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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

Caterpillar Paving Products (Barber-Greene)
DeKalb, Illinois

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National Institute for Occupational Safety and Health
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PLANT SURVEYED:	Caterpillar Paving Products (Historical Name: Barber-Greene) 12101 Barber-Greene Road DeKalb, Illinois 60115
SIC CODE:	1611
SURVEY DATE:	March 12-15, 1996
SURVEY CONDUCTED BY:	Ronald L. Mickelsen Gary S. Earnest Walter M. Haag
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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 March 12-15, 1996, researchers from the National Institute for Occupational Safety and Health (NIOSH) evaluated a prototype engineering control system at Caterpillar Paving Products, DeKalb, Illinois. The control system was designed for the control of asphalt emissions from the auger area during asphalt paving. The Caterpillar 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 Caterpillar phase one evaluation.

The Caterpillar phase one evaluation studied the performance of one engineering control design using two different fans. Both fans were tested indoors and the larger fan was also tested outdoors. The control system design incorporated a long hood mounted on the back of the tractor above the auger area, covering approximately 60 percent of the area between the tractor and the screed. A duct mounted at the top of the slat conveyor connected the hood to a fan mounted under the tractor deck. The fan's exhaust duct extended six feet above the tractor deck. The control system exhaust volume was 1,120 cubic feet per minute (cfm) with the 1.0 horsepower (hp) fan and 1,350 cfm for the 1.5 hp fan. The average indoor capture efficiency was approximately 72 percent with the 1.0 hp fan and 95 percent with the 1.5 hp fan. The outdoor evaluation, using the 1.5 hp fan, revealed an average capture efficiency of 68 percent. Compared to the indoor, the outdoor results showed a 27 percentage point decline in capture efficiency and increased variation in results as wind gusts hampered the control's ability to consistently capture the surrogate contaminant.

The evaluated Caterpillar engineering control system has the potential to significantly reduce worker exposure during asphalt paving processes. The potential reduction is increased when using the larger exhaust fan. Recommendations to Caterpillar design engineers include: (1) Modifying both the transition between the duct and the hood, and the transition between the duct and the fan to reduce static pressure losses and increase exhaust flow rate; (2) Increasing the duct area located above the slat conveyors will also reducing the static pressure losses and increasing the exhaust flow rate; and (3) Increasing the extent of enclosure coverage around the auger area to reduce cross-draft interference and increase capture efficiency.

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. No further design information was provided for 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 March 12-15, 1996, researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted an evaluation of a prototype engineering control system at Caterpillar Paving Products, DeKalb, Illinois. The control system was designed for the control of asphalt emissions from the auger area during asphalt paving. The NIOSH researchers included Leroy Mickelsen, Chemical Engineer; Gary Earnest, Industrial Engineer; and Walt Haag, Industrial Engineer; all from the NIOSH Engineering Control Technology Branch (ECTB), Division of Physical Sciences and Engineering (DPSE). The DPSE researchers were primarily assisted by Jim Placiennik, a Caterpillar Design Engineer.

The Caterpillar engineering control system 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 interagency agreement with DOT's Federal Highway Administration (FHWA). Additionally, the National Asphalt Pavement 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 may sometimes occur 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 Caterpillar 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 Manual [ACGIH, 6500 Glenway Avenue, Building D-7, Cincinnati, Ohio 45211.]

EVALUATION PROCEDURE

The Caterpillar engineering control phase one evaluation was conducted in a large bay area within a separate research building removed from the manufacturing plant. A large overhead door provided access for the paver to be partially driven into the bay area. The paver was positioned in the doorway so that the screed and rear half of the tractor were within the bay area (referred to as the testing area). The front half of the tractor, the paver engine and its exhaust, and the control system's exhaust were all outside of the building. 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 control system exhaust were discharged to the outside of the building. This setup proved very effective at preventing the engine exhaust, engine cooling air, and the captured surrogate contaminants from reentering the testing area.

A theatrical smoke generator produced smoke as a surrogate contaminant. The smoke was released through a perforated distribution tube. The tube placement traversed the width of the auger area between the tractor and the screed and rested on the ground under the augers. 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. After sealing leaks within this barrier, smoke was again released to identify airflow patterns within the test area and to visually observe the control system's performances.

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; and (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.

A photo-acoustic infra-red detector (Bruel & Kjaer Model 1302) was calibrated in the NIOSH laboratories prior to the evaluation. Known amounts of reagent grade SF_6 were injected into 12-liter Milar sampling bags and diluted with nitrogen to predetermined concentrations. Five concentrations ranging from 2 to 100 parts per million (ppm) SF_6/nitrogen were generated. A curve was fit to the data and used to convert detector response to SF_6 concentrations. Calibration data are in Appendix B.

To quantify exhaust flow rate, the tracer gas discharge tubes were placed directly into the exhaust ducts of the engineering control system. A known flow rate of SF_6 was released into the duct(s) and the analytical instrument measured the concentration of SF_6 in the control system's exhaust. Measurements were taken downstream of the exhaust fan to allow for thorough mixing of the exhaust air stream. 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: $\mathbf{Q_{(exh)}}$ = 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. And the * indicates 100 percent 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:

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

where: η = 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.

Both flow rate and capture efficiency tests were repeated. The paver was shut down and background SF_6 measurements taken between trials. The exhaust flow rate of the control system was evaluated at two different paver idle speeds to determine its effect.

Since the Caterpillar engineering control design was tested using two different exhaust fans, the most effective system-fan combination, as determined by the indoor evaluation, was selected for further evaluation outdoors with the paver positioned in prescribed stationary orientations. The paver was randomly oriented in four different directions relative to the prevailing wind. Wind velocity measurements were taken, as well as exhaust flow rates and capture efficiency, during the outdoor evaluations. The outdoor stationary evaluation provided feedback on the sufficiency of the engineering control's hood enclosure for performance in an outdoor environment.

EQUIPMENT

(See Appendix A)

ENGINEERING CONTROL DESIGN DESCRIPTION

The Caterpillar asphalt paving engineering control was a local exhaust ventilation system with no additional enclosures around the auger area. It consisted of a hood, duct, fan, and exhaust stack. The local exhaust ventilation system was designed and installed by engineers at Caterpillar. The control system was retrofitted to a Caterpillar Paver Model AP-1050 with an Extend-o-mat screed no. 10-20B. The hood was located on the rear of the tractor, centered over the auger's drive train, and above the auger. The hood was approximately 6.5' wide. It extended approximately 13" past the rear of the tractor and then curved downward for approximately 6". The hood's size and position created a partial enclosure over the area where hot mix asphalt is delivered to the screw augers. Caterpillar engineers noted that during the asphalt paving process, workers prefer an unobstructed view into the auger area.

The hood was connected to a duct which ran horizontally from the auger to the fan. The cross sectional area of the entire duct was 72.5 square inches (1.25" by 58"). It was located directly above the slat conveyors. The slat conveyors are used to transport asphalt from the hopper (on the front of the paver) to the augers (on the rear of the paver). The duct was connected to the fan inlet. The fan was a high volume, direct drive, centrifugal blower that was manufactured by the Dayton Electric Manufacturing Company. The fan was located under the tractor deck next to the engine. Two different fans were used in this system during the survey. Initially, a 1.0 horsepower (hp) fan that operated at approximately 1,725 revolutions per minute (rpm) was used. During the second day of the study, a 1.5 hp fan, operating at the same rpm, was installed and evaluated.

The hydraulic fan motor was connected to a regulating valve feeding off of the tractor's hydraulic system. This valve enabled the fan to run at a relatively constant fan speed, independent of the engine idle speed. The fan exhausted to the atmosphere through an 8" diameter duct located just behind the main engine exhaust stack. The fan exhaust stack extended approximately 6' above the paver deck.

DATA RESULTS

Smoke Evaluations

The smoke test evaluation provided only qualitative information. After verifying the integrity of the separating barrier, smoke was re-released to identify airflow patterns within the test area and to visually observe the control system's performance. This information assisted the researchers in preparing the test area for the quantitative tracer gas evaluation.

Tracer Gas Evaluation

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

The calibration data from the B&K was used to convert the instrument's response to the actual SF_6 concentration in sampled air. The following equation was derived from calibration data ranging from 0 to 60 ppm in Appendix B:

$$SF_6\ Concentration = 403 - \sqrt{162{,}403 - 844 * Response}$$

Where: Response = the B&K detector response (ppm)

Evaluations conducted indoors are considered controlled conditions. Building pressure fluctuations and air currents from moving people or equipment are considered insignificant compared to outdoor conditions. The results are reported in Tables I and II in terms of an average and a range of the 6 to 10 measurements for each run. Multiple tests were performed for each fan resulting in an average exhaust flow rate of 1,120 cfm for the 1.0 hp fan and 1,350 cfm for the 1.5 hp fan. The average indoor capture efficiency was 72 percent with the 1.0 hp fan and 95 percent with the 1.5 hp fan. For comparison purposes, a pitot tube traverse of the ventilation system's exhaust duct resulted in a calculated average flow rate of 1,280 cfm for the 1.0 hp fan and 1,400 cfm for the 1.5 hp fan. The air velocity at the face of the hood ranged from 110 to 150 fpm.

The outdoor evaluation occurred in a parking area. There were some large trucks in an adjacent lot which may have partially obstructed the wind. Wind gusted from 5 to 10 miles per hour (mph) with most readings averaging approximately 6 mph. Wind velocities were measured with a hot-wire anemometer held by researchers standing on top of the paver deck. The paver was oriented so that each paver profile (front, back, left-side, right-side) faced into the wind for three tests. The sequence of orientations were randomized in blocks of four. Only the 1.5 hp fan was tested outdoors. The outdoor evaluations revealed an overall average capture efficiency of 68 percent. Compared to the indoor evaluation, the outdoor results showed a 27 percentage point decline in capture efficiency and increased variation in results as wind gusts hampered the control's ability to consistently capture the surrogate contaminant. The outdoor exhaust flow rate averaged 1,370 cfm.

TABLE I. EXHAUST FLOW RATE TRIALS

	$Q_{(SF_6)}$	$Q_{(exh)}$ (Range)	$Q_{(exh)}$ (Average)
1.0 hp fan, Indoor 1a	0.569 lpm	1,103 - 1,116 cfm	1,111 cfm
1.0 hp fan, Indoor 1b	1.132 lpm	1,133 - 1,148 cfm	1,139 cfm
1.0 hp fan, Indoor 2a	0.569 lpm	1,090 - 1,109 cfm	1,100 cfm
1.0 hp fan, Indoor 2b*	0.569 lpm	1,096 - 1,109 cfm	1,103 cfm
1.0 hp fan, Indoor 3a*	1.132 lpm	1,141 - 1,152 cfm	1,147 cfm
1.5 hp fan, Indoor 1a	0.566 lpm	1,328 - 1,358 cfm	1,342 cfm
1.5 hp fan, Indoor 1b	1.124 lpm	1,357 - 1,367 cfm	1,360 cfm
1.5 hp fan, Outdoor 1a	0.566 lpm	1,367 - 1,384 cfm	1,375 cfm
1.5 hp fan, Outdoor 1b	1.124 lpm	1,357 - 1,367 cfm	1,361 cfm

- The annotations "a" and "b" are for different SF_6 flow rates during the same test run.

* Engine idle was reduced from 1675 rpms to 800 rpms for two trials.

TABLE II. INDOOR CAPTURE EFFICIENCY TRIALS

	$Q_{(sf6)}$	$Q_{(exh)}$	η (Range)	η (Average)
1.0 hp fan, Indoor 1a	0.569* cfm	1,105 cfm	36 - 88 %	64 %
1.0 hp fan, Indoor 1b	1.132	1,143	54 - 105 %	72 %
1.5 hp fan, Indoor 1a	0.566*	1,342	54 - 98 %	82 %
1.5 hp fan, Indoor 1b	1.124	1,360	74 - 107 %	95 %

- The annotations "a" and "b" are for different SF_6 flow rates during the same test run.
* SF6 released only on the right side of the auger area.

TABLE III. OUTDOOR TRIALS, 1.5 hp FAN ONLY
FRONT OF PAVER FACING THE WIND = ZERO DEGREES

Orientation/Run	$Q_{(SF6)}$	η(Range)	η(Average)	Wind
0°, Run 1	1.124 lpm	57 - 100 %	83 %	5 - 8 mph
270°, Run 1	1.124	30 - 97 %	51 %	5 - 8
180°, Run 1	1.124	24 - 108 %	56 %	7 - 8
90°, Run 1	1.124	51 - 93 %	73 %	3 - 9
180°, Run 2	1.124	31 - 101 %	61 %	8 - 12
90°, Run 2	1.124	36 - 95 %	64 %	2 - 5
0°, Run 2	1.124	68 - 101 %	88 %	3 - 8
270°, Run 2	1.124	29 - 75 %	57 %	2 - 10
180°, Run 3	1.124	70 - 100 %	89 %	3 - 5
90°, Run 3	1.124	47 - 119 %	73 %	1 - 6
270°, Run 3	1.124	27 - 72 %	44 %	5 - 8
0°, Run 3	1.124	59 - 89 %	76 %	3 - 9

η = Capture efficiency

DISCUSSION

The control system flow rate calculations for the two methods, the SF_6 dilution technique and the velocity pressure technique, where within 5 percent of one another. For the indoor evaluation of the 1.0 hp fan, there seemed to be a systematic difference in the flow rates calculated using flow of 0.6 lpm SF_6 (1,105 cfm) verses a flow of 1.1 lpm SF_6 (1,143 cfm). This systematic difference is about 3.5 percent and is probably due to low accuracy in one of the SF_6 delivery flow rate calibrations during the first day. Before testing the 1.5 hp fan, a new calibration was done for the SF_6 delivery system. On the second day, the exhaust flow rate calculated for the 0.6 lpm SF_6 (1,342 cfm) test run was only 1 percent less than the exhaust flow rate for the 1.1 lpm SF_6 (1,360 cfm) test run. These differences are small when compared to the outdoor wind effect on the capture efficiency.

The 1.5 hp fan had a 20 percent increase in flow over the 1.0 hp fan. The larger fan also increased the system's capture efficiency by 23 percent, based on the indoor sampling. The 1.5 hp fan drew the same amount of air when tested outdoors as when tested indoors; however, the capture efficiency decreased by 27 percent. In addition, the variance of the samples increased during the outdoor tests. Achieving a high average capture efficiency and maintaining high capture efficiencies without performance levels fluctuating over a wide range is desired. Empirically, the performance can be evaluated by comparing the sampling data coefficients of variation (CV).

$$CV = \frac{Standard\ deviation}{Mean} X\ 100$$

Controls with smaller CVs are less influenced by the environmental factors and maintained a more consistent capture efficiency. For example, the CVs obtained during indoor testing of the 1.5 hp fan were all less than 20 percent as compared to several CVs greater than 50 percent obtained while testing outdoors. The CVs for each set of data are shown in Appendix B.

CONCLUSIONS, DISCUSSION, AND RECOMMENDATIONS

Based on the evaluation results of this report, the Caterpillar control design, when paired with the larger 1.5 hp fan, has a reasonable potential to significantly reduce worker exposure. The wind speed, asphalt fume emission rate, work habits of individuals, and other factors will effect the actual reductions in worker exposure. For example, if the wind speed is very high (15 mph range), asphalt emissions may be naturally removed from the auger area, reducing the relative effectiveness of the control system. On the other hand, if the wind speed is very low (<1 mph), the wind may not remove a significant amount of asphalt emissions from the auger area. In the low wind case, the ventilation system is expected (based on indoor testing where the wind was minimal) to remove a large percentage of the asphalt emissions, thus, the relative effectiveness of the control system will be high.

Some general recommendations for further improvements to the design follow: The evaluated Caterpillar local exhaust ventilation system included: enclosure, hood design, and mechanical exhaust. The enclosure covered about 60 percent of the area over the augers. Caterpillar engineers expressed concerned that covering any more of this area would obstruct the view of the operator and hamper production. Any additional enclosure techniques, especially above the ends of the auger and the screed extension areas, could increase capture efficiency, increase resistance to cross-draft disturbances, and reduce worker exposure. However, user acceptance must still be a consideration. If the auger area cannot be enclosed any further, then improvements to the hood design and an increase in the exhaust flow rate could be made.

The hood design, including the duct to hood transition and the duct to fan transition, required improvement. Although difficult to measure on this system, significant pressure losses were expected at the hood-to-duct and the duct-to-fan transitions. Smooth (gradual) transition at these transitions would increase the exhaust flow rate of the system. In addition, the short duct height also contributed to increased pressure loss due to the large surface area to cross-sectional area ratio. Re-sizing this duct could reduce frictional losses and increase the exhaust flow rate of the system.

With the 1.5 hp fan, the ventilation system's exhaust flow rate was 1,400 cfm and air velocity measurements taken at the face of the hood ranged from 110 to 150 fpm. The air velocities decreased quickly with distance from the face of the hood. 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.

ACKNOWLEDGMENTS

We would like to thank the Caterpillar management and staff for their gracious hospitality and assistance during our visit to the Caterpillar Paving Products facility. Their commitment to the design and implementation of engineering controls to reduce occupational exposures is an admirable pledge. We would like to thank Walt Haag for his contribution on the field survey.

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.

Laboratory Setup: 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.

Paver Position: 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. Deactivate the engineering controls for comparison purposes.
9. Deactivate 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: **$Q_{(exh)}$** = 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

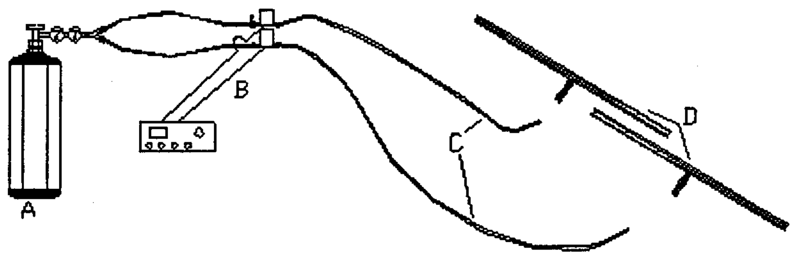
$C^*_{(SF6)}$ = concentration of SF_6 (parts per million) detected in exhaust

[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.

<u>Quantitative Capture Efficiency</u>: 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–Tracer Gas Cylinder with regulator
B–Tylan Mass Flow Controllers with Control Box
C–PTFE Distribution Tubes
D–Tracer Gas Distribution Plenums

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

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

where: η = capture efficiency

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

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

$Q_{(SF_6)}$ = 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 [$Q_{(SF_6)}$] 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 - 18 as time permits.

APPENDIX B

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

TRACER GAS EVALUATION RESULTS

B&K DATA FILES AND CALCULATION RESULTS

Barber-Greene (CAT) DeKalb, Illinois 3/12-15/1996

Summary Table

			Range			
INDOOR, SMALL FAN						
Flow rate #1:	1111 cfm	1103	to	1116	cfm	
Flow rate #2:	1139 cfm	1133	to	1148	cfm	
Flow rate #3:	1100 cfm	1090	to	1109	cfm	
Flow rate #4:*	1103 cfm	1096	to	1109	cfm	
Flow rate #5:*	1147 cfm	1141	to	1152	cfm	
*Engine idle was reduced from 1675 rpm to 800 rpm.						
Capture efficiency, Rt only:	64%	36%	to	88%		
Capture efficiency, Full:	72%	54%	to	105%		
INDOOR, LARGE FAN						
Flow rate #1:	1342 cfm	1328	to	1358	cfm	
Flow rate #2:	1360 cfm	1357	to	1367	cfm	
Capture efficiency, Rt only:	82%	54%	to	98%		
Capture efficiency, Full:	95%	74%	to	107%		
OUTDOOR, LARGE FAN						
Flow rate #1:	1375 cfm	1367	to	1384	cfm	
Flow rate #2:	1361 cfm	1357	to	1367	cfm	
						Wind Speed
OUTDOOR, LARGE FAN, WIND FROM FRONT TO BACK OF PAVER						mph
Capture efficiency, Rt only, #1:	83%	71%	to	107%		5 - 7
Capture efficiency, Full, #1:	83%	57%	to	100%		
Capture efficiency, Rt only, #2:	75%	60%	to	92%		3 - 8
Capture efficiency, Full, #2:	88%	68%	to	101%		
Capture efficiency, Rt only, #3:	81%	70%	to	86%		3 - 9
Capture efficiency, Full, #3:	76%	59%	to	89%		
OUTDOOR, LARGE FAN, WIND FROM RIGHT TO LEFT OF PAVER						
Capture efficiency, Rt only, #1:	55%	28%	to	92%		5 -8
Capture efficiency, Full, #1:	51%	30%	to	97%		
Capture efficiency, Rt only, #2:	76%	56%	to	97%		2 - 5
Capture efficiency, Full, #2:	57%	29%	to	75%		
Capture efficiency, Rt only, #3:	65%	52%	to	86%		1 - 6
Capture efficiency, Full, #3:	44%	27%	to	72%		
OUTDOOR, LARGE FAN, WIND FROM BACK TO FRONT OF PAVER						
Capture efficiency, Rt only, #1:	63%	40%	to	118%		7 - 8
Capture efficiency, Full, #1:	56%	24%	to	108%		
Capture efficiency, Rt only, #2:	69%	30%	to	108%		8 - 12
Capture efficiency, Full, #2:	61%	31%	to	101%		
Capture efficiency, Rt only, #3:	90%	64%	to	113%		3 - 5
Capture efficiency, Full, #3:	89%	70%	to	100%		
OUTDOOR, LARGE FAN, WIND FROM LEFT TO RIGHT OF PAVER						
Capture efficiency, Rt only, #1:	65%	29%	to	102%		3 -9
Capture efficiency, Full, #1:	73%	51%	to	93%		
Capture efficiency, Rt only, #2:	67%	40%	to	143%		2 - 10
Capture efficiency, Full, #2:	64%	36%	to	95%		
Capture efficiency, Rt only, #3:	64%	48%	to	83%		5 - 8
Capture efficiency, Full, #3:	73%	47%	to	119%		

CAT, DeKalb, Illinois 3/12-15/1996				
Small Fan,	Screed inside, engine outside			
- 1302 Measurement Data ------- 1804892/2803 - 1996-03-13 14:49 - Page 1 -				
1302 Settings:				
--				
Compensate for Water Vap. Interference :	NO			
Compensate for Cross Interference :	NO			
Sample Continuously :	YES			
Pre-set Monitoring Period :	NO			
Measure				
Gas A: Formaldehyde :	NO			
Gas B: Carbon dioxide :	NO			
Gas C: Carbon monoxide :	NO			
Gas D: TOC as Propane :	NO			
Gas E: Sulfur hexafluoride :	YES			
Water Vapour :	NO			
Sampling Tube Length :	15.0 ft			
Air Pressure :	760.0 mmHg			
Normalization Temperature :	54.0 F			
General Information:				
--				
Start Time	: 1996-03-13 11:39			
Stop Time	: 1996-03-13 13:15			
Results Not Averaged				
Number of Event Marks :	15			
Number of Recorded Samples :	157			
Samples Measured From 1996-03-13 11:39				
--				

Samp. No.	Time hh:mm:ss	Event	Response PPM	Calibration Correction		
1	11:39:29	.	7.12E-02	0.077999	Background, in exhaust stack	
2	11:40:12	.	3.23E-02	0.037264		
3	11:40:48	.	3.71E-02	0.04229		
4	11:41:43	.	4.12E-02	0.046584	Avg.	0.040385
5	11:42:18	.	3.75E-02	0.042709	Std. Dev.	0.005259
6	11:42:53	.	2.83E-02	0.033076	CV	13.02%
11:43:29	User	1				
7	11:43:29	.	3.09E-02	0.035798	Background, outside of garage	
8	11:44:04	.	2.91E-02	0.033914	Avg.	0.032301
9	11:44:40	.	2.21E-02	0.026584	Std. Dev.	0.003469
10	11:45:15	.	2.74E-02	0.032134	CV	10.74%
11:45:51	User	2				
11	11:45:51	.	2.18E-02	0.02627	Background, inside above screed	

12	11:46:26 .	3.26E-02	0.037578				
13	11:47:01 .	4.42E-02	0.049725				
14	11:47:37 .	4.58E-02	0.0514				
15	11:48:12 .	3.35E-02	0.038521				
16	11:48:48 .	3.82E-02	0.043442				
17	11:49:23 .	4.74E-02	0.053076				
18	11:49:59 .	3.66E-02	0.041767				
19	11:50:34 .	3.99E-02	0.045222	Avg.	0.044406		
20	11:51:20 .	3.60E-02	0.041139	Std. Dev.	0.005352		
21	11:51:56 .	3.70E-02	0.042186	CV	12.05%		
11:52:32	User	3					
22	11:52:32 .	2.62E-02	0.030877	Background, in exhaust stack			
23	11:53:07 .	3.59E-02	0.041034				
24	11:53:42 .	3.47E-02	0.039777				
25	11:54:18 .	3.64E-02	0.041557				
26	11:54:53 .	2.99E-02	0.034751				
27	11:55:29 .	2.52E-02	0.02983				
28	11:56:04 .	2.73E-02	0.032029				
29	11:56:40 .	2.76E-02	0.032343			SF6 flow rates	
30	11:57:15 .	3.18E-02	0.036741			Rt side	
31	11:57:50 .	3.44E-02	0.039463			0.569	lpm
32	11:58:26 .	2.78E-02	0.032552			Both sides	
33	11:59:01 .	2.76E-02	0.032343			1.1319	lpm
34	11:59:37 .	3.84E-02	0.043652				
35	12:00:12 .	3.76E-02	0.042814	Avg.	0.036706		
36	12:00:47 .	3.16E-02	0.036531	Std. Dev.	0.004436		
37	12:01:54 .	3.03E-02	0.03517	CV	12.09%		
12:02:29	User	4					
38	12:02:29 .	2.16E+01	23.29192	Rt side only SF6 100% capture			
39	12:03:10 .	1.69E+01	18.10455				
40	12:03:45 .	1.69E+01	18.10455				
41	12:04:21 .	1.68E+01	17.99494				
42	12:04:56 .	1.70E+01	18.21419	Avg.	18.08629	1110.549	Mean flow
43	12:05:32 .	1.68E+01	17.99494	Std. Dev.	0.082521	1102.75	Min
44	12:06:07 .	1.69E+01	18.10455	CV	0.46%	1116.186	Max
12:06:43	User	5					
45	12:06:43 .	1.86E+01	19.97272	Both sides SF6 100% capture			
46	12:07:18 .	3.18E+01	34.80092				
47	12:07:53 .	3.20E+01	35.03019				
48	12:08:29 .	3.20E+01	35.03019				
49	12:09:04 .	3.21E+01	35.14487				
50	12:09:40 .	3.21E+01	35.14487	Avg.	35.07936	1139.019	Mean flow
51	12:10:15 .	3.21E+01	35.14487	Std. Dev.	0.145902	1133.197	Min
52	12:10:50 .	3.22E+01	35.25959	CV	0.42%	1148.133	Max
53	12:11:45 .	9.76E+00	10.35528				
12:12:23	User	6					
54	12:12:23 .	9.05E-02	0.09821	Background, inside garage			
55	12:13:01 .	4.94E-02	0.05517	SF6 off			
56	12:13:36 .	4.17E-02	0.047107				
57	12:14:12 .	3.99E-02	0.045222				
58	12:14:47 .	4.25E-02	0.047945				

59	12:15:22		3.83E-02	0.043547				
60	12:15:58		4.07E-02	0.04606	Avg.	0.048233		
61	12:16:33		3.90E-02	0.04428	Std. Dev.	0.004924		
62	12:17:09		5.07E-02	0.056531	CV	10.21%		
12:17:44	User	7						
63	12:17:44		4.02E-02	0.045537				
64	12:18:20		1.71E+01	18.32386				
12:19:00	User	8						
65	12:19:00		1.70E+01	18.21419	**Rt side only SF6 100% capture**			
66	12:19:35		1.70E+01	18.21419	engine idle @ 1675 rpm			
67	12:20:11		1.69E+01	18.10455	Avg.	18.25807	1100.1	Mean flow
68	12:20:46		1.71E+01	18.32386	Std. Dev.	0.125047	1089.626	Min
69	12:21:33		1.72E+01	18.43357	CV	0.68%	1109.428	Max
12:22:08	User	9						
70	12:22:08		1.71E+01	18.32386	**Rt side only SF6 100% capture**			
71	12:22:44		1.69E+01	18.10455	engine idle @ 800 rpm			
72	12:23:20		1.70E+01	18.21419				
73	12:23:55		1.70E+01	18.21419				
74	12:24:30		1.69E+01	18.10455				
75	12:25:06		1.70E+01	18.21419	Avg.	18.2142	1102.75	Mean flow
76	12:25:41		1.71E+01	18.32386	Std. Dev.	0.082893	1096.15	Min
77	12:26:17		1.70E+01	18.21419	CV	0.46%	1109.428	Max
12:26:52	User	10						
78	12:26:52		3.18E+01	34.80092	**Both sides SF6 100% capture**			
79	12:27:28		3.19E+01	34.91554	engine idle @ 800 rpm			
80	12:28:03		3.20E+01	35.03019				
81	12:28:38		3.17E+01	34.68634	Avg.	34.83914	1146.873	Mean flow
82	12:29:14		3.17E+01	34.68634	Std. Dev.	0.138799	1140.618	Min
83	12:29:49		3.19E+01	34.91554	CV	0.40%	1151.925	Max
12:30:25	User	11						
84	12:30:25		3.17E+01	34.68634	**Placing SF6 into distribution tees**			
85	12:31:00		1.73E-01	0.184619				
86	12:32:12		5.13E-02	0.05716				
87	12:32:47		4.85E-02	0.054228				
88	12:33:23		3.17E-02	0.036636				
89	12:33:58		3.12E-02	0.036112				
90	12:34:33		2.83E-02	0.033076				
91	12:35:09		3.28E-02	0.037788				
92	12:35:44		3.04E-02	0.035275				
93	12:36:20		2.16E-02	0.02606				
12:36:55	User	12						
94	12:36:55		2.86E-02	0.03339	**Rt side only, distribution**			
95	12:37:31		1.38E+01	14.72103				
96	12:38:09		1.13E+01	12.0137				
97	12:38:44		1.11E+01	11.79793				
98	12:39:19		1.42E+01	15.15595				
99	12:39:55		7.43E+00	7.859351				
100	12:40:30		9.51E+00	10.08672				
101	12:41:25		8.43E+00	8.928631				
102	12:42:01		1.36E+01	14.50375				
103	12:42:36		1.26E+01	13.41916				

104	12:43:11 .	1.11E+01	11.79793				
105	12:43:47 .	6.16E+00	6.505522	Avg.	11.67356	64.19%	Ave Eff
106	12:44:22 .	1.50E+01	16.02727	Std. Dev.	3.032574	35.77%	Min Eff
107	12:44:57 .	8.44E+00	8.939338	CV	25.98%	88.13%	Max Eff
12:45:33 User		13					
108	12:45:33 .	2.05E+01	22.07152	**Both sides, distribution**			
109	12:46:11 .	2.88E+01	31.37892				
110	12:46:46 .	1.93E+01	20.74462				
111	12:47:22 .	2.65E+01	28.77657				
112	12:47:57 .	2.04E+01	21.96077				
113	12:48:32 .	1.88E+01	20.19311				
114	12:49:08 .	1.93E+01	20.74462				
115	12:49:43 .	2.43E+01	26.30419				
116	12:50:19 .	1.79E+01	19.20237				
117	12:50:54 .	2.64E+01	28.66384				
118	12:51:41 .	3.35E+01	36.75425	Avg.	25.16977	72.00%	Ave Eff
119	12:52:16 .	1.75E+01	18.76287	Std. Dev.	5.733306	53.67%	Min Eff
120	12:52:52 .	2.63E+01	28.55114	CV	22.78%	105.13%	Max Eff
121	12:53:27 .	2.53E+00	2.661161				
122	12:54:05 .	2.39E+00	2.513632				
12:54:41 User		14					
123	12:54:41 .	6.78E-01	0.713948	SF6 off, remove tubing & distribution tees			
124	12:55:19 .	7.64E-01	0.804161				
125	12:55:54 .	2.81E-01	0.297763				
126	12:56:29 .	2.87E-01	0.30405				
127	12:57:05 .	4.01E-01	0.423517				
128	12:57:40 .	3.35E-01	0.354348				
129	12:58:16 .	4.29E-01	0.452865				
130	12:58:51 .	3.75E-01	0.396267				
131	12:59:26 .	4.17E-01	0.440287				
132	13:00:02 .	1.69E-01	0.180429				
133	13:00:37 .	2.73E-01	0.289381				
134	13:01:44 .	1.85E-01	0.197189				
135	13:02:19 .	2.56E-01	0.27157				
136	13:02:55 .	1.66E-01	0.177287				
137	13:03:30 .	2.06E-01	0.219187				
138	13:04:05 .	8.70E-02	0.094545				
139	13:04:41 .	1.10E-01	0.118633				
13:05:16 User		15					
140	13:05:16 .	2.62E-01	0.277856	**Background, inside garage**			
141	13:05:51 .	1.79E-01	0.190904	Some Rosco smoke was			
142	13:06:27 .	1.09E-01	0.117585	generated during this time.			
143	13:07:02 .	9.36E-02	0.101457				
144	13:07:38 .	7.79E-02	0.085015				
145	13:08:13 .	6.63E-02	0.072867				
146	13:08:48 .	8.79E-02	0.095488				
147	13:09:24 .	9.14E-02	0.099153				
148	13:09:59 .	9.88E-02	0.106903				
149	13:10:34 .	6.92E-02	0.075904				
150	13:11:29 .	9.57E-02	0.103656				
151	13:12:05 .	8.62E-02	0.093707				

CAT, DeKalb, Illinois 3/12-15/1996						
Large Fan		**Screed inside, engine outside**				
- 1302 Measurement Data ------ 1804892/2803 - 1996-03-14 16:26 - Page 1 -						
1302 Settings:						
--						
Compensate for Water Vap. Interference :		NO				
Compensate for Cross Interference :		NO				
Sample Continuously :		YES				
Pre-set Monitoring Period :		NO				
Measure						
Gas A: Formaldehyde :		NO				
Gas B: Carbon dioxide :		NO				
Gas C: Carbon monoxide :		NO				
Gas D: TOC as Propane :		NO				
Gas E: Sulfur hexafluoride :		YES				
Water Vapour :		NO				
Sampling Tube Length :		15.0 ft				
Air Pressure :		759.0 mmHg				
Normalization Temperature :		50.0 F				
General Information:						
--						
Start Time		: 1996-03-14 09:47				
Stop Time		: 1996-03-14 10:22				
Results Not Averaged						
Number of Event Marks :		5				
Number of Recorded Samples :		56				
Samples Measured From 1996-03-14 09:47						
--						
Samp.	Time	Response	Calibration			
No.	hh:mm:ss Event	PPM	Correction			
--						
1	9:47:48 .	3.40E-02	0.039044	**Background, in exhaust stack**		
2	9:48:31 .	3.03E-02	0.03517			
3	9:49:07 .	2.81E-02	0.032866			**SF6 flow rates**
4	9:50:01 .	3.24E-02	0.037369			Rt side
5	9:50:37 .	3.29E-02	0.037893			0.5662 lpm
6	9:51:12 .	2.93E-02	0.034123			Both sides
7	9:51:48 .	4.41E-02	0.04962			1.1235 lpm
8	9:52:23 .	6.50E-02	0.071506			
9	9:52:58 .	1.89E-01	0.201379	Avg.	0.063435	
10	9:53:34 .	7.47E-02	0.081664	Std. Dev.	0.051267	
11	9:54:09 .	4.71E-02	0.052762	CV	80.82%	
9:54:45 User	1					
12	9:54:45 .	1.37E+01	14.61237	**Rt side only SF6 100% capture**		

13	9:55:23	1.40E+01	14.93843				
14	9:55:58	1.39E+01	14.82971				
15	9:56:33	1.38E+01	14.72103				
16	9:57:09	1.40E+01	14.93843				
17	9:57:44	1.40E+01	14.93843				
18	9:58:20	1.40E+01	14.93843	Avg.	14.89767	1341.61	Mean flow
19	9:58:55	1.41E+01	15.04717	Std. Dev.	0.099596	1328.28	Min
20	9:59:30	1.39E+01	14.82971	CV	0.67%	1357.708	Max
10:00:17 User		2					
21	10:00:17	2.70E+01	29.34076	Both sides SF6 100% capture			
22	10:00:55	2.67E+01	29.00214				
23	10:01:30	2.69E+01	29.22785				
24	10:02:05	2.69E+01	29.22785				
25	10:02:41	2.69E+01	29.22785				
26	10:03:16	2.68E+01	29.11498	Avg.	29.16336	1359.91	Mean flow
27	10:03:52	2.68E+01	29.11498	Std. Dev.	0.088796	1356.909	Min
28	10:04:27	2.69E+01	29.22785	CV	0.30%	1367.47	Max
10:05:03 User		3					
29	10:05:03	1.36E-01	0.145864	Placing SF6 into distribution tees			
30	10:05:43	5.05E-02	0.056322				
31	10:06:18	4.28E-02	0.048259				
10:06:54 User		4					
32	10:06:54	1.53E-01	0.16367	Rt side only, distribution			
33	10:07:29	1.24E+01	13.20261				
34	10:08:07	1.37E+01	14.61237				
35	10:08:43	1.05E+01	11.15131				
36	10:09:18	7.60E+00	8.040924				
37	10:10:24	1.34E+01	14.28659				
38	10:11:00	1.37E+01	14.61237				
39	10:11:35	9.07E+00	9.614495	Avg.	12.19602	81.87%	Ave Eff
40	10:12:11	1.11E+01	11.79793	Std. Dev.	2.299524	53.97%	Min Eff
41	10:12:46	1.17E+01	12.44561	CV	18.85%	98.08%	Max Eff
42	10:13:22	1.48E+01	15.80925				
43	10:13:57	1.61E+01	17.22854				
10:14:33 User		5					
44	10:14:33	1.71E+01	18.32386	Both sides, distribution			
45	10:15:10	2.83E+01	30.81164				
46	10:15:46	2.87E+01	31.26539				
47	10:16:21	2.70E+01	29.34076				
48	10:16:57	2.59E+01	28.10067				
49	10:17:32	2.39E+01	25.85641				
50	10:18:08	2.01E+01	21.62871				
51	10:18:43	2.44E+01	26.41622				
52	10:19:18	2.57E+01	27.87564	Avg.	27.7628	95.20%	Ave Eff
53	10:20:13	2.36E+01	25.52093	Std. Dev.	3.010658	74.16%	Min Eff
54	10:20:49	2.83E+01	30.81164	CV	10.84%	107.21%	Max Eff
55	10:21:24	5.48E-01	0.577619				
56	10:22:05	6.05E-01	0.637388				

CAT DeKalb, Illinois 3/12-15/1996

Large Fan Outside testing

- 1302 Measurement Data ------- 1804892/2803 - 1996-03-14 16:24 - Page 1 -

1302 Settings:

Compensate for Water Vap. Interference :	NO
Compensate for Cross Interference :	NO
Sample Continuously :	YES
Pre-set Monitoring Period :	NO
Measure	
Gas A: Formaldehyde :	NO
Gas B: Carbon dioxide :	NO
Gas C: Carbon monoxide :	NO
Gas D: TOC as Propane :	NO
Gas E: Sulfur hexafluoride :	YES
Water Vapour :	NO
Sampling Tube Length :	15.0 ft
Air Pressure :	759.0 mmHg
Normalization Temperature :	50.0 F

General Information:

Start Time	: 1996-03-14 10:58
Stop Time	: 1996-03-14 12:06
Results Not Averaged	
Number of Event Marks :	7
Number of Recorded Samples :	106

Samples Measured From 1996-03-14 10:58

Samp. No.	Time hh:mm:ss	Event	Response PPM	Calibration Correction		
1	10:58:43	3.67E-02	0.041872	Wind blowing front to back, 0 degrees		
2	10:59:25	3.96E-02	0.044908	Wind speed at about 6 mph		
3	11:00:01	3.03E-02	0.03517	Background, in exhaust stack		
4	11:00:36	2.76E-02	0.032343			
5	11:01:12	2.69E-02	0.03161			SF6 flow rates
6	11:01:47	3.12E-02	0.036112			Both sides
7	11:02:23	3.03E-02	0.03517			1.1235 lpm
8	11:02:58	3.05E-02	0.03538			
9	11:03:33	2.97E-02	0.034542	Avg.	0.034846	
10	11:04:09	2.81E-02	0.032866	Std. Dev.	0.004004	
11	11:04:44	2.57E-02	0.030353	CV	11.49%	
12	11:05:19	3.11E+00	3.272929	Rt side only, distribution		
13	11:05:57	3.54E+00	3.727087			

14	11:06	5E+01	11.15131				
15	11:07:	9E+01	12.66175				
16	11:07:	1E+01	12.878				
17	11:08:	4E+01	13.20261				
18	11:09:0	2E+01	12.98617				
19	11:09:4	6E+01	15.59136				
20	11:10:1	2E+00	10.52726	Avg.	12.41263	83.31%	Ave Eff
21	11:10:5	5E+01	15.48246	Std. Dev.	1.930439	70.65%	Min Eff
22	11:11:27	9E+01	15.91825	CV	15.55%	106.83%	Max Eff
11:12:02 User		1					
23	11:12:0	12E+01	11.9058	**Both sides, distribution**			
24	11:12:33	.94E+01	20.85502				
25	11:13:16	?.11E+01	22.7367				
26	11:13:51	2.65E+01	28.77657				
27	11:14:26	2.27E+01	24.51625				
28	11:15:02	2.23E+01	24.07058				
29	11:15:37	2.56E+01	27.76318				
30	11:16:13	2.40E+01	25.96831				
31	11:16:48	1.53E+01	16.35452	Avg.	23.82946	82.61%	Ave Eff
32	11:17:26	2.28E+01	24.62775	Std. Dev.	3.544242	56.70%	Min Eff
33	11:18:04	2.10E+01	22.62576	CV	14.87%	99.77%	Max Eff
34	11:19:10	5.96E+00	6.292742				
11:19:48 User		2					
35	11:19:48	4.43E-01	0.46754	**Wind blowing right to left, 90 degrees**			
36	11:20:26	4.55E-02	0.051086	**Wind speed at about 6 to 7 mph**			
37	11:21:02	3.50E-02	0.040091				
38	11:21:37	6.09E-02	0.067213				
39	11:22:13	5.16E-02	0.057474				
40	11:22:48	3.14E-02	0.036322				
41	11:23:24	4.16E-02	0.047002				
42	11:23:59	4.09E-02	0.04627				
11:24:34 User		3					
43	11:24:34	2.78E-02	0.032552	**Rt side only, distribution**			
44	11:25:10	2.60E+00	2.734945				
45	11:25:48	3.93E+00	4.139445				
46	11:26:23	7.37E+00	7.795286				
47	11:26:59	1.29E+01	13.74422				
48	11:27:34	6.68E+00	7.059286				
49	11:28:09	7.62E+00	8.062291	Avg.	8.13828	54.62%	Ave Eff
50	11:29:04	7.44E+00	7.870029	Std. Dev.	2.851964	27.78%	Min Eff
51	11:29:40	7.84E+00	8.297405	CV	35.04%	92.24%	Max Eff
11:30:15 User		4					
52	11:30:15	8.10E+00	8.575448	**Both sides, distribution**			
53	11:30:50	4.92E+00	5.188119				
54	11:31:26	9.36E+00	9.925671				
55	11:32:01	8.07E+00	8.543356				
56	11:32:37	9.45E+00	10.02229				
57	11:33:12	1.30E+01	13.85263				
58	11:33:48	1.44E+01	15.3736				
59	11:34:23	1.14E+01	12.12164				
60	11:34:58	1.05E+01	11.15131	Avg.	14.72143	51.04%	Ave Eff

61	11:35:34	2.58E+01	2[illegible]3814	Std. Dev.	6.682565	29.62%	Min Eff
62	11:36:12	2.18E+01	2[illegible]1423	CV	45.39%	97.03%	Max Eff
63	11:36:47	3.23E-01	0.3[illegible]1773				
64	11:37:27	1.02E-01	0.1[illegible]0254				
65	11:38:03	4.08E-02	0.046165				
66	11:38:49	3.47E-02	0.039777				
67	11:39:24	3.00E-02	0.034856	**Wind blowing back to front, 180 degrees**			
68	11:40:00	2.05E-02	0.024909	**Wind speed at about 6 to 7 mph**			
69	11:40:35	3.62E-02	0.041348				
70	11:41:11	2.81E-02	0.032866				
11:41:46	User	5	7				
71	11:41:46	2.45E-01	0.260045	**Rt side only, distribution**			
72	11:42:21	8.11E+00	8.586146				
73	11:42:59	5.59E+00	5.899399				
74	11:43:35	1.64E+01	17.55681				
75	11:44:10	8.29E+00	8.778757				
76	11:44:46	6.22E+00	6.569378				
77	11:45:21	7.34E+00	7.763257				
78	11:45:57	6.92E+00	7,315131	Avg.	9.360972	62.83%	Ave Eff
79	11:46:32	1.11E+01	11.79793	Std. Dev.	3,779396	39.59%	Min Eff
80	11:47:07	8.69E+00	9.207119	CV	40.37%	117.83%	Max Eff
11:47:45	User	6					
81	11:47:45	1.31E+01	13.96108	**Both sides, distribution**			
82	11:48:23	6.67E+00	7.048629				
83	11:49:30	8.53E+00	9.035718				
84	11:50:05	8.73E+00	9.249981				
85	11:50:41	7.90E+00	8.361551				
86	11:51:16	1.96E+01	21.07591				
87	11:51:54	2.49E+01	26.97687	Avg.	16.15689	56.01%	Ave Eff
88	11:52:29	1.53E+01	16.35452	Std. Dev.	9.322035	24.44%	Min Eff
89	11:53:07	2.86E+01	31.1519	CV	57.70%	108.00%	Max Eff
11:53:45	User	7					
90	11:53:45	3.23E+01	35.37435	**Both sides SF6 100% capture**			
91	11:54:21	2.19E+01	23.62543				
92	11:54:56	2.50E+01	27.0891				
93	11:55:31	2.78E+01	30.24523				
94	11:56:07	1.51E+01	16.13632				
95	11:56:45	2.67E+01	29.00214				
96	11:57:22	2.67E+01	29.00214				
97	11:57:58	2.65E+01	28.77657	Avg.	28.84425	1374.955	Mean flow
98	11:58:33	2.64E+01	28.66384	Std. Dev.	0.151303	1367.47	Min
99	11:59:28	2.65E+01	28.77657	CV	0.52%	1383.609	Max
100	12:00:04	2.07E-01	0.220235				
101	12:00:44	6.09E-02	0.067213				
102	12:01:19	4.11E-02	0.046479				
103	12:01:55	3.40E-02	0.039044				
104	12:02:30	3.49E-02	0.039987				
105	12:03:06	3.97E-02	0.045013				
12:05:58	1302						
106	12:05:58	4.68E-02	0.052448				
1.	12:07:44		3.23E-02	0.037264	**Wind blowing left to right, 270 degrees**		

2	12:08:27		3.36E-02	0.0	Wi[illegible]d speed at about 6 mph			
3	12:09:02		3.42E-02	0.03	Background, in exhaust stack			
12:09:37 User		1						
4	12:09:37		2.55E-02	0.030	Rt side only, distribution			
5	12:10:12		4.05E+00	4.266				
6	12:10:50		1.42E+01	15.155				
7	12:11:26		1.08E+01	11.47				
8	12:12:01		1.04E+01	11.043				
9	12:12:36		8.48E+00	8.9821				
10	12:13:12		5.60E+00	5.9100	Avg.	9.678156	64.95%	Ave Eff
11	12:13:47		9.96E+00	10.570	Std. Dev.	3.380239	28.63%	Min Eff
12	12:14:22		9.45E+00	10.0222	CV	34.93%	101.72%	Max Eff
12:14:58 User		2						
13	12:14:58		1.03E+01	10.93601	Both sides, distribution			
14	12:15:33		3.30E+01	36.17866				
15	12:16:22		1.37E+01	14.61237				
16	12:17:00		2.13E+01	22.95869				
17	12:17:37		2.14E+01	23.06973				
18	12:18:13		1.59E+01	17.00985				
19	12:18:50		2.47E+01	26.75251				
20	12:19:28		1.91E+01	20.52392	Avg.	21.03742	72.95%	Ave Eff
21	12:20:04		1.90E+01	20.41362	Std. Dev.	3.823434	50.67%	Min Eff
22	12:20:39		2.13E+01	22.95869	CV	18.17%	92.76%	Max Eff

CAT, DeKalb, Illinois 3/12-15/1996
Large fan Outside testing

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1302 Settings:

Compensate for Water Vap. Interference	:	NO
Compensate for Cross Interference	:	NO
Sample Continuously	:	YES
Pre-set Monitoring Period	:	NO

Measure

Gas A: Formaldehyde	:	NO
Gas B: Carbon dioxide	:	NO
Gas C: Carbon monoxide	:	NO
Gas D: TOC as Propane	:	NO
Gas E: Sulfur hexafluoride	:	YES
Water Vapour	:	NO

Sampling Tube Length	:	15.0 ft
Air Pressure	:	759.0 mmHg
Normalization Temperature	:	50.0 F

General Information:

Start Time	:	1996-03-14 14:09
Stop Time	:	1996-03-14 15:10
Results Not Averaged		
Number of Event Marks	:	10
Number of Recorded Samples	:	98

Samples Measured From 1996-03-14 14:10

Samp. No.	Time hh:mm:ss	Event	Response PPM	Calibration Correction	
12:21:14	User	3			
23	12:21:14	.	8.53E-01	0.897541	Wind blowing back to front, 180 degrees
24	12:21:55	.	7.35E-02	0.080407	Wind speed at about 9 mph
25	12:22:30	.	3.16E-02	0.036531	
26	12:23:06	.	3.16E-02	0.036531	
27	12:23:41	.	4.40E-02	0.049516	
28	12:24:16	.	4.68E-02	0.052448	
29	12:24:52	.	1.16E+00	1.21982	
12:25:27	User	4			
30	12:25:27	.	2.33E-01	0.247473	Rt side only, distribution
31	12:26:03	.	7.08E+00	7.485786	
32	12:27:11	.	1.51E+01	16.13632	
33	12:27:47	.	1.58E+01	16.90055	

34	12:28:22	9.05E+00	9.593044				
35	12:28:58	8.98E+00	9.517973				
36	12:29:33	4.20E+00	4.425173	Avg.	10.28636	69.04%	Ave Eff
37	12:30:08	1.13E+01	12.0137	Std. Dev.	4.484421	29.70%	Min Eff
38	12:30:44	5.89E+00	6.218295	CV	43.60%	108.30%	Max Eff
12:31:19 User		5					
39	12:31:19	8.12E+00	8.596844	Both sides, distribution			
40	12:31:55	8.50E+00	9.003589				
41	12:32:30	1.78E+01	19.09245				
42	12:33:06	8.75E+00	9.271414				
43	12:33:41	1.93E+01	20.74462				
44	12:34:19	1.91E+01	20.52392				
45	12:34:54	1.23E+01	13.09438	Avg.	17.46514	60.56%	Ave Eff
46	12:35:32	1.75E+01	18.76287	Std. Dev.	6.768027	31.22%	Min Eff
47	12:36:08	2.69E+01	29.22785	CV	38.75%	101.34%	Max Eff
1	14:10:04	3.91E-02	0.044385	Wind blowing left to right, 270 degrees			
2	14:10:47	3.13E-02	0.036217	Wind speed at 3 to 4 mph			
3	14:11:23	2.61E-02	0.030772	Background, in exhaust stack			
4	14:11:58	2.86E-02	0.03339				
14:12:33 User		1					
5	14:12:33	3.20E+00	3.367943	Rt side only, distribution			
6	14:13:11	8.50E+00	9.003589				
7	14:13:47	1.36E+01	14.50375				
8	14:14:22	5.67E+00	5.984413				
9	14:14:57	5.69E+00	6.005669				
10	14:15:33	7.45E+00	7.880708				
11	14:16:08	7.03E+00	7.432448	Avg.	10.0279	67.30%	Ave Eff
12	14:16:43	1.98E+01	21.29694	Std. Dev.	5.286167	40.16%	Min Eff
13	14:17:21	7.67E+00	8.115714	CV	52.71%	142.93%	Max Eff
14:17:59 User		2					
14	14:17:59	4.37E+00	4.605181	Both sides, distribution			
15	14:18:34	1.32E+01	14.06955				
16	14:19:10	2.48E+01	26.86467				
17	14:19:48	1.31E+01	13.96108				
18	14:20:37	9.91E+00	10.51651				
19	14:21:12	1.34E+01	14.28659				
20	14:21:47	1.30E+01	13.85263	Avg.	18.52231	63.56%	Ave Eff
21	14:22:22	2.54E+01	27.53835	Std. Dev.	7.257959	36.09%	Min Eff
22	14:23:00	2.50E+01	27.0891	CV	39.18%	94.50%	Max Eff
14:23:36 User		3					
23	14:23:36	1.48E+01	15.80925	Wind blowing front to back, 0 degrees			
24	14:24:14	1.35E+00	1.419405	Wind speed at 5 to 6 mph			
25	14:24:52	3.66E-02	0.041767				
26	14:25:27	4.65E-02	0.052133				
27	14:26:03	9.45E-02	0.102399				
28	14:26:38	4.49E-02	0.050458				
29	14:27:13	5.13E-02	0.05716				
30	14:27:49	3.70E-02	0.042186				
31	14:28:24	1.27E-01	0.136437				
32	14:29:00	2.54E-02	0.030039				

33	14:29:35		2.29E-02	0.027422				
34	14:30:10		8.48E-02	0.092241				
35	14:31:17		1.81E-01	0.192999				
14:31:52	User	4						
36	14:31:52		6.27E+00	6.6226	Rt side only, distribution			
37	14:32:30		1.29E+01	13.74422				
38	14:33:06		8.60E+00	9.110697				
39	14:33:41		1.12E+01	11.9058				
40	14:34:16		1.16E+01	12.33759				
41	14:34:52		8.49E+00	8.99288				
42	14:35:27		1.13E+01	12.0137	Avg.	11.23911	75.43%	Ave Eff
43	14:36:02		9.84E+00	10.44126	Std. Dev.	1.636863	60.35%	Min Eff
44	14:36:38		1.07E+01	11.36673	CV	14.56%	92.24%	Max Eff
14:37:13	User	5						
45	14:37:13		5.28E+00	5.570141	Both sides, distribution			
46	14:37:49		2.66E+01	28.88934				
47	14:38:27		2.42E+01	26.1922				
48	14:39:02		2.72E+01	29.56667				
49	14:39:38		2.45E+01	26.52829				
50	14:40:13		1.85E+01	19.86258				
51	14:41:08		2.41E+01	26.08024	Avg.	25.6859	88.15%	Ave Eff
52	14:41:43		2.13E+01	22.95869	Std. Dev.	3.113776	68.16%	Min Eff
53	14:42:19		2.35E+01	25.40916	CV	12.12%	101.46%	Max Eff
14:42:54	User	6						
54	14:42:54		2.36E+01	25.52093	Both sides SF6 100% capture			
55	14:43:30		2.60E+00	2.734945				
56	14:44:07		1.38E+01	14.72103				
57	14:44:43		1.41E+01	15.04717			SF6 flow rates	
58	14:45:18		1.41E+01	15.04717			Both sides	
59	14:45:54		2.68E+01	29.11498			1.1235	lpm
60	14:46:31		2.68E+01	29.11498				
61	14:47:07		2.69E+01	29.22785				
62	14:47:42		2.69E+01	29.22785				
63	14:48:18		2.68E+01	29.11498				
64	14:48:53		2.67E+01	29.00214				
65	14:49:28		2.68E+01	29.11498	Avg.	29.13756	1361.114	Mean flow
66	14:50:04		2.69E+01	29.22785	Std. Dev.	0.094423	1356.909	Min
67	14:50:50		2.69E+01	29.22785	CV	0.32%	1367.47	Max
14:51:26	User	7						
68	14:51:26		1.78E-01	0.189856	Wind blowing right to left, 90 degrees			
69	14:52:06		4.77E-02	0.05339	Wind speed at about 6 to 7 mph			
70	14:52:41		3.31E-02	0.038102				
71	14:53:17		2.88E-02	0.033599				
72	14:53:52		3.01E-02	0.034961				
73	14:54:27		2.94E-02	0.034228				
74	14:55:03		3.42E-02	0.039254				
75	14:55:38		2.60E-02	0.030668				
14:56:14	User	8						
76	14:56:14		3.10E-02	0.035903	Rt side only, distribution			
77	14:56:49		3.23E-01	0.341773				
78	14:57:25		7.86E+00	8.318786				

79	14:58:03	.	9.84E+00	10.44126				
80	14:58:38	.	1.22E+01	12.98617				
81	14:59:13	.	1.36E+01	14.50375				
82	14:59:49	.	1.24E+01	13.20261				
83	15:00:55	.	1.06E+01	11.25901	Avg.	11.37516	76.34%	Ave Eff
84	15:01:31	.	7.82E+00	8.276025	Std. Dev.	2.266603	55.54%	Min Eff
85	15:02:06	.	1.13E+01	12.0137	CV	19.93%	97.34%	Max Eff
15:02:42	User	9						
86	15:02:42	.	1.25E+01	13.31087	**Both sides, distribution**			
87	15:03:17	.	1.72E+01	18.43357				
88	15:03:52	.	1.16E+01	12.33759				
89	15:04:28	.	1.61E+01	17.22854				
90	15:05:03	.	7.94E+00	8.404321				
91	15:05:39	.	1.44E+01	15.3736				
92	15:06:14	.	2.02E+01	21.73936	Avg.	16.57277	56.87%	Ave Eff
93	15:06:52	.	1.86E+01	19.97272	Std. Dev.	4.384926	28.84%	Min Eff
94	15:07:27	.	1.78E+01	19.09245	CV	26.46%	74.60%	Max Eff
15:08:03	User	10						
95	15:08:03	.	1.39E+01	14.82971	end			
96	15:08:41	.	1.85E-01	0.197189				
97	15:09:18	.	4.60E-02	0.05161				
98	15:09:54	.	2.67E-02	0.031401				

CAT, DeKalb, Illinois 3/12-15/1996							
Large fan		Outside testing					
- 1302 Measurement Data ------- 1804892/2803 - 1996-03-14 16:21 - Page 1 -							
1302 Settings:							
--							
Compensate for Water Vap. Interference : NO							
Compensate for Cross Interference : NO							
Sample Continuously : YES							
Pre-set Monitoring Period : NO							
Measure							
Gas A: Formaldehyde : NO							
Gas B: Carbon dioxide : NO							
Gas C: Carbon monoxide : NO							
Gas D: TOC as Propane : NO							
Gas E: Sulfur hexafluoride : YES							
Water Vapour : NO							
Sampling Tube Length : 15.0 ft							
Air Pressure : 759.0 mmHg							
Normalization Temperature : 50.0 F							
General Information:							
--							
Start Time : 1996-03-14 15:14							
Stop Time : 1996-03-14 16:17							
Results Not Averaged							
Number of Event Marks : 8							
Number of Recorded Samples : 100							
Samples Measured From 1996-03-14 15:15							
--							
Samp. No.	Time hh:mm:ss	Event	Response PPM	Calibration Correction			
1	15:15:04	.	2.55E-02	0.030144	Wind blowing back to front, 180 degrees		
2	15:15:47	.	3.08E-02	0.035694	Wind speed at about 4 to 5 mph		
3	15:16:22	.	9.65E-02	0.104494			
4	15:16:58	.	1.14E-01	0.122822			
5	15:17:33	.	7.10E-02	0.077789			
15:18:08	User	1					
6	15:18:08	.	7.89E+00	8.35086	Rt side only, distribution		
7	15:18:46	.	9.93E+00	10.53801			
8	15:19:22	.	9.04E+00	9.582318			
9	15:19:57	.	1.16E+01	12.33759			
10	15:20:43	.	1.39E+01	14.82971			
11	15:21:19	.	1.51E+01	16.13632	Avg.	13.42278	90.09% Ave Eff
12	15:21:54	.	1.29E+01	13.74422	Std. Dev.	2.739877	64.31% Min Eff

13	15:22:29	1.57E+01	16.79128	CV	20.41%	112.69%	Max Eff
15:23:04 User	2						
14	15:23:04	9.97E+00	10.58102	Both sides, distribution			
15	15:23:40	8.91E+00	9.442917				
16	15:24:16	2.40E+01	25.96831				
17	15:24:53	2.40E+01	25.96831				
18	15:25:29	2.68E+01	29.11498				
19	15:26:04	2.59E+01	28.10067				
20	15:26:39	2.97E+01	32.4022				
21	15:27:15	1.97E+01	21.18641	Avg.	25.93084	88.99%	Ave Eff
22	15:27:50	2.24E+01	24.18195	Std. Dev.	3.991621	70.43%	Min Eff
23	15:28:25	1.91E+01	20.52392	CV	15.39%	99.91%	Max Eff
24	15:29:01	1.42E+00	1.492961				
25	15:29:41	6.90E-02	0.075695				
26	15:30:17	4.65E-01	0.490602				
27	15:31:23	6.44E-02	0.070878				
28	15:31:58	4.41E-02	0.04962				
29	15:32:34	6.54E-02	0.071925				
30	15:33:09	6.52E-02	0.071716				
31	15:33:45	2.24E-01	0.238044				
32	15:34:20	2.98E-01	0.315576				
33	15:34:55	9.15E-02	0.099258				
15:35:31 User	3						
34	15:35:31	1.41E-01	0.151101	Wind blowing left to right, 270 degrees			
35	15:36:07	7.64E+00	8.083659	Wind speed at 3 to 4 mph			
36	15:36:44	1.08E+01	11.47449	Rt side only, distribution			
37	15:37:20	8.80E+00	9.325				
38	15:37:55	7.28E+00	7.699208				
39	15:38:31	7.65E+00	8.094344				
40	15:39:06	1.13E+01	12.0137	Avg.	9.526898	63.94%	Ave Eff
41	15:39:41	1.16E+01	12.33759	Std. Dev.	2.099929	48.24%	Min Eff
42	15:40:17	6.80E+00	7.187188	CV	22.04%	82.80%	Max Eff
15:41:11 User	4						
43	15:41:11	1.91E+01	20.52392	Both sides, distribution			
44	15:41:49	1.29E+01	13.74422				
45	15:42:27	2.07E+01	22.29312				
46	15:43:05	2.11E+01	22.7367				
47	15:43:40	1.56E+01	16.68204				
48	15:44:18	1.69E+01	18.10455				
49	15:44:54	3.18E+01	34.80092	Avg.	21.35597	73.29%	Ave Eff
50	15:45:32	2.07E+01	22.29312	Std. Dev.	6.280786	47.17%	Min Eff
51	15:46:07	1.88E+01	20.19311	CV	29.41%	119.43%	Max Eff
52	15:46:42	7.84E-01	0.825143				
53	15:47:22	8.09E-02	0.088157				
54	15:47:58	2.89E-02	0.033704				
55	15:48:33	3.18E-02	0.036741				
56	15:49:09	2.45E-02	0.029097				
57	15:49:44	2.80E-02	0.032762				
58	15:50:31	3.83E-02	0.043547				
59	15:51:06	4.15E-01	0.438191				
15:51:41 User	5						

60	15:51:41	.	3.86E+00	4.065401	Wind blowing right to left, 90 degrees			
61	15:52:19	.	1.08E+01	11.47449	Wind speed at about 6 to 7 mph			
62	15:52:55	.	7.39E+00	7.81664	Rt side only, distribution			
63	15:53:30	.	1.20E+01	12.76986				
64	15:54:05	.	9.39E+00	9.957876				
65	15:54:41	.	8.59E+00	9.099985	Avg.	9.709183	65.16%	Ave Eff
66	15:55:16	.	9.23E+00	9.786148	Std. Dev.	1.980177	52.46%	Min Eff
67	15:55:52	.	6.68E+00	7.059286	CV	20.39%	85.70%	Max Eff
15:56:27	User	6						
68	15:56:27	.	8.92E+00	9.453638	Both sides, distribution			
69	15:57:03	.	1.16E+01	12.33759				
70	15:57:38	.	1.12E+01	11.9058				
71	15:58:13	.	1.21E+01	12.878				
72	15:58:49	.	7.78E+00	8.233269				
73	15:59:24	.	1.43E+01	15.26476				
74	15:59:59	.	7.57E+00	8.008876	Avg.	12.79517	43.91%	Ave Eff
75	16:01:06	.	1.21E+01	12.878	Std. Dev.	4.06718	27.48%	Min Eff
76	16:01:41	.	1.94E+01	20.85502	CV	31.79%	71.57%	Max Eff
77	16:02:19	.	1.44E+01	15.3736				
78	16:02:57	.	6.02E-02	0.06648				
79	16:03:35	.	2.78E-02	0.032552				
80	16:04:10	.	2.46E-02	0.029202				
81	16:04:45	.	2.35E-02	0.02805				
82	16:05:21	.	5.93E-02	0.065537				
16:05:56	User	7						
83	16:05:56	.	2.26E-01	0.24014	Wind blowing front to back, 0 degrees			
84	16:06:32	.	1.11E+01	11.79793	Wind speed at about 6 mph			
85	16:07:09	.	1.13E+01	12.0137	Rt side only, distribution			
86	16:07:45	.	1.14E+01	12.12164				
87	16:09:49	.	1.17E+01	12.44561				
88	16:10:24	.	1.19E+01	12.66175				
89	16:11:00	.	1.17E+01	12.44561	Avg.	12.08314	81.09%	Ave Eff
90	16:11:35	.	9.81E+00	10.40902	Std. Dev.	0.75209	69.86%	Min Eff
91	16:12:10	.	1.20E+01	12.76986	CV	6.22%	85.70%	Max Eff
16:12:46	User	8						
92	16:12:46	.	1.12E+01	11.9058	Both sides, distribution			
93	16:13:21	.	2.39E+01	25.85641				
94	16:13:59	.	2.22E+01	23.95924				
95	16:14:34	.	2.18E+01	23.51423				
96	16:15:09	.	2.21E+01	23.84794				
97	16:15:45	.	2.00E+01	21.51808				
98	16:16:20	.	1.61E+01	17.22854	Avg.	22.19447	76.16%	Ave Eff
99	16:16:58	.	2.25E+01	24.29335	Std. Dev.	3.25377	59.12%	Min Eff
100	16:17:36	.	1.62E+01	17.33793	CV	14.66%	88.73%	Max Eff

CAT, DeKalb, Illinois 3/12-15/1996

Calibration done in the lab prior to survey.

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1302 Settings:

Compensate for Water Vap. Interference	: NO	
Compensate for Cross Interference	: NO	This is the B&K used in
Sample Continuously	: YES	the Barber-Greene,Caterpillar
Pre-set Monitoring Period	: NO	March '96 servey.

Measure

Gas A: Formaldehyde	: NO
Gas B: Carbon dioxide	: NO
Gas C: Carbon monoxide	: NO
Gas D: TOC as Propane	: NO
Gas E: Sulfur hexafluoride	: YES
Water Vapour	: NO

Sampling Tube Length	: 15.0 ft
Air Pressure	: 768.9 mmHg
Normalization Temperature	: 74.5 F

General Information:

Start Time	: 1996-03-08 08:21
Stop Time	: 1996-03-08 10:29
Results Not Averaged	
Number of Event Marks	: 10
Number of Recorded Samples	: 209

Samples Measured From 1996-03-08 08:21

Samp. No.	Time hh:mm:ss	Event	SF6 Gas ppm		
1	8:21:35	.	1.91E-02		
2	8:22:18	.	1.33E-02		
3	8:22:53	.	1.52E-02		
4	8:23:28	.	1.15E-02		
5	8:24:04	.	1.58E-02		
6	8:24:39	.	1.85E-02		
7	8:25:14	.	1.55E-02	Room air, vent lab	
8	8:25:50	.	1.37E-02	Average =	0.0154
9	8:26:25	.	1.63E-02	Std. Dev.=	0.0024
8:27:01	User	1			
10	8:27:01	.	1.17E-02		
11	8:27:36	.	9.69E-03		
12	8:28:12	.	1.17E-02		

13	8:28:47		1.18E-02	N2 supply bag	
14	8:29:22		9.41E-03	Average =	0.0116
15	8:29:58		1.51E-02	Std. Dev.=	0.0020
31:04 User		2			
16	8:31:04		1.83E-02	N2 supply bag 2	
17	8:31:40		1.65E-02		
32:15 User		3			
18	8:32:15		1.43E-02		
19	8:32:50		8.97E-03	N2 only in calibration bag	
20	8:33:26		1.54E-02	Average =	0.0120
21	8:34:01		9.16E-03	Std. Dev.=	0.0034
34:37 User		4			
22	8:34:37		1.00E-02		
23	8:35:12		1.62E-02		
24	8:35:48		1.66E-02		
25	8:36:23		1.20E-02		
26	8:36:59		1.25E-02		
27	8:37:34		1.44E-02		
28	8:38:10		1.38E-02		
29	8:38:45		1.34E-02		
30	8:39:20		1.50E-02		
31	8:39:56		1.40E-02		
32	8:40:51		1.24E-02		
33	8:41:26		1.55E-02		
34	8:42:01		1.12E-02		
35	8:42:37		1.15E-02		
36	8:43:12		1.34E-02		
37	8:43:48		1.66E-02		
38	8:44:23		1.34E-02		
39	8:44:58		1.39E-02		
40	8:45:34		1.30E-02		
41	8:46:09		1.71E-02		
42	8:46:45		1.62E-02		
43	8:47:20		1.42E-02		
44	8:47:55		1.61E-02		
45	8:48:31		1.03E-02		
46	8:49:06		1.20E-02		
47	8:49:41		1.40E-02		
48	8:50:28		1.45E-02		
49	8:51:03		1.17E-02		
50	8:51:38		1.44E-02		
51	8:52:14		1.83E-02		
52	8:52:49		1.60E-02		
53	8:53:25		1.21E-02		
54	8:54:00		1.19E-02		
55	8:54:35		1.50E-02		
56	8:55:11		1.43E-02		
57	8:55:46		1.32E-02		
58	8:56:22		8.05E-03		
59	8:56:57		1.70E-02		
60	8:57:32		1.33E-02		

61	8:[illegible]:08	1.77E-02		
62	8:[illegible]:43	1.45E-02		
63	8:59:19	1.35E-02		
64	8:59:54	1.45E-02		
65	9:01:01	1.53E-02		
66	9:01:36	1.47E-02		
67	9:02:11	1.37E-02		
68	9:02:47	1.29E-02		
69	9:03:22	1.26E-02		
70	9:03:58	1.63E-02		
71	9:04:33	1.21E-02		
72	9:05:09	1.53E-02		
73	9:05:44	1.54E-02		
74	9:06:19	9.10E-03		
75	9:06:55	1.33E-02		
76	9:07:30	1.19E-02		
77	9:08:06	1.53E-02		
78	9:08:41	1.79E-02		
79	9:09:16	1.24E-02		
80	9:09:52	1.72E-02	Room air, vent lab	
81	9:10:47	1.61E-02	Average =	0.0141
82	9:11:22	2.07E-02	Std. Dev.=	0.0021
9:11:57	User	5		
83	9:11:57	1.89E-02		
84	9:12:33	1.01E-02		
85	9:13:08	1.59E-02		
86	9:13:43	1.18E-02		
87	9:14:19	8.29E-03	N2 in a calibration bag	
88	9:14:54	1.12E-02	Average =	0.0113
89	9:15:30	1.06E-02	Std. Dev.=	0.0025
90	9:16:05	1.66E-02		
91	9:16:40	1.27E-02		
92	9:17:16	1.37E-02		
93	9:17:51	1.23E-02		
94	9:18:27	1.31E-02		
95	9:19:02	1.50E-02		
96	9:19:37	1.63E-02		
97	9:20:24	1.36E-02		
98	9:20:59	1.63E-02		
99	9:21:34	1.54E-02		
100	9:22:10	1.51E-02		
101	9:22:45	1.58E-02		
102	9:23:20	1.50E-02		
103	9:23:56	1.26E-02		
104	9:24:31	1.26E-02		
105	9:25:07	1.28E-02		
106	9:25:42	1.71E-02		
107	9:26:17	1.55E-02		
108	9:26:53	1.69E-02		
109	9:27:28	1.66E-02		
110	9:28:04	1.37E-02		

111	9:28:39	1.23E-02		
112	9:29:14	1.94E-02		
113	9:29:50	1.18E-02		
114	9:30:56	1.47E-02		
115	9:31:32	1.44E-02		
116	9:32:07	1.52E-02		
117	9:32:42	1.47E-02		
118	9:33:18	1.38E-02		
119	9:33:53	1.43E-02		
120	9:34:29	2.10E-02		
121	9:35:04	2.41E-02		
122	9:35:40	2.09E-02		
123	9:36:15	2.22E-02		
124	9:36:50	1.82E-02		
125	9:37:26	1.74E-02		
126	9:38:01	1.91E-02		
127	9:38:37	1.70E-02		
128	9:39:12	1.50E-02		
129	9:39:47	1.54E-02		
130	9:40:42	2.01E-02		
9:41:18 User		6		
131	9:41:18	2.85E-02		
132	9:41:53	1.90E+00		
133	9:42:31	1.90E+00		
134	9:43:06	1.90E+00	2 ppm SF6 in N2	
135	9:43:42	1.91E+00	Average =	1.9033
136	9:44:17	1.90E+00	Std. Dev.=	0.0052
137	9:44:53	1.91E+00		
138	9:45:28	1.86E+01	20 ppm SF6 in N2	
139	9:46:03	1.87E+01	Average =	18.6667
140	9:46:39	1.87E+01	Std. Dev.=	0.0577
141	9:47:16	8.01E-02		
142	9:47:54	2.93E-02		
143	9:48:30	2.52E-02		
144	9:49:05	1.76E-02		
145	9:49:40	1.96E-02		
146	9:50:27	1.87E-02		
147	9:51:02	1.29E-02		
148	9:51:37	1.73E-02		
149	9:52:13	1.29E-02		
150	9:52:48	4.00E-02		
151	9:53:23	2.28E-02		
152	9:53:59	1.40E-02		
153	9:54:34	1.76E-02		
9:55:10 User		7		
154	9:55:10	2.33E+01		
155	9:55:50	2.34E+01		
156	9:56:25	2.34E+01		
157	9:57:01	2.34E+01	25 ppm SF6 in N2	
158	9:57:36	2.35E+01	Average =	23.4000
159	9:58:12	2.34E+01	Std. Dev.=	0.0632

160	9:58:47	.	9.25E		
161	9:59:27	.	2.81E-		
10:00:03	User	8			
162	10:00:03	.	5.28E+01	.3 ppm SF6 in N2	
163	10:01:14	.	5.32E+01	verage =	53.0333
164	10:01:50	.	5.31E+01	d. Dev.=	0.2082
165	10:02:25	.	2.20E-0		
166	10:03:05	.	5.32E-02		
167	10:03:41	.	3.47E-02		
168	10:04:16	.	2.47E-02		
10:04:52	User	9			
169	10:04:52	.	2.17E-02		
170	10:05:27	.	2.13E-02		
171	10:06:03	.	2.24E-02	N2 supply bag	
172	10:06:38	.	1.85E-02	Average =	0.0210
173	10:07:13	.	2.12E-02	Std. Dev.=	0.0015
10:07:49	User	10			
174	10:07:49	.	2.52E-02		
175	10:08:24	.	7.77E+01	99.7 ppm SF6 in N2	
176	10:09:05	.	7.80E+01	Average =	77.9333
177	10:09:40	.	7.81E+01	Std. Dev.=	0.2082
178	10:10:35	.	3.15E-01		
179	10:11:15	.	6.68E-02		
180	10:11:51	.	4.64E-02		
181	10:12:26	.	3.23E-02		
182	10:13:01	.	2.59E-02		
183	10:13:37	.	2.59E-02		
184	10:14:12	.	2.73E-02		
185	10:14:48	.	2.27E-02		
186	10:15:23	.	1.95E-02		
187	10:15:58	.	2.20E-02		
188	10:16:34	.	2.53E-02		
189	10:17:09	.	1.88E-02		
190	10:17:45	.	2.24E-02		
191	10:18:20	.	1.77E-02		
192	10:18:56	.	1.74E-02		
193	10:19:31	.	1.68E-02		
194	10:20:17	.	1.17E-02		
195	10:20:53	.	1.63E-02		
196	10:21:28	.	1.72E-02		
197	10:22:04	.	1.81E-02		
198	10:22:39	.	2.32E-02		
199	10:23:14	.	1.65E-02		
200	10:23:50	.	2.18E-02		
201	10:24:25	.	1.89E-02		
202	10:25:01	.	1.69E-02		
203	10:25:36	.	1.09E-02		
204	10:26:12	.	1.47E-02		
205	10:26:47	.	1.99E-02		
206	10:27:22	.	1.71E-02		
207	10:27:58	.	2.06E-02	Room air, vent lab	

208	10:28:33	1.83E-02	Average =	0.0175	
209	10:29:09	1.82E-02	Std. Dev.=	0.0031	

Calibration curve data for ECTB#1267 B&K

Concentra	Response	Calibration Correction
0	0.0120	0.015964
2	1.9033	2.001218
20	18.6667	20.04617
25	23.4000	25.29743
60.3	53.0333	59.99566
99.7	77.9333