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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PLANT SURVEYED	Caterpillar Paving Products (Historical Name Barber-Greene) 12101 Barber-Greene Road DeKalb, Illinois 60115
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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 $Q_{(exh)}$ = 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 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

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

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

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

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)

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

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 $\mathbf{Q_{(exh)}}$ = 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

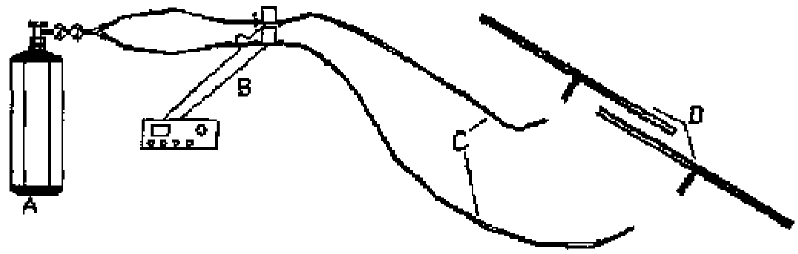
$\mathbf{C^*_{(SF6)}}$ = concentration of SF_6 (parts per million) detected in exhaust

[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–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

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

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 [$Q_{(SF_6)}$] 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

INDOOR, SMALL FAN			Range			
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	87%	
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%	38%	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	Time		Response	Calibration		
No	hh mm ss	Event	PPM	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 No	Time hh mm ss Event	Response PPM	Calibration 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 82871				
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 26	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... ...Kalb, 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 _1	11 15131				
15	11 07	8E+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 95E+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 138445				
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]8814	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					
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			

O Fan

2	12 08 27	3 36E-02	0 0..	Wind speed at about 6 mph		
3	12 09 02	3 42E-02	0 0.	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	10 022	CV	34 93%	101 72% Max Eff
12 14 58 User	2					
13	12 14 58	1 03E+01	10 9360	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 636853	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 16		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	6			
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 6 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 11496				
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 492951				
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 070678				
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 40802	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.

- 1302 Measurement Data ------- 1804892/2803 - 1996-03-08 10 31 - Page 1 -

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		8 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 5[illegible] 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 83E-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	[illegible]	20 ppm SF6 in N2	
139	9 46 03	1.87E+01	Average =	18 6667
140	9 46 39	[illegible]	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	erage = 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 88E-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 69E-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 89566
99 7	77 9333