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IN-DEPTH SURVEY REPORT:

A LABORATORY EVALUATION OF PROTOTYPE ENGINEERING CONTROLS DESIGNED TO REDUCE OCCUPATIONAL EXPOSURES DURING ASPHALT PAVING OPERATIONS

at

Cedarapids Incorporated
Cedar Rapids, Iowa

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DISCLAIMER

Mention of company names or products does not constitute endorsement by the Centers for Disease Control and Prevention (CDC).

EXECUTIVE SUMMARY

On April 26-28, 1995, researchers from the National Institute for Occupational Safety and Health (NIOSH) evaluated prototype engineering controls designed for the control of fugitive asphalt emissions during asphalt paving. The Cedarapids engineering controls evaluation was completed as part of a Department of Transportation (DOT) project to evaluate the effectiveness of engineering controls on asphalt paving equipment. NIOSH researchers are conducting the research through an inter-agency agreement with DOT's Federal Highway Administration. Additionally, the National Asphalt Paving Association is playing a critical role in coordinating the paving manufacturers' and paving contractors' voluntary participation in the study.

The study consists of two major phases. During the primary phase, NIOSH researchers visited each participating manufacturer and evaluated their engineering control designs under managed environmental conditions. The indoor evaluation used tracer gas analysis techniques to both quantify the control's exhaust flow rate and determine the capture efficiency. Results from the indoor evaluations provided equipment manufacturers with the necessary information to maximize engineering control performance prior to the second phase of the study, performance evaluation of the prototype engineering controls under "real-life" paving conditions. The scope of this report is limited to the Cedarapids phase one evaluation.

The Cedarapids phase one evaluation studied the performance of three engineering control designs. The prototype designs were installed and evaluated, one at a time, on a Cedarapids CR411 asphalt paving machine. The best of the tested designs consisted of a long hood mounted above the auger area with a heavy rubber cover extending out and over the remaining auger area between the paver and the screed. Two exhaust fans removed air from the auger area and transported the exhaust air to the tractor engine's air-intake and exhaust systems to dispose of the captured contaminant. The average indoor capture efficiency for this design was 51 percent with an exhaust flow rate near 255 cubic feet per minute. Outdoor evaluations revealed average capture efficiencies of 31 percent when the tractor was oriented with the wind and 39 percent when oriented into the wind. Outdoor efficiency results showed increased variation in capture efficiency as wind gusts hampered the control's ability to consistently capture the surrogate contaminant.

Recommendations to Cedarapids design engineers include: (1) Modifying the hood design to improve exhaust distribution; (2) Increasing hood enclosure to minimize the wind effect near the ends of the auger area; and (3) Redesign and increase the volumetric handling capacity of the exhaust system in order to capture and remove asphalt fume and other auger-area contaminants before they escape into the workers' breathing zones.

Since the intent of the phase one evaluations was to provide equipment manufacturers with engineering performance and design feedback, various original and imaginative approaches were developed with the knowledge that these prototypes would undergo preliminary performance testing to identify which designs showed the most merit. Each manufacturer received design modification recommendations specific to their prototypes' performance during the phase one

testing. Prior to finalization of this report, each manufacturer received the opportunity to identify what modifications and/or new design features were incorporated into the "final" prototype design prior to the phase two evaluations. This design information for the Cedarapids engineering control is included, as it was received, in Appendix C of this report.

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH), a Federal agency located in the Centers for Disease Control and Prevention under the Department of Health and Human Services, was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct research and educational 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 the lead within NIOSH to study and develop engineering controls and assess their impact on reducing occupational illness. Since 1976, ECTB has conducted a large number of studies to evaluate engineering control technology based upon industry, process, or control technique. The objective of each of these studies has been to identify or design engineering control techniques and to evaluate their effectiveness in reducing potential health hazards in an industry or at specific processes. Information on effective control strategies is subsequently published and distributed throughout the affected industry and to the occupational safety and health community.

BACKGROUND

On April 26-28, 1995, researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted an evaluation of prototype engineering controls designed for the reduction of fugitive asphalt emissions during asphalt paving. The NIOSH researchers included Ken Mead, Mechanical Engineer, Leroy Mickelsen, Chemical Engineer, and Dan Watkins, Engineering Technician, all from the NIOSH Engineering Control Technology Branch (ECTB), Division of Physical Sciences and Engineering (DPSE). The DPSE researchers were assisted by two Cedarapids, Inc. engineers, David L. Swearingen and Joseph E. Musil.

The Cedarapids engineering control evaluation was completed as part of a Department of Transportation (DOT) project to evaluate the effectiveness of engineering controls on asphalt paving equipment. NIOSH/DPSE researchers are conducting the research through an inter-agency agreement with DOT's Federal Highway Administration (FHWA). Additionally, the National Asphalt Paving Association (NAPA) has played a critical role in coordinating the paving manufacturers' voluntary participation in the study. The study consisted of two major phases. During the primary phase, NIOSH researchers visited each participating manufacturer and evaluated their engineering control designs under managed environmental conditions. [General protocols for the indoor evaluations are located in Appendix A. Minor deviations from these protocols sometimes occurred depending upon available time, prototype design, equipment performance, and available facilities.] Results from the phase one evaluations are provided to the equipment manufacturers along with design change recommendations to maximize engineering control performance prior to the phase two evaluations. The second phase evaluations, which began in mid-1996, include a performance evaluation of the prototype engineering controls under "real-life" conditions at an actual paving site. The results from the Cedarapid's phase two evaluation will be published in a separate report.

DESIGN REQUIREMENTS

When designing a ventilation control, the designer must apportion the initial design criteria among three underlying considerations; the level of enclosure, the hood design, and the available control ventilation. When possible, an ideal approach is to maximize the level of enclosure in order to contain the contaminant emissions. With a total or near-total enclosure approach, hood design is less critical, and the required volume of control ventilation is reduced. Many times, worker access or other process requirements limit the amount of enclosure allowed. Under these constraints, the designer must compromise on the level of enclosure and expend increased attention to hood design and control ventilation.

In the absence of a totally enclosed system, the hood design plays a critical role in determining a ventilation control's capture efficiency. Given a specified exhaust flow rate, the hood shape and configuration affect the ventilation control's ability to capture the contaminant, pull it into the hood, and direct it toward the exhaust duct. A well-engineered hood design strives to achieve a uniform velocity profile across the open hood face. When good hood design is combined with proper enclosure techniques, cross-drafts and other airflow disturbances have less of an impact on the ventilation control's capture efficiency.

In addition to process enclosure and hood design, a third area of consideration when designing a ventilation control, is the amount of ventilation air (volumetric flow and/or velocity) required to capture the contaminant and remove it from the working area. For most work processes, the contaminant must be "captured" and directed into the contaminant removal system. For ventilation controls, this is achieved with a moving air stream. The velocity of the moving air stream is often referred to as the capture velocity. In order to maintain a protected environment, the designed capture velocity must be sufficient to overcome process-inherent contaminant velocities, convective currents, cross-drafts, or other potential sources of airflow interference. The minimum required exhaust flow rate (Q) is easily calculated by inputting the desired capture velocity and process geometry information into the design equations specific to the selected hood design. Combining Q with the calculated pressure losses within the exhaust system allows the designer to appropriately select the system's exhaust fan.

For most ventilation controls, including the asphalt paving controls project, these three fundamentals; process enclosure, hood design, and capture velocity are interdependent. A design which lacks process enclosure can overcome this shortcoming with good hood design and increased air flow. Alternatively, lower capture velocities may be adequate if increased enclosure and proper hood design techniques are followed. Additional information on designing ventilation controls can be found in the American Conference of Governmental Industrial

Hygienists' (ACGIH) *"INDUSTRIAL VENTILATION: A Manual of Recommended Practice"* [ACGIH, 6500 Glenway Avenue, Building D-7, Cincinnati, Ohio 45211.]

EVALUATION PROCEDURE

For the Cedarapids phase one evaluation, three engineering control designs were identified for individual assessment. These are referred to as, Design A: Long hood w/cover, Design B: Long hood w/o cover, and Design C: Short hood. All three designs differed only in their hood design and thus utilized the same duct, plenum, and fan systems. The three control designs were evaluated in a large bay area within the manufacturing plant. Adjacent to the bay area was a painting area which included a large paint booth. An overhead door separated the two areas. The paver was parked with the screed and rear half of the tractor positioned in the bay area (referred to as the testing area) and the front half of the tractor positioned in the painting area. The overhead door was lowered to rest on top of the tractor and the remaining doorway openings around the tractor were sealed to isolate the front and rear halves of the paver. During each test run, the engine exhaust and the engineering control exhaust were discharged into the painting area where the paint booth's fan exhausted them to the outdoors. This setup proved very effective at preventing the engine exhaust and the captured surrogate contaminants from reentering the testing area.

Two smoke generators produced theatrical smoke as a surrogate contaminant and discharged the smoke through a pair of perforated distribution tubes. The tube placement traversed the width of the auger area between the tractor and the screed. The augers were not installed during the test. Initially, the smoke was used to observe airflow patterns around the paver and to observe capture by the control systems. (The general smoke test protocol is in Appendix A.) This test also helped to identify failures in the integrity of the barrier separating the front and rear portions of the paver. The Cedarapids evaluation was the first evaluation under the phase one protocol. In accordance with the original smoke test protocol, aerosol monitors were to quantify the smoke concentrations escaping from the auger area for comparison of the control-on vs. control-off test scenarios.

The second method of evaluation was the tracer gas evaluation. This evaluation was designed to: (1) Calculate the total volumetric exhaust flow of each hood design; (2) Evaluate each hood's effectiveness in controlling and capturing a surrogate contaminant under the "controlled" indoor scenario. Sulfur hexafluoride (SF_6) was the selected tracer gas. At the concentrations generated for these evaluations, SF_6 behaves as a non-toxic, surrogate contaminant which follows the air currents of the ambient air in which it is released. Since SF_6 is not naturally found within ambient environments, it is an excellent tracer gas for studying ventilation system characteristics. The general protocol for the tracer gas evaluation is in Appendix A. Since Cedarapids had more than one prospective design, the most effective engineering control design, as determined by the indoor evaluation, was selected for further evaluation outdoors with the paver positioned in prescribed stationary orientations. The outdoor stationary evaluation provided feedback on the sufficiency of the engineering control's hood enclosure for performance in an outdoor environment.

To quantify exhaust flow rate, the tracer gas discharge tubes were placed directly into the exhaust ducts of the engineering control. We released a known flow rate of SF_6 into the ducts and used a direct-reading analytical instrument on the discharge side of the control to measure the concentration of the contaminant in the exhaust. The exhaust flow rate was calculated using the following equation:

$$Q_{(exh)} = \frac{Q_{(SF_6)}}{C^*_{(SF_6)}} \times 10^6 \qquad \text{Equation 1}$$

where: **$Q_{(exh)}$** = flow rate of air exhausted through the ventilation system (lpm or cfm)

$Q_{(SF6)}$ = flow rate of SF_6 (lpm or cfm) introduced into the system

$C^*_{(SF6)}$ = concentration of SF_6 (parts per million) detected in exhaust. And the * indicates 100% capture of the released SF_6

[To convert from liters per minute (lpm) to cubic feet per minute (cfm), divide lpm by 28.3.]

To quantify capture efficiency, we released the SF_6 through distribution plenums. Each discharge hose fed from the SF_6 regulator, through a mass flow controller and into a T-shaped distribution plenum. Each plenum was approximately 4' wide and designed to release the SF_6 evenly throughout its width. During the capture efficiency test, we placed the discharge plenums within the auger area between the paving tractor and the screed. A known quantity of SF_6 slowly discharged through the plenums into the auger area. A direct-reading analytical instrument measured the concentration of the tracer gas in the exhaust on the discharge side of the control. The capture efficiency was calculated using the following equation:

$$\eta = 100 \times \frac{\dfrac{C_{(SF_6)} \times Q_{(exh)}}{10^6}}{Q_{(SF_6)}} \qquad \text{Equation 2A}$$

where: η = capture efficiency

$C_{(SF6)}$ = concentration of SF_6 (parts per million) detected in exhaust

$Q_{(exh)}$ = flow rate of air exhausted through the ventilation system (lpm or cfm)

$Q_{(SF6)}$ = flow rate of SF_6 (lpm or cfm) introduced into the system

[To convert from liters per minute (lpm) to cubic feet per minute (cfm), divide lpm by 28.3.]

NOTE: When the flow rate of SF_6 [$Q_{(SF6)}$] used to determine the engineering control's capture efficiency is the same as that used to quantify the exhaust flow rate, equation 2A may be simplified to:
where the definitions for $C^*_{(SF6)}$, η, and $C_{(SF6)}$ remain the same as in equations 1 and 2A.

$$\eta = \frac{C_{(SF_6)}}{C^*_{(SF_6)}} \times 100 \qquad \text{Equation 2B}$$

EQUIPMENT

(See Appendix A)

ENGINEERING CONTROL DESIGN DESCRIPTION

Cedarapids engineers had developed three individual hood designs, each using the same exhaust fans and duct system. Each hood design consisted of two half-hoods, one mounted on each side of the augers' drive gear. A centrifugal exhaust fan was attached to each half-hood. The fan specifications were unavailable; however, the fans were originally acquired for use as blowers for the screed heating system. Two 4" diameter flexible ducts carried the exhaust streams from the fans. The flexible ducts attached to a converging tee which fed through a flexible connection into a common plenum. Air from the plenum provided all the intake-air for the tractor's engine. By design, plenum air volume in excess of the engine's requirements would exit the plenum through an eductor exhaust system. This system utilized a venturi attachment on the engine's exhaust to create a negative pressure and thus pull the excess plenum air into the engine's exhaust stream.

Both Design A (Long hood w/cover) and Design B (Long hood w/o cover) used the same long hood system. Each half-hood measured approximately 53" long and 10" wide and was mounted to the back of the tractor, on each side of the auger drive gear assembly. The exhaust fans mounted directly to the top of each half-hood. Each of the half-hoods had a tapered top such that the inner portion of the half-hood had a receiving depth approximately 2-3 times that of the outer portion. On design A, a single rubber cover, similar in appearance to a wide mud flap, was bolted to the rear horizontal edge of both half-hoods. The cover extended away from the hood and over the remaining area between the tractor and the screed to enclose the top of the auger area. The rubber cover measured approximately 110" long, 21" wide, and ½" thick and included a center notch to accommodate the auger drive gear assembly.

Hood Design C (Short hood) consisted of two half-hoods, shorter than the hoods used in designs A or B. Each half-hood measured approximately 31" long x 16 ½" wide and was mounted above the auger area on each side of the auger gear assembly. The short half-hoods were tapered with a receiving depth varying from approximately 5 ½" to ½" as the hood extended away from the tractor. As in the previous designs, the exhaust fans were mounted directly to the top of the short half-hoods.

DATA RESULTS

Smoke Evaluations

The Cedarapids evaluation was the first evaluation under the phase one protocol. Under the original protocol, the smoke test evaluation was to provide two levels of assistance. First, the theatrical smoke was to assist in verifying the integrity of the separation barrier between the testing and exhaust areas. Second, through the addition of handheld aerosol monitors, the theatrical smoke would help to quantify the capture performance of the prototype engineering control.

The initial smoke tests revealed openings in the barrier between the testing and exhaust areas. After resealing the separating barrier, smoke was re-released to identify airflow patterns within the test area and to visually observe the control system's performance. During this stage of the evaluation, we identified positive pressure leaks out of the duct system which were repaired prior to the tracer gas evaluation. Next, we attempted to use the aerosol monitors to quantify the smoke which escaped from the auger area. Concentrations of escaped smoke with the engineering controls on were to be compared with the concentrations measured when the engineering controls were off. However, once the protocol was put into practice, it was clear that the limitations of single point sampling, and the smoke generators' inability to sustain a consistent flow rate, collectively proved this method to be of little value in quantifying the engineering control performance. At this point, the smoke test protocol was revised to only a setup verification and qualitative performance evaluation tool. This information assisted the researchers in performing the quantitative tracer gas evaluation of the engineering control designs. [The protocol in Appendix A is the revised protocol.]

Tracer Gas Evaluation

(A copy of the tracer gas evaluation data files and associated calculations are included in Appendix B).

Indoor Evaluations

All three hood configurations were evaluated under the indoor conditions described above. Exhaust flow experiments were repeated using different SF_6 flow rates ($Q_{(SF6)}$) to increase accuracy. Once an engineering control exhaust flow rate ($Q_{(exh)}$) was determined, the SF_6 was distributed into the auger region for the capture efficiency (η) evaluation. Following this determination, if changes were made to the paver's engine speed, the exhaust flow rate was again determined for comparison purposes.

The evaluations were conducted indoors under semi-controlled conditions. Since building pressure fluctuations and air currents from moving people or equipment could momentarily disrupt the control's airflow characteristics, the results are reported in terms of an average and a range.

DESIGN A: LONG HOOD W/COVER

	$Q_{(SF6)}$	$Q_{(exh)}$ (Range)	$Q_{(exh)}$ (Average)
Exhaust Test #1	0.34 lpm	250 - 258 cfm	253 cfm
Exhaust Test #2	0.64 lpm	249 - 254 cfm	251 cfm

	Q(exh)	η (Range)	η(Average)
Capture Efficiency	251 cfm	47 - 55 %	51 %

DESIGN B: LONG HOOD W/O COVER

	$Q_{(SF6)}$	$Q_{(exh)}$ (Range)	$Q_{(exh)}$ (Average)
Exhaust Test #1	0.34 lpm	244 - 246 cfm	245 cfm
Exhaust Test #2	0.64 lpm	245 - 249 cfm	246 cfm
Exhaust Test #3	0.64 lpm	246 - 251 cfm	248 cfm

	Q(exh)	η(Range)	η(Average)
Capture Efficiency	246 cfm	01 - 32 %	07 %

DESIGN C: SHORT HOOD

	$Q_{(SF6)}$	$Q_{(exh)}$ (Range)	$Q_{(exh)}$ (Average)
Exhaust Test #1	0.34 lpm	253 - 254 cfm	253 cfm
Exhaust Test #2	0.64 lpm	251 - 255 cfm	252 cfm
Exhaust Test #3	0.64 lpm	234 - 248 cfm	242 cfm

	$Q_{(exh)}$	η (Range)	η (Average)
Capture Efficiency	252 cfm	19 - 48 %	31 %

Outdoor Evaluations

Since Design A (Long Hood W/Cover) performed best under the laboratory testing scenario, this design was selected for the outdoor evaluation. The outdoor evaluation occurred in an open parking area. Two paver orientations, one pointed with the wind and another pointed into the wind were evaluated. Wind gusts were estimated between 5-15 miles per hour.

LONG HOOD W/COVER, OUTDOOR EVALUATION: ORIENTED WITH THE WIND

	$Q_{(SF6)}$	$Q_{(exh)}$ (Range)	$Q_{(exh)}$ (Average)
Exhaust Test #1	0.35 lpm	261 - 269 cfm	264 cfm
Exhaust Test #2	0.69 lpm	277 - 279 cfm	278 cfm

	$Q_{(exh)}$	η (Range)	η (Average)
Capture Efficiency	278 cfm	14 - 57 %	31 %

LONG HOOD W/COVER, OUTDOOR EVALUATION: ORIENTED INTO THE WIND

	$Q^*_{(exh)}$	η (Range)	η (Average)
Capture Efficiency	278 cfm	25 - 55 %	39 %

* **Note**: The $\mathbf{Q_{(exh)}}$ used for this set of efficiency calculations is the same as that measured during the "with the wind" calculations. Since the engine idle speed may have changed after reorienting the paver and thus affected the control's exhaust flow rate, the ideal approach would have been to re-determine the $\mathbf{Q_{(exh)}}$ under the new orientation. Due to an oversight, this was not done.

DATA ANALYSIS

Test results from the Cedarapids engineering control evaluations confirm the fundamental ventilation control design theories previously described. All of the controls used the same exhaust system over the same process. However, the resulting capture efficiencies were quite different. A comparison of Designs B (long hood w/o cover) and C (short hood) reveals that while both hoods cover roughly the same amount of area above the auger (when looked at from above, as in a plan view), much of the hood in Design B had little or no receiving depth and there was no evidence of a capture velocity near the outer edges of Design B's hood face. A comparison of capture efficiencies shows that Design C was much more efficient (31% vs. 07%) at controlling the surrogate contaminant (SF_6) during the controlled evaluation. However, Design A (long hood w/cover), which uses the Design B hood plus the additional process enclosure, sufficiently increased the capture efficiency to outperform Design C (51% vs. 31%).

Achieving a high average capture efficiency is only part of the ventilation control design approach. Another consideration is the control's ability to maintain high capture efficiencies without performance levels fluctuating over a wide range. Each excursion into the poor capture efficiency range represents an opportunity for contaminant to escape into a worker's breathing zone. Empirically, the performance can be evaluated by comparing the sampling data coefficients of variation (CV=100 x (standard deviation divided by the mean)) in addition to the mean capture efficiency. Controls with smaller CV's were less subject to outside interferences and maintained more consistent capture efficiencies. The calculated CV's for both exhaust flow rate and capture efficiency evaluations are shown in Appendix B.

Data analysis and comparison reveal that Design A, Long Hood w/Cover, outperformed Designs B and C in terms of both mean capture efficiency and consistent performance. However, when evaluated in the outdoor environment, Design A's average capture efficiency dropped by as much as 20 percent (from 51 percent-indoors to 31 percent-outdoors oriented with the wind) and the CV increased from 6 percent up to 45 percent.

CONCLUSIONS AND RECOMMENDATIONS

Based on the evaluation results comparing the three prototype designs, we recommend Design A as your starting design from which to improve performance. General recommendations for further improvement of Design A include:

Enclosure

In general, Design A maintains fairly good enclosure over the width of the auger. Any additional enclosure techniques, especially above the ends of the auger and the screed extension areas, could greatly increase the ventilation control's resistance to cross-draft disturbances. Hinged cover plates manufactured from clear or partially-perforated material may allow for increased enclosure without eliminating the screed operators line of sight into the auger area.

Hood Design

The current Design A hood functions more as an extended flange as opposed to a large hood. An alternative design which evenly distributes exhaust airflow across the hood's face area will increase protection across the full length of the auger area instead of just below the two exhaust fans. This can be achieved through the use of a slot hood or similar plenum-type exhaust configuration or through the use of additional exhaust sources above the hood.

Ventilation Exhaust Flow Rate

The ACGIH Industrial Ventilation Manual provides guidance to facilitate the selection of minimum capture velocities. Additionally, we can assist in selecting a capture velocity based upon your intended control design. At a minimum, given the physical properties of the asphalt fume, the vapor contaminants, and the process by which they are generated, we recommend a minimum design capture velocity of 100' per minute throughout the entire auger area. This recommendation assumes very good enclosure to minimize wind interference during paving operations. Based upon the selected hood design and the dimensions of the auger area, this velocity will be incorporated into the design calculations to determine a minimum exhaust flow rate requirement. There is some concern regarding convective currents and the generated volume of rising air induced above the hot paving process. However, adequate process enclosure plus an appropriately selected capture velocity will produce a sufficient exhaust flow rate to control and remove this convective exhaust volume. Additional information on controlling contaminants from hot processes may also be found in the ACGIH Ventilation Manual.

Exhaust System Design

The existing exhaust system (exhaust fans, engine intake, and exhaust eductor system) in Design A was incompatible with the exhaust requirements of a properly operating ventilation control. Once the exhaust fans are correctly sized and selected, there must be an exhaust path designed within the performance capacity of the selected fans. If you still want to use the engine's air-intake to process some of the ventilation control's exhaust air, you should determine its capacity requirements at typical operating loads and supply exhaust air to meet that requirement. If the eductor system is still desired, you may consider relocating the intake to this system so that it does not have to compete with the engine air intake. Possible alternatives include ducting one or both of the exhaust streams directly to the atmosphere or perhaps letting one exhaust fan serve the eductor while the other serves the engine's air intake (bypass options may be required depending upon the paired volumetric handling capacities). Regardless of the selected exhaust route, it should be compatible with the volume and static pressure limitations of the exhaust fans and the exhaust should exit the system away from the workers' breathing zones.

ACKNOWLEDGMENTS

We would like to thank the Cedarapids management and staff for their gracious hospitality and assistance during our visit to the Cedarapids facility. Their commitment to the design and implementation of engineering controls to reduce occupational exposures is an admirable pledge.

APPENDIX A

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

PHASE ONE (LABORATORY) EVALUATION PROTOCOL

PURPOSE: To evaluate the efficiency of ventilation engineering controls used on highway-class hot mix asphalt (HMA) pavers in an indoor stationary environment.

SCOPE OF USE: This test procedure was developed to aid the HMA industry in the development and evaluation of prototype ventilation engineering controls with an ultimate goal of reducing worker exposures to asphalt fumes. This test procedure is a first step in evaluating the capture efficiency of paver ventilation systems and is conducted in a controlled environment. The test is not meant to simulate actual paving conditions. The data generated using this test procedure have not been correlated to exposure reductions during actual paving operations.

For the laboratory evaluation, we will conduct a two-part experiment where the surrogate "contaminant" is injected into the auger region behind the tractor and in front of the screed. For part A of the evaluation, smoke from a smoke generator is the surrogate contaminant. For part B, the surrogate contaminant is sulfur hexafluoride, an inert and relatively safe (when properly used) gas, commonly used in tracer gas studies.

SAFETY: In addition to following the safety procedures established by the host facility the following concerns should be addressed at each testing site:

1. The discharge of the smoke generating equipment can be hot and should not be handled with unprotected hands.
2. The host may want to contact building and local fire officials in order that the smoke generators do not set off fire sprinklers or create a false alarm.
3. In higher concentrations, smoke generated from the smoke generators may act as an irritant. Direct inhalation of smoke from the smoke generators should be avoided.
4. All compressed gas cylinders should be transported, handled, and stored in accordance with the safety recommendations of the Compressed Gas Association.
5. The Threshold Limit Value for sulfur hexafluoride is 1000 ppm. While the generated concentrations will be below this level, the concentration in the cylinder is near 100 percent. For this reason, the compressed cylinder will be maintained outdoors whenever possible. Should a regulator malfunction or some other major accidental release occur, observers should stand back and let the tank pressure come to equilibrium with the ambient environment.

<u>Laboratory Setup</u>: The following laboratory setup description is based on our understanding of the facilities available at the asphalt paving manufacturing facilities participating in the study. The laboratory evaluation protocol may vary slightly from location to location depending upon the available facilities.

<u>Paver Position</u>: The paving tractor, with screed attached, will be parked underneath an overhead garage door such that both the tractor exhaust and the exhaust from the engineering controls exits into the ambient air. The garage door will be lowered to rest on top of the tractor and plastic or an alternative barrier will be applied around the perimeter of the tractor to seal the remainder of the garage door opening.

Laboratory Ventilation Exhaust: For this evaluation, smoke generated from Rosco Smoke Generators (Rosco, Port Chester, NY) is released into a perforated plenum and dispersed in a quasi-uniform distribution along the length of the augers. Due to interferences created by the auger's gear box, this evaluation may require a separate smoke generator and distribution plenum on each side of the auger region. Releasing theatrical smoke as a surrogate contaminant within the auger region provides excellent qualitative information concerning the engineering control's performance. Areas of diminished control performance are easily determined and minor modifications can be incorporated into the design prior to quantifying the control performance. Additionally, the theatrical smoke helps to verify the barrier integrity separating the front and rear halves of the asphalt paver. A video camera will be used to record the evaluation. The sequence from a typical test run is outlined below:

1. Position paving equipment within door opening and lower overhead door.
2. Seal the remaining door opening around the tractor.
3. Place the smoke distribution tube(s) directly underneath the auger.
4. Connect the smoke generator(s) to the distribution tube(s).
5. Activate video camera, the engineering controls and the smoke generator(s).
6. Inspect the separating barrier for integrity failures and correct as required.
7. Inspect the engineering control and exhaust system for unintended leaks.
8. De-activate the engineering controls for comparison purposes.
9. De-activate smoke generators and wait for smoke levels to subside.
10. End the smoke test evaluation.

Evaluation Part B (Tracer Gas): The tracer gas test is designed to: (1) calculate the total exhaust flow rate of the paver ventilation control system; and (2) evaluate the effectiveness in capturing and controlling a surrogate contaminant under a "controlled" indoor conditions. SF_6 will be used as the surrogate contaminant.

Quantify Exhaust Volume: To determine the total exhaust flow rate of the engineering control, a known quantity of sulfur hexafluoride (SF_6) is released directly into the engineering control's exhaust hood, thus creating a 100 percent capture condition. The SF_6 release is controlled by two Tylan Mass Flow controllers (Tylan, Inc., San Diego, CA). Initially, the test will be performed with using a single flow controller calibrated at 0.35 lpm. A hole drilled into the engineering control's exhaust duct allows access for a multi-point monitoring wand into the exhaust stream. The monitoring wand is oriented such that the perforations are perpendicular to the moving air stream. A sample tube connects the wand to a Bruel & Kjaer (B&K) Model 1302 Photo acoustic Infra-red Multi-gas Monitor (California Analytical Instruments, Inc., Orange, CA) positioned on the exterior side of the overhead door. The gas monitor analyzes the air sample and records the concentration of SF_6 within the exhaust stream. The B&K 1302 will be programmed to repeat this analysis approximately once every 30 seconds. Monitoring will continue until we approximate steady-state conditions are achieved. The mean concentration of SF_6 measured in the exhaust stream will be used to calculate the total exhaust flow rate of the engineering control. The equation for determining the exhaust flow rate is:

$$Q_{(exh)} = \frac{Q_{(SF_6)}}{C^*_{(SF_6)}} \times 10^6 \qquad \text{Equation 1}$$

where: $\mathbf{Q_{(exh)}}$ = flow rate of air exhausted through the ventilation system (lpm or cfm)

$\mathbf{Q_{(SF6)}}$ = flow rate of SF_6 (lpm or cfm) introduced into the system

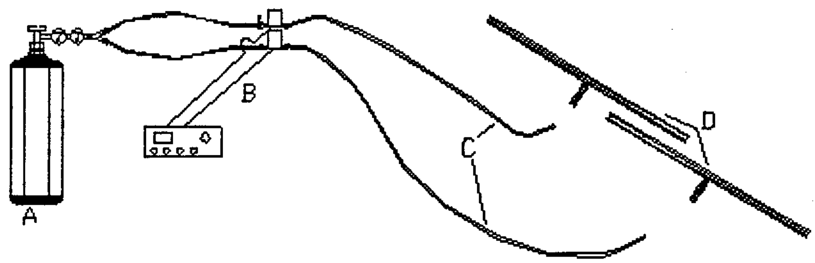
$\mathbf{C^*_{(SF6)}}$ = concentration of SF_6 (parts per million) detected in exhaust

[To convert from liters per minute (lpm) to cubic feet per minute (cfm), divide lpm by 28.3.]

In order to increase accuracy, the exhaust flow rate will be calculated a second time using two mass flow controllers, each calibrated at approximately 0.35 lpm of SF_6. Sufficient time will be allowed between all test runs to allow area concentrations to decay below 0.1 ppm before starting subsequent test runs.

Quantitative Capture Efficiency: The test procedure to determine capture efficiency is slightly different than the exhaust volume procedure. The mass flow controllers will each be calibrated for a flow rate approximating 0.35 liters per minute (lpm) of 99.8 percent SF_6. The discharge tubes from the mass flow controllers will each feed a separate distribution plenum, one per side, within the paver's auger area. The distribution plenums are designed to distribute the SF_6 in a uniform pattern along the length of the auger area. (See Figure 1) The B&K multi-gas monitor analyzes the air sample and records the concentration of SF_6 within the exhaust stream until approximate steady-state conditions develop. Once this occurs, the SF_6 source will be discontinued and the decay concentration of SF_6 within the exhaust stream will be monitored to indicate the extent in which general area concentrations of non-captured SF_6 contributed to the concentration measured in the exhaust stream.

FIGURE 1



LEGEND

A–Trocer Gos Cylinder with regulotor
B–Tylon Moss Flow Controllers with Control Box
C–PTFE Distribution Tubes
D–Trocer Gos Distribution Plenums

A capture efficiency can be calculated for the control using the following equation:

$$\eta = 100 \times \frac{\dfrac{C_{(SF_6)} \times Q_{(exh)}}{10^6}}{Q_{(SF_6)}} \qquad \text{Equation 2A}$$

where: $\boldsymbol{\eta}$ = capture efficiency

$\mathbf{C_{(SF6)}}$ = concentration of SF_6 (parts per million) detected in exhaust

$\mathbf{Q_{(exh)}}$ = flow rate of air exhausted through the ventilation system (lpm or cfm)

$\mathbf{Q_{(SF6)}}$ = flow rate of SF_6 (lpm or cfm) introduced into the system

[To convert from liters per minute (lpm) to cubic feet per minute (cfm), divide lpm by 28.3.]

NOTE: When the flow rate of SF_6 [$Q_{(SF6)}$] used to determine the engineering control's capture efficiency is the same as that used to quantify the exhaust flow rate, equation 2A may be simplified to:

$$\eta = \frac{C_{(SF_6)}}{C^*_{(SF_6)}} \times 100 \qquad \text{Equation 2B}$$

where the definitions for $C^*_{(SF6)}$, η, and $C_{(SF6)}$ remain the same as in equations 1 and 2A.

The sequence from a typical test run is outlined below:

1. Position paving equipment and seal openings as outlined above.
2. Calibrate (outdoors) both mass flow meters at approximately 0.35 lpm of SF_6.
3. Drill an access hole in the engineering control's exhaust duct on the outdoor side of the overhead door and position the sampling wand into the hole.
4. While maintaining the SF_6 tanks outdoors, run the discharge hoses from the mass flow meters to well-within the exhaust hood(s) to create 100 percent capture conditions.
5. With the engineering controls activated, begin monitoring with the B&K 1302 to determine background interference levels.
6. Initiate flow of SF_6 through a single mass flow meter.
7. Continue monitoring with the B&K for five minutes or until three repetitive readings are recorded.
8. Deactivate flow of the SF_6 and calculate exhaust flow rate using the calculation identified above.
9. Repeat steps #2 through #8 using both mass flow controllers.
10. Allow engineering control exhaust system to continue running until SF_6 has ceased leaking from the discharge hoses then remove the hoses from the hoods.
11. End the exhaust flow rate test.
12. Locate an SF_6 distribution plenum on each side of the auger area and connect each plenum to the discharge hose of a mass flow meter.
13. Initiate B&K monitoring to establish background interference levels until levels reach 0.1 ppm or below.
14. Initiate SF_6 flow through the mass flow meters and monitor with the B&K until approximate steady state conditions appear.
15. Once steady state is achieved, discontinue SF_6 flow and quickly remove the distribution plenums and discharge hoses from the auger area.
16. Continue monitoring with the B&K to determine the general area concentration of SF_6 which escaped auger area into the laboratory area.
17. Discontinue B&K monitoring when concentration decay is complete.
18. Calculate the capture efficiency.
19. Repeat steps 11 - 17 as time permits.

APPENDIX B

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

TRACER GAS EVALUATION RESULTS

B&K DATA FILES AND CALCULATION RESULTS

Calculations From Data Sheet 1: Short Hood

Comment	SF6 (ppm)	SF6 Flow	Q exh					
1st Q exh ave	47.44	0.34	253.25	cfm		SF6 Flow	0.34	lpm
Low Range	47.55	0.34	252.66	cfm		Average	47.44	ppm
High Range	47.22	0.34	254.44	cfm		Std. Dev.	0.14	
						CV	0.00	
2nd Q exh ave	89.64	0.64	251.89	cfm		SF6 Flow	0.64	lpm
Low Range	89.99	0.64	250.91	cfm		Average	89.64	ppm
High Range	88.44	0.64	255.32	cfm		Std. Dev.	0.60	
						CV	0.01	
3rd Q exh ave	93.32	0.64	241.95	cfm		SF6 Flow	0.64	lpm
Low Range	96.32	0.64	234.41	cfm		Average	93.32	ppm
High Range	91.10	0.64	247.85	cfm		Std. Dev.	2.59	
						CV	0.03	
Comment	**SF6 (ppm)**	**SF6 Flow**	**Qexh**	**Capture Efficiency**				
Average Capture	28.05	0.64	251.89	31%		SF6 Flow	0.64	lpm
Low Range	17.44	0.64	251.89	19%		Average	28.05	ppm
High Range	43.33	0.64	251.89	48%		Std. Dev.	7.33	
						CV	0.26	

Calculations From Data Sheet 2: Long Hood w/o Cover

Comment	SF6 (ppm)	SF6 Flow	Q exh					
1st Q exh ave	48.98	0.34	245.30	cfm		SF6 Flow	0.34	lpm
Low Range	49.22	0.34	244.09	cfm		Average	48.98	ppm
High Range	48.88	0.34	245.77	cfm		Std. Dev.	0.13	
						CV	0.00	
2nd Q exh ave	91.64	0.64	246.40	cfm		SF6 Flow	0.64	lpm
Low Range	92.32	0.64	244.57	cfm		Average	91.64	ppm
High Range	90.55	0.64	249.37	cfm		Std. Dev.	0.61	
						CV	0.01	
3rd Q exh ave	90.99	0.64	248.15	cfm		SF6 Flow	0.64	lpm
Low Range	91.99	0.64	245.45	cfm		Average	90.99	ppm
High Range	89.88	0.64	251.22	cfm		Std. dev.	0.89	
						CV	0.01	
Comment	**SF6 (ppm)**	**SF6 Flow**	**Qexh**	**Capture Efficiency**				
Average Capture	6.86	0.64	246.40	7%		SF6 Flow	0.64	lpm
Low Range	0.74	0.64	246.40	1%		Average	6.86	ppm
High Range	29.44	0.64	246.40	32%		Std. dev.	7.20	
						CV	1.05	

Calculations From Data Sheet 3: Long Hood w/Cover

Comment	SF6 (ppm)	SF6 Flow	Q exh					
1st Q exh ave	47.55	0.34	252.66	cfm		SF6 Flow	0.34	lpm
Low Range	48.11	0.34	249.74	cfm		Average	47.55	ppm
High Range	46.66	0.34	257.47	cfm		Std. Dev.	0.63	
						CV	0.01	
2nd Q exh ave	89.95	0.64	251.03	cfm		SF6 Flow	0.64	lpm
Low Range	90.66	0.64	249.06	cfm		Average	89.95	ppm
High Range	88.99	0.64	253.73	cfm		Std. Dev.	0.67	
						CV	0.01	
Comment	**SF6 (ppm)**	**SF6 Flow**	**Qexh**	**Capture Efficiency**				
Average Capture	46.13	0.64	251.03	51%		SF6 Flow	0.64	lpm
Low Range	42.55	0.64	251.03	47%		Average	46.13	ppm
High Range	49.22	0.64	251.03	55%		Std. dev.	2.90	
						CV	0.06	

Calculations From Data Sheet 4: Long Hood w/Cover (Outside W/Wind)								
Comment	**SF6 (ppm)**	**SF6 Flow**	**Q exh**					
1st Q exh ave	46.46	0.35	263.92	cfm		SF6 Flow	0.35	lpm
Low Range	47.00	0.35	260.91	cfm		Average	46.46	ppm
High Range	45.55	0.35	269.18	cfm		Std. Dev	0.51	
						CV	0.01	
2nd Q exh ave	88.01	0.69	277.84	cfm		SF6 Flow	0.69	lpm
Low Range	87.77	0.69	278.60	cfm		Average	88.01	ppm
High Range	88.20	0.69	277.24	cfm		Std. Dev	0.15	
						CV	0.00	
Comment	**SF6 (ppm)**	**SF6 Flow**	**Qexh**	**Capture Efficiency**				
Average Capture	27.65	0.69	277.84	31%		SF6 Flow	0.69	lpm
Low Range	12.44	0.69	277.84	14%		Average	27.65	ppm
High Range	50.44	0.69	277.84	57%		Std. Dev.	12.45	
						CV	0.45	
Calculations From Data Sheet 5: Long Hood w/Cover (Outside/Into Wind)								
Comment	**SF6 (ppm)**	**SF6 Flow**	**Q exh**					
Note: (We probably should have re-measured the Q exhaust flow after reorienting the paver due to possibility of resetting paver's rpm and thus affecting the exhaust flow. Use Q exh calculated from previous test run).								
Comment	**SF6 (ppm)**	**SF6 Flow**	**Qexh**	**Capture Efficiency**				
Average Capture	34.43	0.69	277.84	39%		SF6 Flow	0.69	lpm
Low Range	22.11	0.69	277.84	25%		Average	34.43	ppm
High Range	48.44	0.69	277.84	55%		Std. Dev.	7.22	
						CV	0.21	

Short Hood Evaluation

1302.00	Measurement	Data	-------	1788611/2803		-	1995-04-2	13:14	
1302.00	Settings:								
Compensate	for	Water	Vap.	Interference		:	no		
Compensate	for	Cross	Interference			:	no		
Sample	Continuously					:	yes		
Pre-set	Monitoring	Period				:	no		
Measure									
Gas	A:	Sulfur	hexafluoride			:	yes		
Water	Vapour					:	no		
Sampling	Tube	Length	15.00	ft					
Air	Pressure		760.00	mmHg					
Normalization	Temperature		70.00	F					
General	Information:								
Start	Time	1995-04-27	11:40						
Stop	Time	1995-04-27	13:05						
Results	Not	Averaged							
Gas	A:								
1302.00	Measurement	Data	1788611/2803	-	1995-04-27		13:14		
Samples	Measured	From	1995-04-27	11:41					
Samp.		Time		Gas A	Calibration		Comments		
No.		hh:mm:ss		ppm	correction				
1.00		11:41:11		4.41E-02	0.04		Background		
2.00		11:41:54		4.55E-02	0.05				
3.00		11:42:30		4.73E-02	0.05				
4.00		11:43:05		4.56E-02	0.05				
5.00		11:43:40		5.78E-02	0.06				
6.00		11:44:16		3.90E-02	0.04				
7.00		11:44:51		3.11E-02	0.03				
		11:44:51		Event 1			Start SF6 @ 0.340 lpm		
							SF6 tube is in exhaust hood.		
							Leak test around exhaust hood fitting.		
8.00		11:45:27		1.81E+00	1.81				
9.00		11:46:02		5.55E+00	5.55				
10.00		11:46:40		4.20E+00	4.20				
11.00		11:47:15		1.86E+00	1.86				
12.00		11:47:53		1.07E+00	1.07				
13.00		11:48:39		3.95E-02	0.04				
		11:48:39		Event 2			Moving B&K Sample inlet into		
							control's exhaust plenum		
14.00		11:49:15		2.36E-01	0.24		(ignore: probe not in place)		
15.00		11:49:50		4.38E+01	47.55				
16.00		11:50:30		4.38E+01	47.55				
17.00		11:51:06		4.36E+01	47.33				
18.00		11:51:41		4.35E+01	47.22		SF6 Flow	0.34	lpm
19.00		11:52:17		4.37E+01	47.44		Average	47.44	ppm
20.00		11:52:52		4.38E+01	47.55		Std. Dev.	0.14	
		11:53:27		Event 3			Start SF6 @ 0.639 lpm		
							SF6 outlet tubes are both in hoods.		
21.00		11:53:27		8.06E+01	88.44				
22.00		11:54:03		8.19E+01	89.88				
23.00		11:54:38		8.20E+01	89.99				
24.00		11:55:14		8.20E+01	89.99		SF6 Flow	0.64	lpm
25.00		11:55:49		8.18E+01	89.77		Average	89.64	ppm
26.00		11:56:25		8.18E+01	89.77		Std. Dev.	0.60	

		11:57:00		Event 4		Check room background.			
27.00		11:57:00		4.03E-01	0.40				
28.00		11:57:41		8.59E-02	0.09				
		11:58:16		Event 5		Check for leaks around exhaust fittings.			
29.00		11:58:16		5.22E-02	0.05				
30.00		11:59:22		1.50E+00	1.50				
31.00		11:59:58		4.17E-01	0.42				
		12:00:33		Event 6		Turn SF6 off and check velocity pressures.			
32.00		12:00:33		4.66E+00	4.66		Background Readings		
33.00		12:01:11		2.53E-01	0.25		"		
34.00		12:01:49		4.02E-02	0.04		"		
35.00		12:02:25		3.27E-02	0.03		"		
36.00		12:03:00		3.40E-02	0.03		"		
37.00		12:03:36		3.33E-02	0.03		"		
38.00		12:04:11		3.80E-02	0.04		"		
39.00		12:04:46		2.40E-02	0.02		"		
40.00		12:05:22		3.66E-02	0.04		"		
41.00		12:05:57		3.38E-02	0.03		"		
42.00		12:06:33		3.18E-02	0.03		"		
43.00		12:07:08		2.36E-02	0.02		"		
44.00		12:07:44		2.76E-02	0.03		"		
45.00		12:08:19		3.51E-02	0.04		"		
46.00		12:09:14		2.73E-02	0.03		"		
47.00		12:09:49		3.14E-02	0.03		"		
48.00		12:10:25		2.62E-02	0.03		"		
49.00		12:11:00		2.39E-02	0.02		"		
50.00		12:11:36		3.15E-02	0.03		"		
51.00		12:12:11		3.09E-02	0.03		"		
52.00		12:12:46		2.60E-02	0.03		"		
53.00		12:13:22		2.40E-02	0.02		"		
54.00		12:13:57		2.62E-02	0.03		"		
55.00		12:14:33		3.04E-02	0.03		"		
56.00		12:15:08		2.09E-02	0.02		"		
57.00		12:15:43		2.65E-02	0.03		"		
58.00		12:16:19		3.02E-02	0.03		"		
59.00		12:16:54		2.53E-02	0.03		"		
60.00		12:17:30		2.90E-02	0.03		"		
61.00		12:18:05		2.95E-02	0.03		"		
62.00		12:18:52		2.75E-02	0.03		"		
63.00		12:19:27		2.44E-02	0.02		"		
64.00		12:20:02		2.84E-02	0.03		"		
65.00		12:20:37		2.50E-02	0.03		"		
66.00		12:21:13		2.05E-02	0.02		"		
67.00		12:21:48		2.67E-02	0.03		"		
68.00		12:22:24		2.28E-02	0.02		"		
69.00		12:22:59		2.09E-02	0.02		"		
70.00		12:23:34		2.57E-02	0.03		"		
71.00		12:24:10		2.43E-02	0.02		"		
72.00		12:24:45		2.32E-02	0.02		"		
73.00		12:25:21		2.19E-02	0.02		"		
74.00		12:25:56		1.97E-02	0.02		"		
75.00		12:26:31		2.28E-02	0.02		"		
76.00		12:27:07		2.24E-02	0.02		"		
77.00		12:27:42		2.76E-02	0.03		"		
78.00		12:28:18		2.39E-02	0.02		"		
79.00		12:29:24		2.30E-02	0.02		"		
80.00		12:29:59		2.65E-02	0.03		"		
81.00		12:30:35		2.39E-02	0.02		"		
82.00		12:31:10		1.89E-02	0.02		"		
83.00		12:31:46		2.61E-02	0.03		"		
84.00		12:32:21		2.57E-02	0.03		"		
85.00		12:32:57		2.96E-02	0.03		"		
86.00		12:33:32		2.41E-02	0.02		"		
87.00		12:34:07		1.56E-02	0.02		"		
88.00		12:34:43		2.58E-02	0.03		"		
89.00		12:35:18		2.29E-02	0.02		"		

90.00	12:35:53	2.18E-02	0.02		"		
91.00	12:36:29	2.29E-02	0.02		"		
92.00	12:37:04	2.50E-02	0.03		"		
93.00	12:37:40	2.27E-02	0.02		"		
94.00	12:38:15	2.67E-02	0.03		"		
95.00	12:39:10	2.44E-02	0.02		"		
96.00	12:39:45	2.62E-02	0.03		"		
97.00	12:40:21	2.67E-02	0.03		"		
98.00	12:40:56	3.03E-02	0.03		"		
99.00	12:41:32	2.76E-02	0.03		"		
100.00	12:42:07	2.35E-02	0.02		"		
101.00	12:42:42	2.32E-02	0.02		"		
102.00	12:43:18	2.40E-02	0.02		"		
103.00	12:43:53	2.23E-02	0.02		"		
104.00	12:44:29	1.75E-02	0.02		"		
105.00	12:45:04	2.07E-02	0.02		"		
106.00	12:45:39	2.39E-02	0.02		"		
107.00	12:46:15	1.93E-02	0.02		"		
108.00	12:46:50	2.40E-02	0.02		"		
109.00	12:47:26	2.47E-02	0.02		"		
110.00	12:48:01	2.67E-02	0.03		"		
	12:48:47	Event 7		Place SF6 outlets into distribution tubing.			
111.00	12:48:47	2.82E-02	0.03				
112.00	12:49:23	3.74E-02	0.04				
113.00	12:49:59	3.29E-02	0.03				
114.00	12:50:34	3.68E-02	0.04				
	12:50:34	Event 8		Start SF6 through distribution tubes.			
				SF6 flow	0.639 lpm		
115.00	12:51:09	3.40E+00	3.40	(ignore: transition measurement)			
116.00	12:51:47	2.45E+01	26.11				
117.00	12:52:23	1.92E+01	20.22				
118.00	12:52:58	2.43E+01	25.89				
119.00	12:53:34	2.89E+01	31.00				
120.00	12:54:11	4.00E+01	43.33				
121.00	12:54:47	1.91E+01	20.11				
122.00	12:55:25	1.67E+01	17.44				
123.00	12:56:00	2.63E+01	28.11				
124.00	12:56:38	2.98E+01	32.00	SF6 Flow	0.64	lpm	
125.00	12:57:13	3.06E+01	32.89	Average	28.05	ppm	
126.00	12:57:49	2.93E+01	31.44	Std. Dev.	7.33		
	12:57:49	Event 9		Moving SF6 outlets into hoods			
127.00	12:58:55	8.77E+01	96.32				
128.00	12:59:31	8.62E+01	94.66	SF6 Flow	0.64	lpm	
129.00	13:00:06	8.31E+01	91.21	Average	93.32	ppm	
130.00	13:00:42	8.30E+01	91.10	Std. Dev.	2.59		
	13:01:17	Event 10		Stop SF6 and test SF6			
				background levels near screed.			
131.00	13:01:17	3.99E-01	0.40				
132.00	13:01:57	7.93E-02	0.08				
133.00	13:02:33	4.80E-02	0.05				
134.00	13:03:08	4.40E-02	0.04				
135.00	13:03:43	3.81E-02	0.04				
136.00	13:04:19	3.27E-02	0.03				
137.00	13:04:54	3.18E-02	0.03				
Comments:	**Short wide hood only.**						

LONG HOOD W/O COVER

1302.00	Measure	Data	-------	1788611/2803	-		1995-04-2	15:56		
1302.00	Settings:									
Compens	for	Water	Vap.	Interference		:	NO			
Compens	for	Cross	Interference			:	NO			
Sample	Continuously					:	YES			
Pre-set	Monitorin	Period				:	NO			
Measure										
Gas	A:	Sulfur	hexafluoride			:	YES			
Water	Vapour					:	NO			
Sampling	Tube	Length	15.00	ft						
Air	Pressure		760.00	mmHg						
Normaliza	Temperature		72.00	F						
General	Information:									
Start	Time	1995-04-2	15:11							
Stop	Time	1995-04-2	15:51							
Results	Not	Averaged								
Gas	A:									
1302.00	Measure	Data	-------	1788611/2803			1995-04-2	15:56		
Samples	Measured	From	1995-04-2	15:11						
Samp.		Time		Gas A	Calibration			Comments		
No.		hh:mm:ss		ppm	correction					
1.00		15:11:59		2.60E-02	0.03		Begin Background Readings			
2.00		15:12:42		2.53E-02	0.03					
3.00		15:13:17		2.75E-02	0.03					
4.00		15:13:52		2.52E-02	0.03					
5.00		15:14:39		3.46E-02	0.03					
6.00		15:15:14		5.36E-02	0.05					
7.00		15:15:49		3.67E-02	0.04		Average	3.33E-02		
8.00		15:16:25		3.78E-02	0.04		Std. Dev.	0.01		
		15:16:25		Event 1			Start SF6 @ 0.340 lpm			
							Outlet of SF6 in in exhaust hood.			
9.00		15:17:00		9.34E+01	102.66		(ignore: initial flow surge)			
10.00		15:17:41		4.53E+01	49.22					
11.00		15:18:16		4.50E+01	48.88					
12.00		15:18:51		4.50E+01	48.88					
13.00		15:19:27		4.51E+01	49.00		SF6 Flow	0.34	lpm	
14.00		15:20:02		4.50E+01	48.88		Average	48.98	ppm	
15.00		15:20:37		4.51E+01	49.00		Std. Dev.	0.13		
		15:20:37		Event 2			Start SF6 @ 0.639 lpm			
							SF6 Outlets are both in hoods.			
16.00		15:21:13		8.25E+01	90.55					
17.00		15:21:49		8.41E+01	92.32					
18.00		15:22:24		8.37E+01	91.88					
19.00		15:22:59		8.38E+01	91.99		SF6 Flow	0.64	lpm	
20.00		15:23:35		8.34E+01	91.55		Average	91.64	ppm	
21.00		15:24:10		8.34E+01	91.55		Std. Dev.	0.61		
		15:24:10		Event 3			Place SF6 outlets into distribution tubing.			
22.00		15:25:17		3.41E+00	3.41					
23.00		15:25:55		2.30E+00	2.30					
24.00		15:26:30		1.11E+01	11.22					
25.00		15:27:06		1.86E+01	19.55					
26.00		15:27:41		3.59E+00	3.59					
27.00		15:28:17		1.16E+01	11.78					
28.00		15:28:52		2.70E+00	2.70					
29.00		15:29:27		2.69E+00	2.69					
30.00		15:30:03		1.12E+01	11.33					

31.00	15:30:38	2.75E+01	29.44				
32.00	15:31:16	2.41E+00	2.41				
33.00	15:31:54	3.72E+00	3.72				
34.00	15:32:29	2.65E+00	2.65				
35.00	15:33:05	1.14E+01	11.55				
36.00	15:33:40	3.18E+00	3.18				
37.00	15:34:16	1.13E+00	1.13				
38.00	15:35:13	4.19E+00	4.19				
39.00	15:35:50	7.35E-01	0.74	SF6 Flow	0.64	lpm	
40.00	15:36:28	6.20E+00	6.20	Average	6.86	ppm	
41.00	15:37:06	3.47E+00	3.47	Std. dev.	7.20		
	15:37:06	Event 4		Place SF6 @ 0.639 back into hoods.			
42.00	15:37:42	5.30E+01	57.77	(ignore: transition measurement)			
43.00	15:38:20	8.38E+01	91.99				
44.00	15:38:55	8.32E+01	91.32	SF6 Flow	0.64	lpm	
45.00	15:39:30	8.27E+01	90.77	Average	90.99	ppm	
46.00	15:40:06	8.19E+01	89.88	Std. dev.	0.89		
	15:40:06	Event 5		Stop SF6 and allow to bleed off system.			
				Detector inlet in screed area.			
47.00	15:40:41	6.88E-01	0.69	(ignore: bleed off)			
48.00	15:41:22	8.23E-02	0.08				
49.00	15:41:57	5.70E-02	0.06				
50.00	15:42:32	6.00E-02	0.06				
51.00	15:43:08	5.14E-02	0.05				
52.00	15:43:43	4.61E-02	0.05				
53.00	15:44:19	4.16E-02	0.04				
54.00	15:45:05	3.46E-02	0.03				
55.00	15:45:40	3.64E-02	0.04				
56.00	15:46:15	3.17E-02	0.03				
57.00	15:46:51	3.56E-02	0.04		Screed area		
58.00	15:47:26	3.53E-02	0.04		Background readings		
59.00	15:48:02	3.31E-02	0.03				
60.00	15:48:37	3.78E-02	0.04				
61.00	15:49:12	3.56E-02	0.04				
62.00	15:49:48	3.53E-02	0.04				
63.00	15:50:23	3.95E-02	0.04				
64.00	15:50:59	3.30E-02	0.03		Average	0.04	
65.00	15:51:34	3.55E-02	0.04		Std. dev.	0.01	
Comment **Long hood w/o flap**							

Long hood w/ rubber flap.

-	1302.00	Measurem	Data .		1788611/2803	1995-04-2	16:46			
1302.00	Settings:									
Compensate	for	Water	Vap.	Interference		: no				
Compensate	for	Cross	Interference			: no				
Sample	Continuously					: yes				
Measure										
Gas	A:	Sulfur	hexafluoride			yes				
Water	Vapour					no				
Sampling	Tube	Length	15.00	ft						
Air	Pressure		760.00	mmHg						
Normalization	Temperature		72.00	F						
General	Information:									
Start	Time	1995-04-27	16:00							
Stop	Time	1995-04-27	16:36							
Results	Not	Averaged								
Gas	A:									
1302.00	Measurement	Data	1788611/2803		1995-04-27					
Samples	Measured	From	1995-04-27	16:00						
Sample		Time		Gas A	Calibration					
No.		hh:mm:ss		ppm	correction					
1.00		16:00:27		3.66E-02	0.04					
2.00		16:01:09		2.67E-02	0.03					
3.00		16:01:45		3.32E-02	0.03					
4.00		16:02:20		3.75E-02	0.04					
5.00		16:02:55		3.09E-02	0.03					
6.00		16:03:31		6.99E-01	0.70					
7.00		16:04:06		7.68E-01	0.77					
8.00		16:04:42		1.80E-01	0.18					
9.00		16:05:17		1.21E-01	0.12					
10.00		16:05:52		1.62E-01	0.16					
11.00		16:06:28		1.11E-01	0.11					
12.00		16:07:03		7.23E-02	0.07	Average	1.80E-01			
13.00		16:07:38		5.99E-02	0.06	Std. Dev.	0.25			
		16:07:38		Event 1		Start SF6 @ 0.340 lpm				
						Outlet of SF6 in in exhaust hood.				
14.00		16:08:14		4.30E+01	46.66					
15.00		16:08:54		4.41E+01	47.88	SF6 Flow	0.34	lpm		
16.00		16:09:29		4.38E+01	47.55	Average	47.55	ppm		
17.00		16:10:05		4.43E+01	48.11	Std. Dev.	0.63			
		16:10:05		Event 2		Start SF6 @ 0.639 lpm				
						Outlets of SF6 are both in hoods.				
18.00		16:10:51		8.26E+01	90.66					
19.00		16:11:26		8.22E+01	90.21					
20.00		16:12:02		8.23E+01	90.32	SF6 Flow	0.64	lpm		
21.00		16:12:37		8.16E+01	89.55	Average	89.95	ppm		
22.00		16:13:13		8.11E+01	88.99	Std. Dev.	0.67			
		16:13:13		Event 3		Turn off SF6				
						Place SF6 outlets into distribution tubing.				
23.00		16:13:48		5.79E-01	0.58					
24.00		16:14:28		9.65E-02	0.10					
25.00		16:15:04		6.27E-02	0.06					
26.00		16:15:39		5.40E-02	0.05					
		16:15:39		Event 4		Start SF6 @ 0.639 through distribution tubing.				
27.00		16:16:15		2.79E+01	29.89	(ignore: transition measurement)				

28.00		16:16:55		4.09E+01	44.33						
29.00		16:17:30		4.69E+01	50.99						
30.00		16:18:06		4.14E+01	44.88						
31.00		16:18:41		4.53E+01	49.22						
32.00		16:19:17		4.23E+01	45.88						
33.00		16:19:52		4.03E+01	43.66		SF6 Flow	0.64	lpm		
34.00		16:20:27		4.38E+01	47.55		Average	46.13	ppm		
35.00		16:21:34		3.93E+01	42.55		Std. dev.	2.90			
		16:22:09		Event 5			Stop SF6 and allow to bleed off system.				
36.00		16:22:09		1.84E+01	19.33						
37.00		16:22:47		1.15E+01	11.67						
38.00		16:23:23		3.60E+00	3.60						
39.00		16:23:58		1.26E-01	0.13						
		16:23:58		Event 6			Place detector inlet in screed area				
							to follow SF6 decay in the room.				
40.00		16:24:36		4.70E-02	0.05						
41.00		16:25:11		4.61E-02	0.05						
42.00		16:25:47		4.15E-02	0.04						
43.00		16:26:22		3.36E-02	0.03						
44.00		16:26:57		3.43E-02	0.03						
45.00		16:27:33		3.81E-02	0.04						
46.00		16:28:08		3.91E-02	0.04						
47.00		16:28:44		3.70E-02	0.04						
48.00		16:29:19		3.95E-02	0.04						
49.00		16:29:54		3.20E-02	0.03						
50.00		16:30:30		3.86E-02	0.04						
51.00		16:31:24		3.19E-02	0.03						
52.00		16:32:00		2.87E-02	0.03						
53.00		16:32:35		2.80E-02	0.03						
54.00		16:33:11		3.14E-02	0.03						
55.00		16:33:46		3.16E-02	0.03						
56.00		16:34:21		2.68E-02	0.03						
57.00		16:34:57		3.35E-02	0.03						
58.00		16:35:32		3.29E-02	0.03		Average	0.04			
59.00		16:36:08		3.03E-02	0.03		Std. dev.	0.01			
Comments	Laboratory study		**Long hood w/ rubber flap.**								

LONG HOOD W/RUBBER FLAP

OUTSIDE EVALUATION

(Paver oriented with wind)

1302.00	Measurement	Data		1788611/2803		1995-04-28	11:50	
1302.00	Settings:							
Compensate	for	Water	Vap.	Interference		: NO		
Compensate	for	Cross	Interference			: NO		
Sample	Continuously					: YES		
Pre-set	Monitoring	Period				: NO		
Measure								
Gas	A:	Sulfur	hexafluoride			: YES		
Water	Vapour					: NO		
Sampling	Tube	Length	15.00	ft				
Air	Pressure		760.00	mmHg				
Normalization	Temperature		54.00	F				
General	Information:							
Start	Time	1995-04-28	10:52					
Stop	Time	1995-04-28	11:18					
Results	Not	Averaged						
Gas	A:							
1302.00	Measurement	Data	1788611/2803		1995-04-28	11:50		
Samples	Measured	From	1995-04-28	10:52				
Sample No.		Time hh:mm:ss		Gas ppm	Calibration correction	COMMENTS		
1.00		10:52:53		2.48E-02	0.02	Background		
2.00		10:53:36		2.14E-02	0.02	Detector near equipment.		
3.00		10:54:11		2.30E-02	0.02			
4.00		10:54:46		2.75E-02	0.03			
5.00		10:55:22		3.21E-02	0.03	Average	2.63E-02	
6.00		10:55:57		2.92E-02	0.03	Std. Dev	0.00	
		10:56:32		Event 1		Detector inlet in duct, no SF6		
7.00		10:56:32		4.24E-02	0.04			
8.00		10:57:08		3.80E-02	0.04			
9.00		10:57:43		4.01E-02	0.04			
10.00		10:58:19		4.05E-02	0.04			
11.00		10:58:54		3.64E-02	0.04			
12.00		11:00:00		3.97E-02	0.04	Average	0.04	
13.00		11:00:36		3.70E-02	0.04	Std Dev	0.00	
		11:00:36		Event 2		Start 0.347 lpm pure SF6		
						SF6 outlet is in hood opening.		
14.00		11:01:12		4.32E+01	46.88			
15.00		11:01:52		4.33E+01	47.00			
16.00		11:02:27		4.29E+01	46.55			
17.00		11:03:03		4.27E+01	46.33	SF6 Flow	0.35	lpm
18.00		11:03:38		4.28E+01	46.44	Average	46.46	ppm
19.00		11:04:14		4.20E+01	45.55	Std. Dev	0.51	
		11:04:14		Event 3		Start 0.692 lpm pure SF6		
						SF6 outlets are in hood opening.		
20.00		11:04:49		8.01E+01	87.88			
21.00		11:05:24		8.00E+01	87.77			
22.00		11:06:00		8.02E+01	87.99			
23.00		11:06:35		8.04E+01	88.21			
24.00		11:07:10		8.03E+01	88.10	SF6 Flow	0.69	lpm
25.00		11:07:46		8.02E+01	87.99	Average	88.01	ppm
26.00		11:08:21		8.03E+01	88.10	Std. Dev	0.15	

	11:08:21		Event 4		Stop SF6 and attach outlets to distribution tubing.				
27.00	11:08:57		5.42E-01	0.54					
28.00	11:09:56		7.31E-02	0.07					
	11:09:56		Event 5		Start SF6 through both distribution tubes, 0.692 lpm.				
29.00	11:10:32		1.22E+01	12.44					
30.00	11:11:10		1.67E+01	17.44					
31.00	11:11:45		3.52E+01	38.00					
32.00	11:12:23		4.64E+01	50.44					
33.00	11:12:59		1.31E+01	13.44					
34.00	11:13:36		2.80E+01	30.00					
35.00	11:14:14		3.02E+01	32.44					
36.00	11:14:50		2.28E+01	24.22					
37.00	11:15:25		2.49E+01	26.55					
38.00	11:16:00		1.47E+01	15.22	SF6 Flow	0.69	lpm		
39.00	11:16:38		2.39E+01	25.44	Average	27.65	ppm		
40.00	11:17:16		4.25E+01	46.11	Std. Dev.	12.45			
	11:17:16		Event 6		Stop SF6				
41.00	11:17:52		1.21E+01	12.33	(ignore: transition data)				
See notes for event markers.		**Long hood w/ rubber flap.**			**Outside**				

			LONG HOOD W/RUBBER FLAP							
			OUTSIDE EVALUATION							
			(Paver oriented into wind)							
1302.00	Measurement	Data		1788611/2803	•		1995-04-2	11:46		
1302.00	Settings:									
Compensate	for	Water	Vap.	Interference		:	no			
Compensate	for	Cross	Interference			:	no			
Sample	Continuously					:	yes			
Pre-set	Monitoring	Period				:	no			
Measure										
Gas	A:	Sulfur	hexafluoride			:	yes			
Water	Vapour					:	no			
Sampling	Tube	Length	15 feet							
Air	Pressure		760 mm							
Normalizatio	Temperature		70 F							
Results	Not	Averaged								
Gas	A:									
1302.00	Measurement	Data	1788611/2803		1995-04-28		11:46			
Samples	Measured	From	1995-04-28	11:28						
Samp.		Time		Gas	Calibration			Comments		
No.		hh:mm:ss		ppm	correction					
							Begin SF6 in auger area			
							0.692 lpm SF6			
1.00		11:28:03		7.36E-02	0.07		(ignore: transition measurement)			
2.00		11:28:46		2.09E+01	22.11					
3.00		11:29:55		4.46E+01	48.44					
4.00		11:30:33		3.64E+01	39.33					
5.00		11:31:08		3.41E+01	36.77					
6.00		11:31:44		3.85E+01	41.66					
7.00		11:32:19		3.13E+01	33.66					
8.00		11:32:55		2.57E+01	27.44					
9.00		11:33:30		2.88E+01	30.89					
10.00		11:34:05		2.76E+01	29.55		SF6 Flow	0.69	lpm	
11.00		11:34:41		3.04E+01	32.66		Average	34.43	ppm	
12.00		11:35:16		3.36E+01	36.22		Std. Dev.	7.22		
		11:35:16		User	Event 1		SF6 Deactivated			
13.00		11:35:52		1.98E-01	0.20					
14.00		11:36:32		5.33E-02	0.05					

* Outdoor tests w/ paver oriented into the wind at a 260 deg azimuth.
Only event marker indicates when SF6 was turned off and wand pulled.
First reading may be low due to start-up transition of SF6.
Note: (We probably should have re-measured the Q exhaust flow after reorienting the paver due to possibility of resetting paver's rpm and thus affecting the exhaust flow. Use Q exh calculated from previous test run).

APPENDIX C

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

CEDARAPIDS PROTOTYPE DESIGN MODIFICATIONS PRIOR TO PHASE TWO FIELD EVALUATIONS

Cedarapids Inc
916 Sixteenth St NE
Cedar Rapids IA 52402 USA

Cedarapids
A Raytheon Company

December 29, 1995

Mr. Kenneth R. Mead
Engineering Control Technology Branch,
Division of Physical Sciences and Engineering
National Institute for Occupational Safety and Health
4676 Columbia Parkway
Mail Stop R-5
Cincinnati, OH 45226

Dear Ken:

SUBJECT: Configuration of engineering controls for Cedarapids pavers.

The engineering control system tested during your visit in April consisted of hoods located over the augers, hood mounted blowers, and an eductor in the engine exhaust plumbing. The purpose of the eductor was to allow the low static pressure blowers to feed into the higher pressure engine exhaust. Capture ratios for this version varied from 13% to 50% indoors, depending on which type ducts used. Capture ratios averaged about 35% when outdoors.

After measuring airflow in different parts of the system, we discovered the combination of the eductor and the blowers used were incapable of overcoming the engine exhaust pressure. This resulted in lower than expected flow rates. Therefore, we replaced the blowers with high pressure models capable of delivering 500 cfm at 3 in. static pressure minimum[1]. These blowers will allow us to forego the eductor and feed the fumes directly into the engine exhaust. Fig. 1 is a block diagram of the system as modified. This is the configuration of the engineering controls installed on Milestone's CR411 and Rea Construction's CR451 pavers.

[1] See fan performance curve attached.

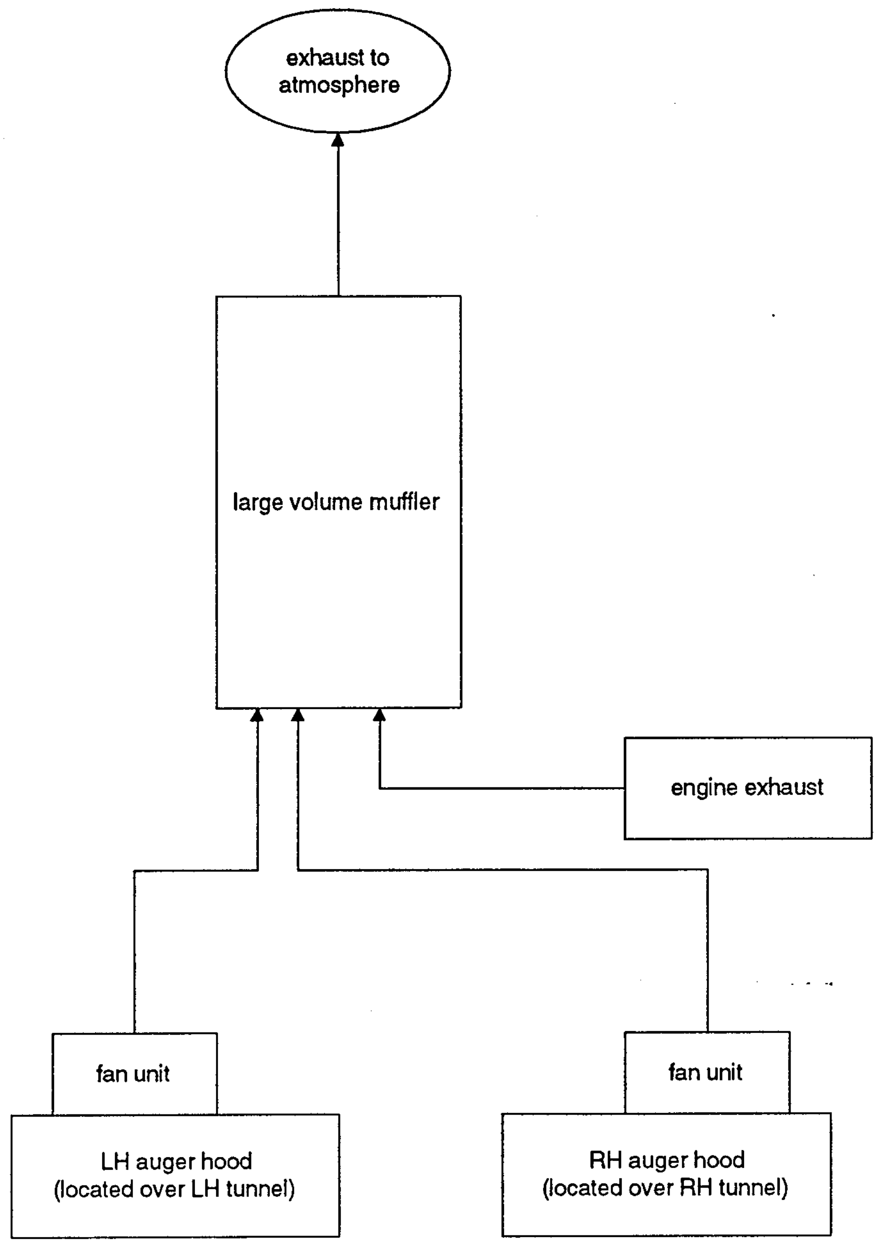
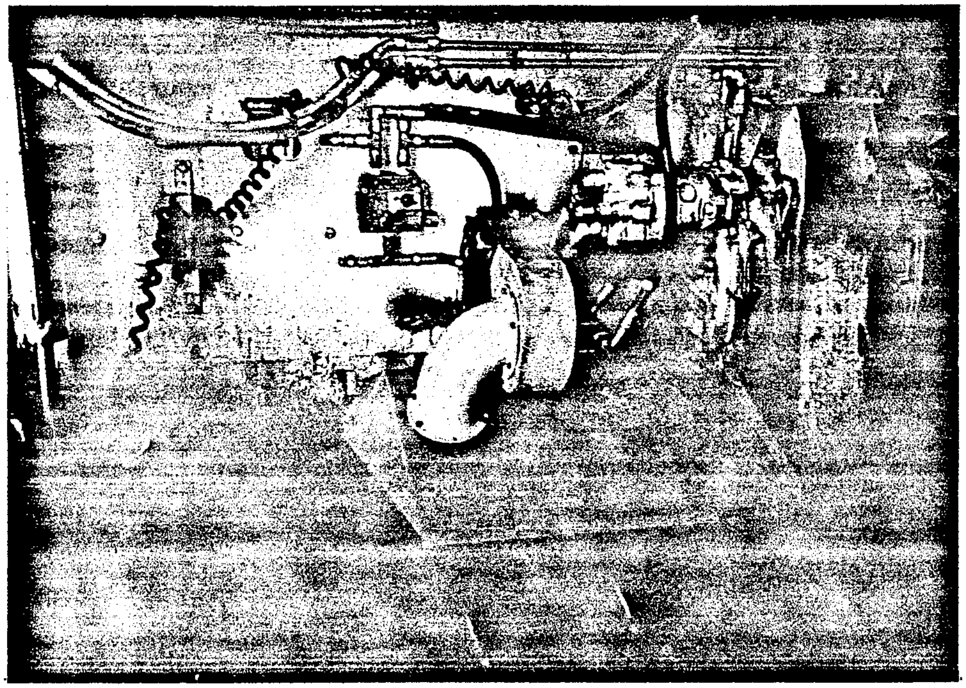


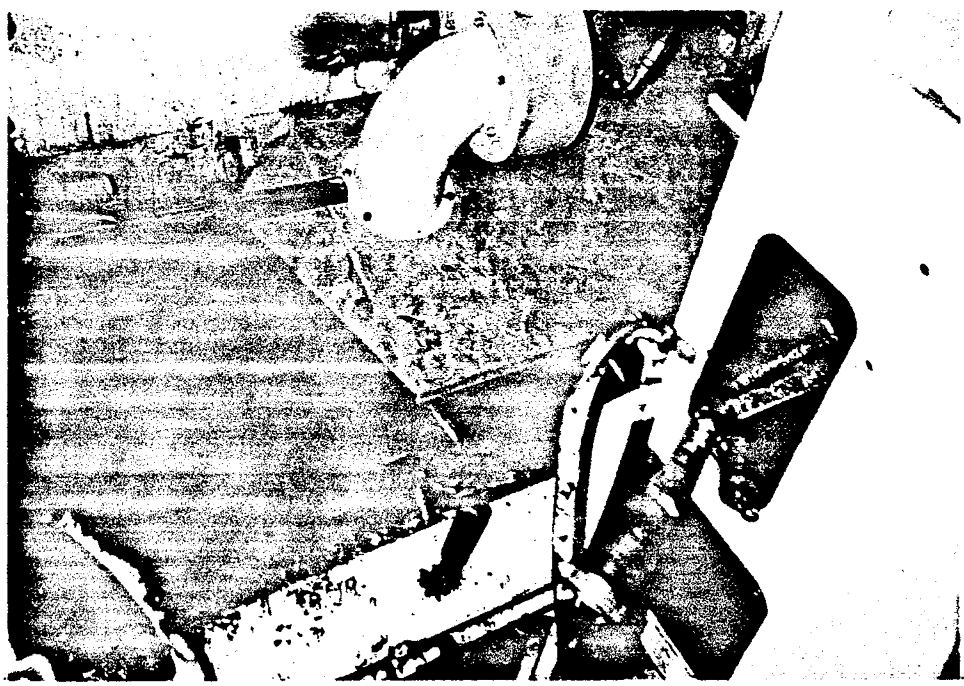
Fig. 1

In testing at the factory, we measured flow rates of 400 to 500 cfm per side (800 to 1,000 cfm total).

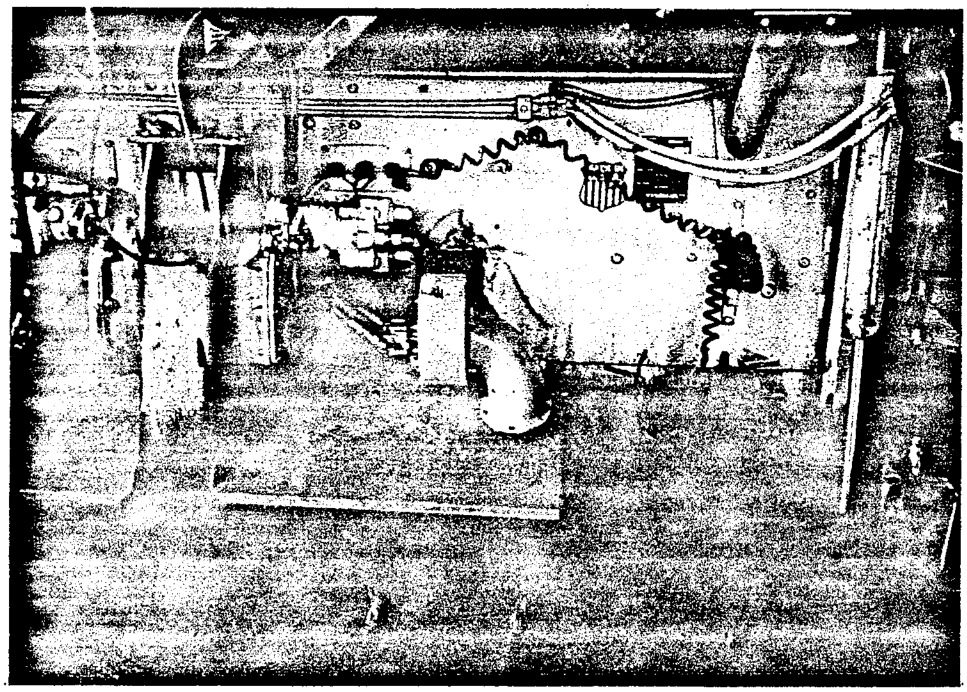
Below are photographs to document the actual installation:



LH duct w/o screed installed

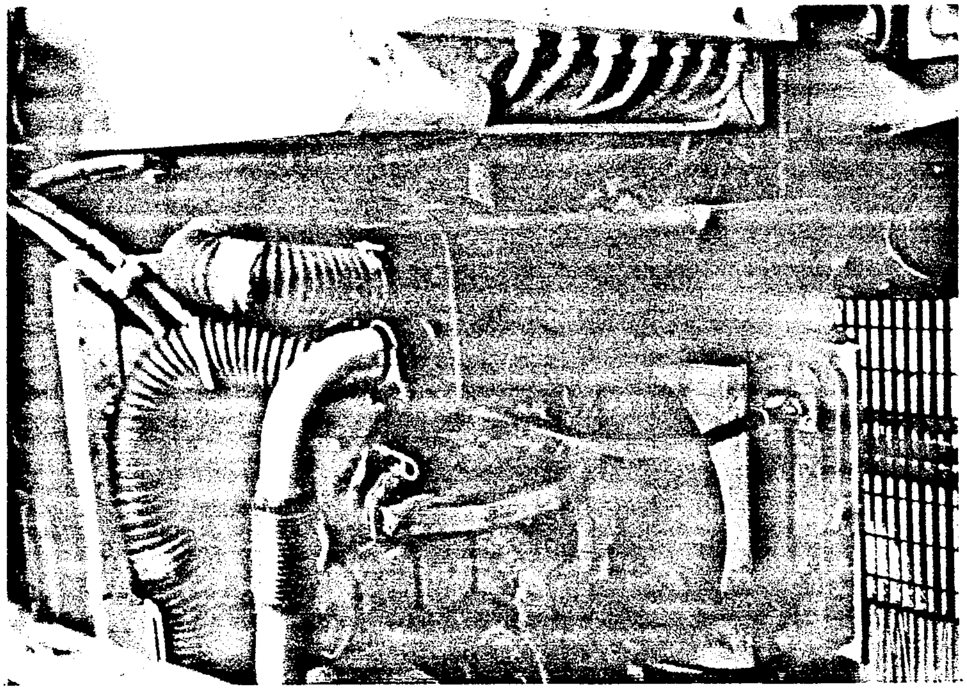


LH duct w/screed installed

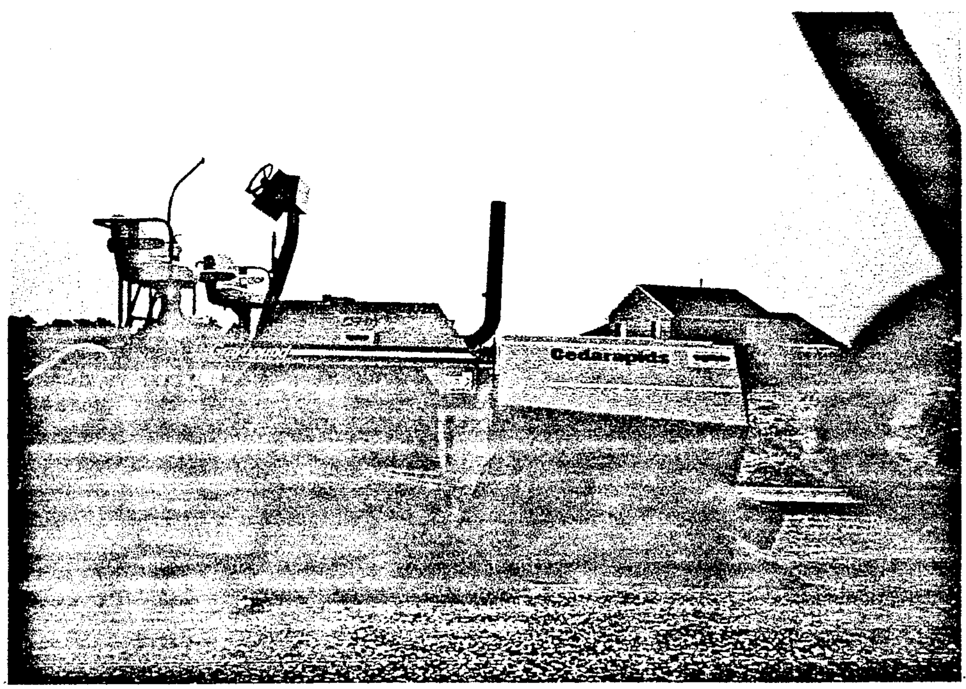


RH duct w/o screed installed

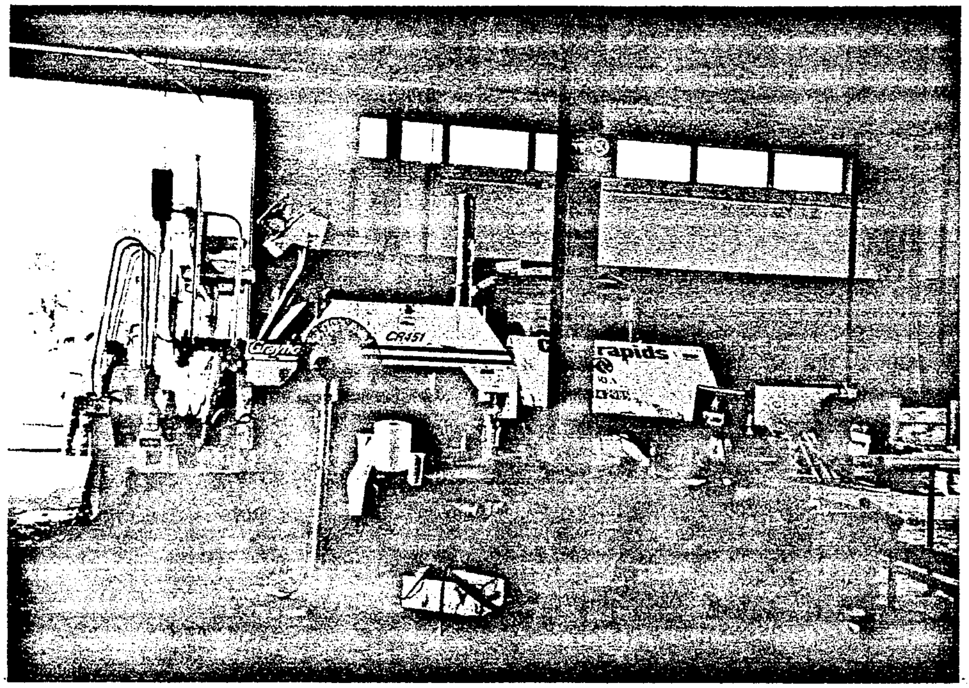
RH duct w/screed installed



Large volume muffler to combine engine and fume exhausts



Side view of Milestone's CR411 w/system installed



Side view of Rea Construction's CR451 w/system installed

Based on subjective feedback from the end users, the system does make a noticeable difference in collecting fumes from the hot mix asphalt. We are very interested in the NIOSH field testing to quantify the system effectiveness.

Please don't hesitate to contact me if you need additional information.

Sincerely,
Cedarapids, Inc.

David Swearingen

David Swearingen
Chief Engineer,
Mobile Equipment

Enclosure

copy: P.J. Schlarmann
J.L. Richmond
T.E. Brumagin - NAPA

SCOTT INDUSTRIAL BLOWER CO.,INC.
15 WEST END DRIVE
GILBERTS ILLINOIS 60136
PH 708-426-8800 FAX 708-426-8068

DRAWING NO.	30-11-30	
REVISION:		BY: JRP
		DATE:

CURVEGRF

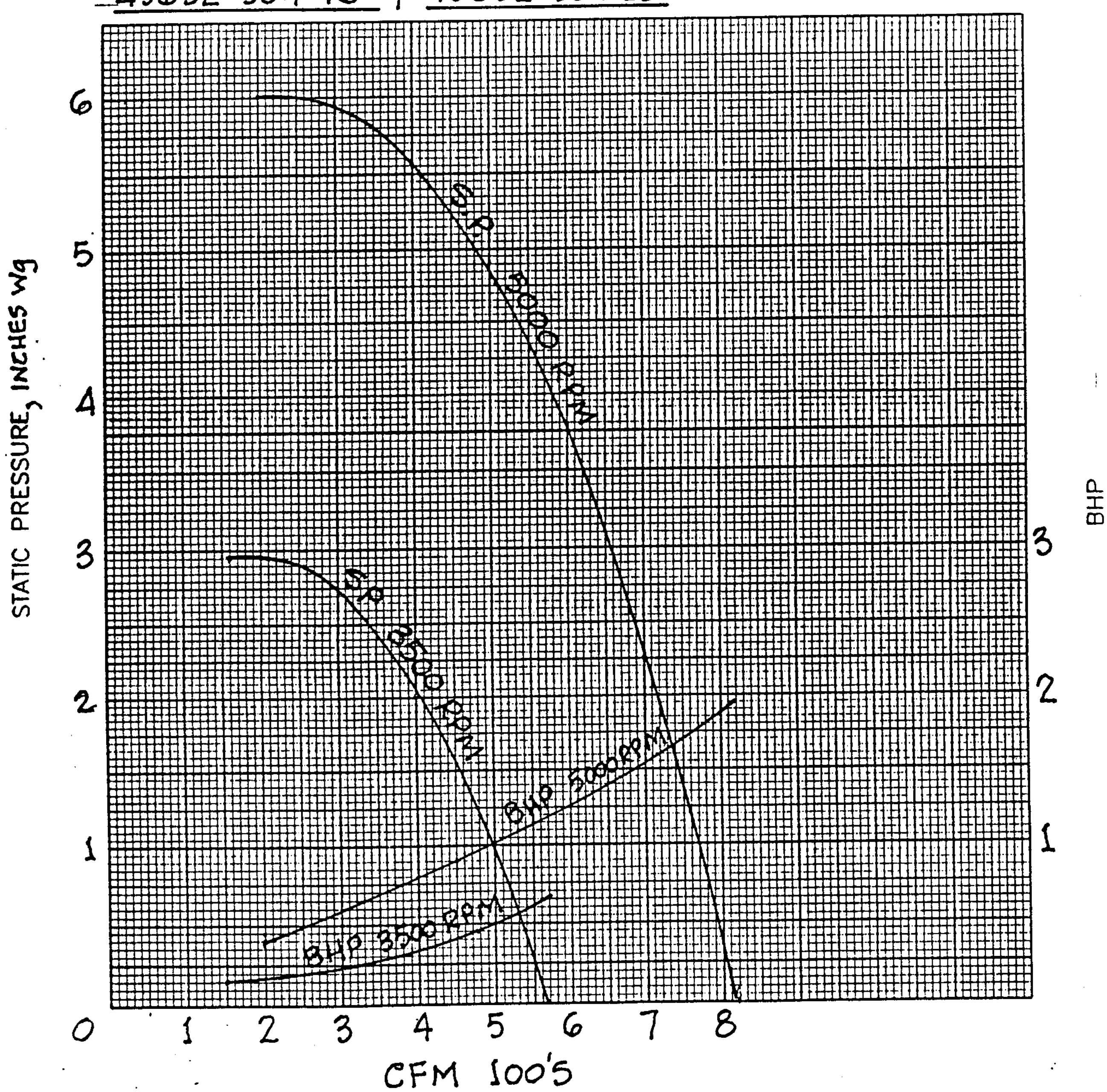
FAN PERFORMANCE CURVE

FAN SIZE 55 FRC WHEEL DIA. 5½

CFM 350-500 S.P. 3"-5" RPM 3500-5000

INLET DENSITY .075 LBS./FT3 TEMP 70° DEG.F.

45652-504-16 & 45652-504-15



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