data showed that the ambulance with the supplemental HEPA filtration system cleared particles faster than the ambulance without the supplemental system, when tested under similar conditions. The effective air change rates ranged from about 43 to 46 ACH in the HEPA ambulance, and from 26 to 32 ACH in the non–HEPA ambulance. It should be noted, however, that these comparisons were made using two different ambulances (the HEPA ambulance was a 1995 model and the non–HEPA ambulance was a 1994 model, same manufacturer). Although we were informed that the two ambulances were nearly identical with respect to layout and HVAC system design, there may be other factors that we did not evaluate that could have influenced ACH rates in the non–HEPA ambulance. Despite this fact, the calculated air change rates for the non–HEPA ambulance generally fell in the range specified in the Federal Specification for the Star–of–Life Ambulance.[1] This specification requires that the ventilation system(s) of the driver and patient compartments provide a complete change of ambient air at least every two minutes (i.e., 30 ACH) with the vehicle stationary. Although measurements in the non–HEPA ambulance were made while the vehicle was mobile, the air change rates measured in the HEPA ambulance showed little variation between stationary and mobile runs.

This evaluation also showed that particle clearance could be improved by the use of the rear vent fan (when positioned on "high") in conjunction with the provision of outside air through the main HVAC systems. For the HEPA ambulance, an effective air change rate of about 56 ACH was calculated for the run where the vent fan was used and outside air provided, as compared with 45 and 46 ACH without these additions. Thus for vehicles that do not have supplemental HEPA filtration systems, using the vent fan and providing outside air through the main vehicle HVAC system will improve aerosol clearance and potentially reduce the risk of TB transmission. Opening windows may also be beneficial in diluting potential contaminants such as Mtb, but may not always be appropriate for other reasons (noise, temperature and humidity control, etc.).

RECOMMENDATIONS

1. While supplemental engineering controls such as the HEPA filtration unit described above can improve particle clearance in the ambulance, they will not eliminate the potential for exposure to droplet nuclei containing Mtb. Thus, respiratory protection should be used by EMS personnel during transport of patients who have, or are suspected of having active tuberculosis. The Occupational Safety and Health Administration's (OSHA) enforcement procedures for tuberculosis[2] require that respirators meeting the criteria outlined in the most recent CDC guidelines[3] be used by workers when transporting such patients in enclosed vehicles. The OSHA guidelines require at a minimum the use of NIOSH–approved N95 respirators. These respirators should be used in conjunction with a respiratory protection program meeting the requirements outlined in the OSHA respirator standard.[4]

2. The manufacturer of the HEPA filtration system should be consulted to determine the best method of leak testing the HEPA filter, and the desired frequency of such testing. Leak testing is an important part of a preventive maintenance program for HEPA filters and is particularly important in this situation because of the potential for considerable movement and vibration during ambulance runs. In addition, periodic visual inspections should be made (e.g. weekly) to check the positioning and evaluate the integrity of the pre–filter and HEPA filter.

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TABLE 1

AIR CHANGE RATES BASED ON AEROSOL CLEARANCE IN TYPE III AMBULANCES WITH AND WITHOUT SUPPLEMENTAL HEPA FILTRATION

HETA 95–0031
UNIVERSITY HOSPITAL
NEWARK, NEW JERSEY

CONDITIONS		RUN DATE	EFFECTIVE AIR CHANGES PER HOUR (ACH)†				
			ATTENDANT SEAT	FAMILY MEMBER SEAT	BACK–GROUND DRIVER	GURNEY	MEAN ACH
HEPA AMBULANCE #113							
ENGINE: OFF HEPA SYSTEM: OFF VENT FAN: OFF	A/C CAB: OFF A/C REAR: OFF AMBULANCE: STATIONARY	7/26/95	4.0	3.1	1.1	3.5	2.9
ENGINE: ON HEPA SYSTEM: ON VENT FAN: OFF	A/C CAB: MAX, RECIRC. A/C REAR: ON, RECIRC. AMBULANCE:STATIONARY	7/26/95 7/26/95	34.4 45.6	45.1 47.4	53.6 51.8	39.1 41.4	43.0 46.6
ENGINE: ON HEPA SYSTEM: ON VENT FAN: OFF	A/C CAB: MAX, RECIRC. A/C REAR: ON, RECIRC. AMBULANCE: MOBILE	7/26/95 7/27/95	41.5 41.7	48.5 45.4	41.4 50.4	48.4 47.9	45.0 46.4
ENGINE: ON HEPA SYSTEM: ON VENT FAN: HIGH	A/C CAB: OUTSIDE AIR A/C REAR: ON, OPEN AMBULANCE: MOBILE	7/27/95	60.9	58.4	46.7	57.6	55.9
NON–HEPA AMBULANCE #109							

TABLE 1

AIR CHANGE RATES BASED ON AEROSOL CLEARANCE IN TYPE III AMBULANCES WITH AND WITHOUT SUPPLEMENTAL HEPA FILTRATION

HETA 95–0031
UNIVERSITY HOSPITAL
NEWARK, NEW JERSEY

ENGINE: ON HEPA SYS: NOT PRESENT VENT FAN: OFF A/C CAB: MAX, RECIRC. A/C REAR: ON, RECIRC. AMBULANCE: MOBILE	7/27/95 7/27/95 7/27/95	31.3 30.6 23.7	24.2 32.5 29.9	22.3 34.8 30.2	25.6 30.3 26.8	25.8 32.0 27.6
ENGINE: ON HEPA SYS: NOT PRESENT VENT FAN: MEDIUM A/C CAB: OUTSIDE AIR A/C REAR: ON, OPEN AMBULANCE: MOBILE	7/27/95 7/27/95	28.6 24.4	30.1 0.85	36.2 29.6	29.8 29.2	31.2 27.7‡

†AIR CHANGE RATES WERE CALCULATED BASED ON CLEARANCE OF PARTICLES 3.0 MICRONS OR GREATER IN SIZE.
‡MEAN ACH DID NOT INCLUDE THE FAMILY MEMBER SEAT LOCATION BECAUSE THIS VALUE WAS AN OUTLIER.

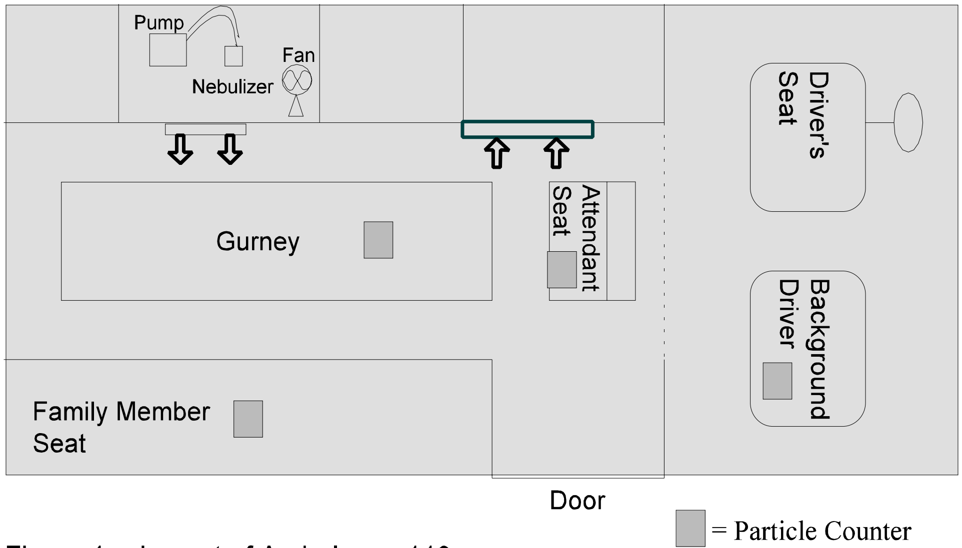
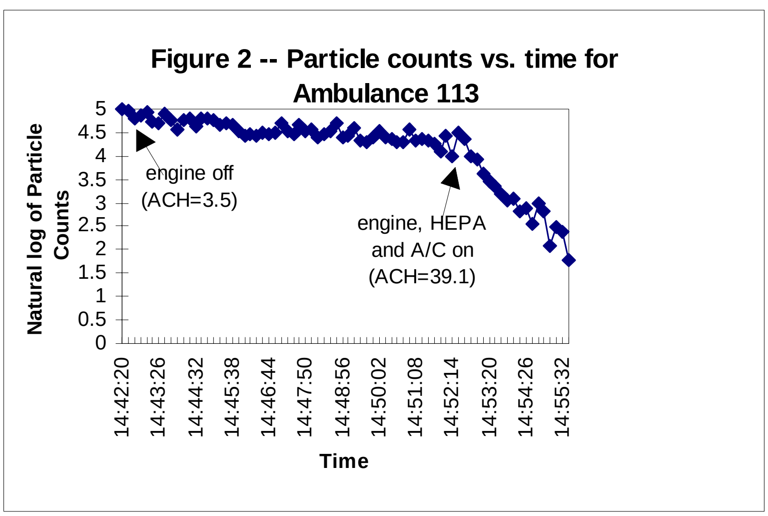


Figure 1 -- Layout of Ambulance 113



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