IN-DEPTH SURVEY REPORT:

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

at

Roadtec Incorporated
Chattanooga, Tennessee

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REPORT DATE
August 12, 1999

REPORT NO
ECTB 208-13a

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Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
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SIC CODE	1611
SURVEY DATE	June 5-7, 1995
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EXECUTIVE SUMMARY

On June 5-7, 1995, researchers from the National Institute for Occupational Safety and Health (NIOSH) evaluated prototype engineering controls designed for the control of fugitive asphalt emissions during asphalt paving The Roadtec engineering control evaluation was completed as part of a Department of Transportation (DOT) project to evaluate the effectiveness of engineering controls on asphalt paving equipment NIOSH researchers are conducting the research through an inter-agency agreement with DOT's Federal Highway Administration Additionally, the National Asphalt Pavement 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 visit each participating manufacturer and evaluate their engineering control designs under managed environmental conditions The indoor evaluation uses tracer gas analysis techniques to both quantify the control's exhaust volume 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 Roadtec phase one evaluation

The Roadtec phase one evaluation studied the performance of a single engineering control design The prototype control was installed and evaluated on a Roadtec Model RP-180 asphalt paving machine The control design consisted of a long hood mounted above the auger area and a heavy canvas cover extending over the top of the auger area between the tractor and the screed Two exhaust fans removed air from within the partially enclosed auger area and from the rear of the slat conveyer tunnel The fans exhausted the air through two stacks mounted on the paver deck The average indoor capture efficiency was 100 percent with an exhaust volume near 2600 cubic feet per minute The average outdoor capture efficiency varied according to paver orientation When the paver was outdoors with the front facing north and the wind blowing from the north-northwest, evaluations revealed a capture efficiency of 96 percent on the right side and 64 percent on the left side resulting in an average capture efficiency of 81 percent When the paver was rotated so that the front faced to the west, evaluations revealed a capture efficiency of 66 percent on the right side and 96 percent on the left side resulting in an average capture efficiency of 81 percent Outdoor efficiency results also showed increased variation in capture efficiency as wind gusts hampered the control's ability to consistently capture the surrogate contaminant

Recommendations to Roadtec design engineers include (1) Increasing hood enclosure to minimize the wind effect near the ends of the auger area, (2) Modifying the hood enclosure so that workers in the screed area would be able to see into the auger area, and (3) Increasing the exhaust air distribution across the full length of the exhaust hood, possibly by modifying the hood to a slot inlet Although these recommendations are designed to further increase the prototype control's performance, the unmodified control system, as is, may be sufficient to significantly reduce worker exposures

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 received 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 document and evaluate control techniques and to determine 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 June 5-7, 1995, researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted an evaluation of a prototype engineering control designed for the control of fugitive asphalt emissions during asphalt paving The NIOSH researchers included Leroy Mickelsen, Chemical Engineer, Ken Mead, Mechanical Engineer, and Ronald Kovein, Engineering Technician, all from the NIOSH Engineering Controls Technology Branch (ECTB), Division of Physical Sciences and Engineering (DPSE) The DPSE researchers were assisted by Roadtec, Inc Staff, Chris McSharry, Chief Engineer, and Bart Harris, Engineering Technician

The Roadtec engineering control evaluation was completed as part of a Department of Transportation (DOT) project to evaluate the effectiveness of engineering controls on asphalt paving equipment NIOSH/DPSE researchers are conducting the research through an inter-agency agreement with DOT's Federal Highway Administration (FHWA) Additionally, the National Asphalt 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 were provided to the equipment manufacturers along with design change recommendations to maximize engineering control performance prior to the phase two evaluations The phase two evaluations, which began in mid-1996, included a performance evaluation of the prototype engineering controls under "real-life" conditions at an actual paving site The results from the Roadtec 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 the hood design and control ventilation parameters

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

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

For most ventilation controls, including the asphalt paving controls project, these three fundamentals, process enclosure, hood design, and capture velocity are interdependent A design which lacks process enclosure can overcome this shortcoming with good hood design and increased air flow Alternatively, lower capture velocities may be adequate if increased enclosure and proper hood design techniques are followed Additional information on designing ventilation controls can be found in the American Conference of Governmental Industrial Hygienists' (ACGIH) ***"INDUSTRIAL VENTILATION: A Manual of Recommended Practice"*** [ACGIH, 6500 Glenway Avenue, Building D-7, Cincinnati, Ohio 45211]

EVALUATION PROCEDURE

The Roadtec engineering control design was evaluated in a large bay area within the manufacturing plant The paver was parked with the screed and rear half of the tractor positioned in the bay area (referred to as the testing area) and the front half of the tractor, which included the engine and the ventilation control's exhaust outlets, positioned outside the building An overhead door separated the two areas The door was lowered to rest on top of the tractor and the remaining doorway openings around the tractor were sealed to isolate the front and rear halves of the paver During each test run, the engine exhaust and the engineering control exhaust were discharged 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 that was subsequently discharged 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 design, (2) Evaluate each hood's effectiveness in controlling and capturing a surrogate contaminant under the "controlled" indoor scenario Sulfur hexafluoride (SF_6) was the selected tracer gas At the concentrations generated for these evaluations, SF_6 behaves as a non-toxic, surrogate contaminant which follows the air currents of the ambient air in which it is released Since SF_6 is not naturally found within ambient environments, it is an excellent tracer gas for studying ventilation system characteristics The general protocol for the tracer gas evaluation is in Appendix A

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 A known volumetric 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% 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

$C_{(SF_6)}$ = 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
where the definitions for $C^*_{(SF_6)}$, η, and $C_{(SF_6)}$ remain the same as in equations 1 and 2A

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

Exhaust flow rate experiments were conducted for both sides of the control system Each exhaust sampling point for concentrations of SF_6 was located within the exhaust stack, downstream from the fan, to ensure sufficient mixing of the SF_6 within the air stream Once the exhaust flow rates ($Q_{(exh)}$) for each fan was known, the SF_6 was distributed into the auger region for the capture efficiency (η) evaluations A capture efficiency was determined for each side of the control, and the two results averaged into a single efficiency for the overall engineering control performance Both flow rate and capture efficiency tests were repeated The paver was shut down between trials The airflow rate of the control system was partially governed by the paver idle speed which may have changed slightly between trials

In addition to the indoor evaluation, an outdoor evaluation was completed with the paver positioned in prescribed stationary orientations The outdoor stationary evaluation provided feedback on the sufficiency of the engineering control's hood enclosure for performance in an outdoor environment

EQUIPMENT

(See Appendix A)

ENGINEERING CONTROL DESIGN DESCRIPTION

The Roadtec engineering control prototype incorporated two identical exhaust hoods Each hood measured approximately 48" long and 8" wide and was mounted to the back of the tractor The hoods were centered above the augers on each side of the auger drive gear assembly An opaque canvas material connected the trailing edge of the two hoods to the front of the screed, totally enclosing the top of the auger area The sides of the auger area were not covered Two hydraulically driven exhaust fans were mounted under the tractor deck, one on each side of the engine The specifications for these fans were unavailable Each fan pulled air from its own exhaust plenum, located under the rear paver deck Three, four-inch flexible ducts fed into each exhaust plenum Two of the ducts connected to the exhaust hood and the third duct connected to the top of the slat conveyor tunnel for the respective side of the tractor The outlet of each fan fed into its own exhaust stack, each extending about 6' above the tractor's paver deck This control design allowed the exhaust from each side of the control system to be monitored separately

DATA RESULTS

Smoke Evaluations

The initial smoke tests revealed openings in the barrier between the testing and exhaust areas After resealing the separating barrier, smoke was re-released to identify airflow patterns within the test area and to visually observe the control system's performance 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)

Indoor Evaluations

The prototype hood configuration was evaluated under the semi-controlled conditions described above Exhaust flow experiments were repeated using different SF_6 flow rates ($Q_{(SF_6)}$) to increase accuracy Since building pressure fluctuations and air currents from moving people or equipment could momentarily disrupt the control's airflow characteristics, the results are reported in terms of an average and a range of the 6 to 14 measurements

TABLE I. INDOOR TRIAL ONE

	$Q_{(SF6)}$	$Q_{(exh)}$ (Range)	$Q_{(exh)}$ (Average)
Exhaust Right Side	1 03 lpm	1250 - 1290 cfm	1270 cfm
Exhaust Left Side	1 04 lpm	1370 - 1400 cfm	1380 cfm
Both Combined	2 07 lpm	2630 - 2690 cfm	2650 cfm

	Q(exh)	η (Range)	η(Average)
Capture Eff Right	1270 cfm	95 - 123 %	107 %
Capture Eff Left	1380 cfm	102 - 105 %	103 %
Both Combined	2650 cfm	97 - 114 %	105 %

TABLE II. INDOOR TRIAL TWO

	$Q_{(SF6)}$	$Q_{(exh)}$ (Range)	$Q_{(exh)}$ (Average)
Exhaust Right Side	1 03 lpm	1260 - 1270 cfm	1260 cfm
Exhaust Left Side	1 04 lpm	1310 - 1380 cfm	1350 cfm
Both Combined	2 07 lpm	2570 - 2650 cfm	2610 cfm

	Q(exh)	η(Range)	η(Average)
Capture Eff Right	1260 cfm	103 - 128 %	115 %
Capture Eff Left	1350 cfm	92 - 109 %	98 %
Both Combined	2610 cfm	98 - 119 %	107 %

Outdoor Evaluations

The outdoor evaluation occurred in an open parking area Two paver orientations were evaluated The wind was from the northwest at 8 miles per hour (mph) as reported at the local airport Wind gusts were estimated between 5-15 mph The paver was oriented with the front pointing north for one trial and pointing west for the other trial

TABLE III. OUTDOOR TRIAL ONE: Paver Oriented North

	$Q_{(SF6)}$	$Q_{(exh)}$ (Range)	$Q_{(exh)}$ (Average)
Exhaust Right Side	1 07 lpm	1360 - 1380 cfm	1370 cfm
Exhaust Left Side	1 07 lpm	1490 - 1510 cfm	1500 cfm
Both Combined	2 14 lpm	2860 - 2890 cfm	2880 cfm

	$Q_{(exh)}$	η (Range)	η (Average)
Capture Eff Right	1370 cfm	76 - 117 %	96 %
Capture Eff Left	1500 cfm	34 - 109 %	64 %
Both Combined	2880 cfm	56 - 113 %	81 %

TABLE IV. OUTDOOR TRIAL TWO: Paver Oriented West

	$Q_{(SF6)}$	$Q_{(exh)}$ (Range)	$Q_{(exh)}$ (Average)
Exhaust Right Side	1 07 lpm	1360 - 1380 cfm	1370 cfm
Exhaust Left Side	1 07 lpm	1470 - 1490 cfm	1480 cfm
Both Combined	2 14 lpm	2810 - 2870 cfm	2840 cfm

	$Q_{(exh)}$	η (Range)	η (Average)
Capture Eff Right	1370 cfm	29 - 96 %	66 %
Capture Eff Left	1480 cfm	52 - 135 %	96 %
Both Combined	2840 cfm	40 - 115 %	81 %

DATA ANALYSIS AND DISCUSSION

Test results from the Roadtec engineering control evaluations confirm that a significant portion of the emissions released in the auger area can be effectively captured and removed from the working area The hypothesis is that the control will result in a reduction in worker exposure to asphalt fume Indoor evaluations showed capture efficiencies near 100 percent , while outdoor efficiencies reduced to near 80 percent

Achieving a high average capture efficiency is only part of the ventilation control design approach Another consideration is the control's ability to maintain high capture efficiencies without performance levels fluctuating over a wide range Each excursion into the poor capture efficiency range represents an opportunity for contaminant to escape into a worker's breathing zone Empirically, the performance can be evaluated by comparing the sampling data coefficients of variation (CV)

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

Controls with smaller CV's were less subject to outside interferences and maintained more consistent capture efficiencies For example, the CV obtained during the inside evaluation was less than 10 percent as compared to the CV's of 30 percent obtained outside The calculated CV's for both exhaust flow rate and capture efficiency evaluations are shown in Appendix B

Some of the performance variation between trial runs may result from minor deviations of the engine idle speed Operation of the hydraulic pump is affected by the paver idle speed and could possibly affect the rotation speed of the hydraulic exhaust fans Since a hydraulic pressure regulator attempts to maintain a near-constant fluid pressure, any resulting variation in fan performance is not expected to be substantial

The Roadtec control design allowed each side of the paver to be evaluated independently During the outside evaluation, the side of the paver facing the wind had lower capture efficiencies than the side of the paver that was down wind It is hypothesized that the wind carried part of the tracer gas from the upwind side of the auger to the downwind side where it was partially captured In turn, part of the tracer gas release on the downwind side of the auger was believed to be lost outside of the auger area

CONCLUSIONS AND RECOMMENDATIONS

Based on the evaluation results, the evaluated Roadtec prototype engineering control has a reasonable potential to significantly reduce worker exposures during asphalt paving The wind speed, asphalt fume emission rate, work habits of individuals, and other factors will effect the actual reductions in worker exposure General recommendations for further improvements to the Roadtec prototype design include

Enclosure

In general, the prototype control maintained good enclosure over the width of the auger Any additional enclosure techniques, especially above the ends of the auger and the screed extension areas, could greatly increase the ventilation control's resistance to cross draft disturbances Additional enclosure materials, as well as, the current enclosure could be manufactured from clear or perforated material, thus minimizing any reduced visibility into the auger area

Hood Design

Each of the evaluated hoods (one per side) functions more like two hoods with a common flange as opposed to a single large hood This design will continue to work well as long as the enclosure around the auger area remains intact or is increased as recommended above An alternative design that evenly distributes exhaust airflow across the full length of each hood would improve the uniformity of the exhaust flow and increase the protection across the full length of the auger area If the enclosure of the evaluated design is sufficiently compromised, each hood will remove emissions from primarily two positions corresponding to the two exhaust duct entry points An evenly distributed intake can be achieved through the use of a slot hood or similar plenum-type exhaust hood configuration

ACKNOWLEDGMENTS

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

APPENDIX A

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

PHASE ONE (LABORATORY) EVALUATION PROTOCOL

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

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

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

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

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

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 De-activate the engineering controls for comparison purposes
9 De-activate smoke generators and wait for smoke levels to subside
10 End the smoke test evaluation

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

Quantify Exhaust Volume: To determine the total exhaust flow rate of the engineering control, a known quantity of sulfur hexafluoride (SF_6) is released directly into the engineering control's exhaust hood, thus creating a 100 percent capture condition The SF_6 release is controlled by two Tylan Mass Flow controllers (Tylan, Inc , San Diego, CA) Initially, the test will be performed 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 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

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

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 [$Q_{(SF6)}$] 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

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

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

Summary Calculations From Data Sheets

Roadtec, June 1995

Inside garage "no wind", run 1 of 2			Inside garage "no wind", run 2 of 2		
Rt side, #2	Ventilation flow rate	Capture eff	Rt side, #2	Ventilation flow rate	Capture eff
Mean	1270 cfm	107 %	Mean	1260 cfm	115 %
Min	1250 cfm	95 %	Min	1260 cfm	103 %
Max	1290 cfm	123 %	Max	1270 cfm	128 %
	CV	8 6 %		CV	8 4 %
Left side #3			Left side #3		
Mean	1380 cfm	103 %	Mean	1350 cfm	96 %
Min	1370 cfm	102 %	Min	1310 cfm	92 %
Max	1400 cfm	105 %	Max	1380 cfm	109 %
	CV	1.2 %		CV	8 7 %
Overall, both sides			Overall, both sides		
Mean	2650 cfm	105 %	Mean	2610 cfm	107 %
Min	2630 cfm	97 %	Min	2570 cfm	98 %
Max	2690 cfm	114 %	Max	2650 cfm	119 %

Paver outside facing North, wind 5-10 mph from NW

Rt side, #2	Ventilation flow rate	Capture efficiency
Mean	1370 cfm	96 %
Min	1360 cfm	76 %
Max	1380 cfm	117 %
	CV	12 5 %
Left side #3		
Mean	1500 cfm	64 %
Min	1490 cfm	34 %
Max	1510 cfm	109 %
	CV	37 1 %
Overall both sides		
Mean	2880 cfm	81 %
Min	2860 cfm	56 %
Max	2890 cfm	113 %

Paver outside facing West, wind 5-10 mph from NW

Rt side #2	Ventilation flow rate	Capture efficiency
Mean	1370 cfm	65 %
Min	1360 cfm	29 %
Max	1380 cfm	96 %
	CV	33 5 %
Left side #3		
Mean	1470 cfm	96 %
Min	1470 cfm	52 %
Max	1490 cfm	135 %
	CV	34 6 %
Overall both sides		
Mean	2830 cfm	81 %
Min	2810 cfm	40 %
Max	2870 cfm	115 %

Inside Garage Measurements

1302 Measurem Roadtec

1302 Settings

Compensate for Water Vap Interference	:	NO
Compensate for Cross Interference	:	NO
Sample Continuously	:	YES
Pre-set Monitoring Period	:	NO
Measure		
Gas A Sulfur hexafluoride	:	YES
Water Vapour	:	NO
Sampling Tube Length	:	15 0 ft
Air Pressure		756 0 mmHg
Normalization Temperature	:	76 0 F
General Information		
Start Time		1995-06-06 10 05
Stop Time		1995-06-06 11 40
Results Not Averaged		
Number of Event Marks		18

Inside garage measurements	Data from calibration line	SF6 Flow 1.03 lpm

Samp No	Time hh mm ss	Gas ppm			Corrected ppm			Ventilation Flow cfm and % Capture
1	10 05 29	6 62E-02	Outside on tractor d		0 066637			
2	10 06 12	6 25E-02			0 062913			
3	10 06 47	6 65E-02			0 066939			
4	10 07 23	6 23E-02			0 062711			
5	10 07 58	6 04E-02			0 060799			
6	10 08 33	6.23E-02			0 062711			
7	10 09 09	6 46E-02	Ave	6 29E-02	0 065026	Ave	6 33E-02	
8	10 09 44	6 25E-02	Std Dev	0 002521	0 062913	Std Dev	0 002538	
9	10 10 19	5 88E-02			0 059188	CV	4 01%	
10 11 06 User		Event	1					
10	10 11 06	5 86E-02	inside by screed		0 058987			
11	10 11 41	6 29E-02			0 063316			
12	10 12 16	6 61E-02			0 066536			
13	10 12 52	6 91E-02			0 069556			
14	10 13 27	6.60E-02	Ave	6 60E-02	0 066436	Ave	6 64E-02	
15	10 14 02	6 58E-02	Std Dev	0 002195	0 066234	Std Dev	0 002209	
16	10 14 38	6 93E-02			0 069889	CV	3 33%	

10 15 13 User		Event	2						
17	10 15 13	6 64E-02	In duct #2, no sf6		0 066838				
18	10 15 48	6 46E-02			0 065026				
19	10 16 24	7.20E-02			0 072475				
20	10 16.59	7.13E-02			0 071771				
21	10 17 35	6 44E-02	Ave	6 75E-02	0 064825	Ave	6.80E-02		
22	10 18 10	6 90E-02	Std Dev	0 003212	0 069455	Std Dev	0.003234		
23	10 18 46	6 51E-02			0 06553	CV	4 76%		
10 19 21 User		Event	3						
24	10 19 21	1 59E-01	In duct #3, no SF6		0 160049				
25	10 19 57	7 18E-01			0.722739				
26	10 20 32	7.35E-01			0 739851				
27	10 21 39	7.25E-02			0.072979				
28	10 22 14	6 72E-02	Ave	6 83E-02	0 067644	Ave	6 88E-02		
29	10 22 49	6 52E-02	Std Dev	0 00308	0 06563	Std Dev	0 0031		
30	10 23 25	6 83E-02			0 068751	CV	4 51%		
10 24 00 User		Event	4						
31	10 24 00	7.27E-02	In duct #3, 100% SF		0 07318				
32	10 24 36	2 44E+01			25 94474				
33	10 25 16	2 48E+01			26 38318				
34	10 25 51	2 45E+01			26 05435				
35	10 26 27	2 48E+01			26 38318				
36	10 27 02	2 48E+01	Ave	2 47E+01	26 38318	Ave	2 63E+01	1383 862	Mean
37	10 27 37	2 49E+01	Std Dev	0 182574	26 49279	Std Dev	0 20012	1372 411	Min
38	10 28 13	2 47E+01			26 27357	CV	0 76%	1401 402	Max
10 28 48 User		Event	5						
39	10 28 48	2 16E+01	In duct #2, 100% SF		22 87566				
40	10 29 26	2 64E+01			28 13694				
41	10 30 04	2.66E+01			28 35616				
42	10 30 40	2 69E+01			28 68499				
43	10 31 34	2 72E+01	Ave	2 68E+01	29 01382	Ave	2 86E+01	1271 576	Mean
44	10 32 10	2 69E+01	Std Dev	0 278687	28 68499	Std Dev	0 305469	1253 161	Min
45	10 32 45	2 69E+01			28 68499	CV	1 07%	1292 216	Max
10 33 21 User		Event	6						
46	10 33 21	2 39E-01	Inside by screed		0 240577			Overall	
47	10 34 01	9 75E-02	Sf6 is off		0 098144			2655 438	Mean
48	10 34 37	8 40E-02			0 084554			2625 573	Min
49	10 35 12	7 89E-02			0 079421			2693 617	Max
50	10 35 47	7.90E-02			0 079521				
51	10 36 23	8 94E-02			0 08999				
52	10 36 58	7 01E-02			0 070563				
53	10 37 34	6 98E-02	Ave	7 81E-02	0 070261	Ave	7 86E-02		
54	10 38 09	6 13E-02	Std Dev	0 011088	0 061705	Std Dev	0 011161		
55	10 38 44	7.28E-02			0 07328	CV	14.20%		
10 39 20 User		Event	7						
56	10 39 20	7,55E-02	In duct #3, no SF6		0 075998				
57	10 39 55	6 83E-02			0 068751				
58	10 40 31	6.85E-02			0 068952				
59	10 41 17	6 83E-02			0 068751				
60	10 41 52	7.58E-02			0 0763				
61	10 42 28	7 31E-02			0 073582				

62	10 43 03	6 86E-02			0 069053				
63	10 43 39	7 03E-02			0 070764				
64	10 44 14	6 76E-02			0 068046				
65	10 44 50	6 64E-02			0.066838				
66	10 45 25	6 64E-02			0.066838				
67	10 46 00	6 72E-02	Ave	6 91E-02	0.067644	Ave	6 96E-02		
68	10 46 35	6 59E-02	Std Dev	0.003375	0 066335	Std Dev	0 003398		
69	10 47 11	6 56E-02			0.066033	CV	4.88%		
10 47 47 User		Event	8						
70	10 47 47	6 46E-02	Inside by screed		0 065026				
71	10 48 22	6.41E-02	Ave	6 31E-02	0 064523	Ave	6 36E-02		
72	10 48 58	6 07E-02	Std Dev	0 002122	0 061101	Std Dev	0 002136		
10 49 33 User		Event	9			CV	3 36%		
73	10 49 33	6 64E-02	In duct #3, SF6 distr		0 066838				
74	10 50 08	7 08E-02			0 071267				
75	10 51 15	2 32E+01			24 62942				
76	10 51 53	2.51E+01			26 71201				
77	10 52 28	2 57E+01			27 36967				
78	10 53 06	2 53E+01	Ave	2 55E+01	26 93123	Ave	2 71E+01	103 25%	Mean
79	10 53 41	2 55E+01	Std Dev	0.286356	27 15045	Std Dev	0 313875	101 67%	Min
80	10 54 17	2 58E+01			27 47928	CV	1 16%	104 59%	Max
10 54 52 User		Event	10						
81	10 54 52	6 84E+00	In duct #2, SF6 distr		6 885144				
82	10 55 30	2 92E+01			31.20602			Overall	
83	10 56 08	2 54E+01			27 04084			105 05%	Mean
84	10 56 43	2 96E+01			31 64446			97.97%	Min
85	10 57 19	3 01E+01			32 19251			114 15%	Max
86	10 57 54	2 84E+01			30 32914				
87	10 58 29	2 63E+01			28 02733				
88	10 59 05	2 67E+01	Ave	2 86E+01	28 46577	Ave	3 05E+01	106 69%	Mean
89	10 59 40	3 28E+01	Std Dev	2 402937	35 15198	Std Dev	2 633859	94 57%	Min
90	11 00 16	3 09E-01			0 311039	CV	8.63%	122 94%	Max
11 01 15 User		Event	11						
91	11 01 15	1.21E-01	Inside by screed are		0 121799				
92	11 01 51	1 06E-01	SF6 still on		0 1067				
93	11 02 26	9 71E-02			0 097741				
94	11 03 02	9 14E-02	Ave	9 84E-02	0 092003	Ave	9 91E-02		
95	11 03 37	8 56E-02	Std Dev	0 013146	0 086165	Std Dev	0 013232		
96	11 04 12	8 94E-02			0 08999	CV	13 36%		
11 04 48 User		Event	12						
97	11 04 48	8 07E-02	Inside by screed		0 081233				
98	11 05 23	8 42E-02	AF6 is off		0 084756				
99	11 05 59	8 69E-02			0 087474				
100	11 06 34	8.80E-02			0 088581				
101	11 07 09	8 85E-02	Ave	8 57E-02	0 089084	Ave	8 62E-02		
102	11 07 45	8 57E-02	Std Dev	0 002892	0 086266	Std Dev	0 002911		
103	11 08 20	6 06E-02			0 061	CV	3 38%		
11 08 56 User		Event	13						
104	11 08 56	6 34E-02	Background on pav		0 063818				
105	11 09 31	6 56E-02	Outside on paver de		0 066033				
106	11 10 07	6 08E-02			0 061201				

107	11 10 53	5 92E-02	Ave	6 35E-02	0 059591	Ave	6.39E-02		
108	11 11 29	7 09E-02	Std Dev	0 004295	0 071368	Std Dev	0 004323		
109	11 12 04	6 08E-02			0 061201	CV	6.77%		
11 12 40 User		Event	14						
110	11 12 40	2 20E+01	In duct #2, SF6 distr		23 3141				
111	11 13 18	3 44E+01			36 90574				
112	11 13 56	3.24E+01			34.71354				
113	11 14 31	3 32E+01			35 59042				
114	11 15 07	3 03E+01			32 41173				
115	11 15 42	2 84E+01			30.32914				
116	11 16 17	2.97E+01			31 75407				
117	11 16 53	2 77E+01	Ave	3 09E+01	29 56187	Ave	3 30E+01	114 74%	Mean
118	11 17.28	2 43E+01	Std Dev	2 51907	25 83513	Std Dev	2 761153	102 66%	Min
119	11 18 06	2 33E-01			0.234538	CV	8 36%	128 17%	Max
11 18 44 User		Event	15						
120	11 18 44	2 35E+01	In duct #3, SF6 distr		24 95825			Overall	
121	11 19 22	2 62E+01			27 91772			106 62%	Mean
122	11 19 57	2 77E+01			29 56187			97 67%	Min
123	11 20 35	2 71E+01			28 90421			119 08%	Max
124	11 21 42	2 21E+01			23 42371				
125	11 22 19	2 37E+01	Ave	2 49E+01	25 17747	Ave	2 65E+01	97 97%	Mean
126	11 22 55	2 39E+01	Std Dev	2 105887	25 39669	Std Dev	2 308263	92 35%	Min
127	11 23 30	4 05E+00			4 07673	CV	8 72%	109 39%	Max
11 24 06 User		Event	16						
128	11 24 06	9 81E+01	In duct #3, 100% SF		106 7273				
129	11 24 44	2 60E+01			27 6985				
130	11 25 19	2 58E+01			27 47928				
131	11 25 54	2 51E+01			26 71201				
132	11 26 30	2 48E+01			26 38318				
133	11 27 05	2 53E+01	Ave	2 54E+01	26 93123	Ave	2 70E+01	1345 375	Mean
134	11 27 43	2 53E+01	Std Dev	0 405909	26 93123	Std Dev	0 444917	1312 67	Min
135	11 28 18	2 54E+01			27 04084	CV	1 65%	1378 113	Max
11 28 54 User		Event	17						
136	11 28 54	2 71E+01	In duct #2, 100% SF		28 90421				
137	11 29 29	2 71E+01			28 90421				
138	11 30 05	2 70E+01			28 7946				
139	11 30 40	2 69E+01			28 68499				
140	11 31 35	2 70E+01	Ave	2 70E+01	28 7946	Ave	2 88E+01	1262 702	Mean
141	11 32 10	2 69E+01	Std Dev	0 089443	28 68499	Std Dev	0 098038	1257 914	Min
142	11 32 46	1 95E-01			0 196287	CV	0 34%	1267.527	Max
11 33 23 User		Event	18						
143	11.33 23	9 11E-02	Inside by screed		0 091701			Overall	
144	11 33 59	8 42E-02	SF6 off		0 084756			2608 077	Mean
145	11 34 34	9 32E-02			0 093815			2570 584	Min
146	11 35 09	8 14E-02			0 081937			2645 64	Max
147	11 35 45	7.77E-02			0 078213				
148	11 36 20	7 86E-02			0 079119				
149	11 36 56	7.35E-02			0 073985				
150	11 37 31	8 19E-02			0 082441				
151	11 38 07	7 75E-02			0 078012				
152	11 38 42	7 67E-02			0 077206				

153	11 39 17	7 62E-02	Ave	7 72E-02	0 076703	Ave	7 77E-02		
154	11 39 53	7 66E-02	Std Dev	0 00225	0 077106	Std Dev	0 002265		
155	11 40 28	7 63E-02			0 076804	CV	2 91%		

Paver outside facing North, wind 5-10 mph from NW

1302 Measure Data Roadtec

1302 Settings

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

Measure

Gas A Sulfur hexafluoride	:	YES
Water Vapour	:	NO

Sampling Tube Length	15 0 ft
Air Pressure	756 0 mmHg
Normalization Temperature	68 0 F

General Information

Start	Time	6/6/95	13 44
Stop	Time	6/6/95	14 38
Results	Not	Averaged	
Number of	Event	Marks	6

SF6 flow 1.07 lpm

Paver outside facing North, wind 5-10 mph from NW

Ventilation flow rates and % Capture

Samp No	Time hh mm ss	Gas ppm			Corrected concentration ppm		
1X	13 45 09	6 21E-02	Background, top of p		0 06251		
2X	13 45 52	9 47E-02			0 09533		
3X	13 46 27	5 68E-02			0 05717		
4X	13 47 03	1 44E-01			0 14495		
5X	13 47 38	1 69E-01			0 17012		
6X	13 48 14	4 51E-04			0 00045		
7X	13 48 49	5.61E-02			0 05647		
8X	13 49 24	1 29E-01			0 12985		
9X	13 50 00	2 60E-01			0.26172		
10X	13 50 35	5 09E-02			0 05124		
11X	13 51 11	4 30E-02	Ave	9 05E-02	0 04328	Ave	9 11E-02
12X	13 51 46	1.27E-02	Std Dev	0 070962	0 01278	Std Dev	0 07143
13X	13 52 21	9 83E-02			0 09895	CV	78 37%
13 53 28 User		Event	Number	1			
14X	13 53 28	6 45E-02	In duct #3, no SF6		0 06493		
15X	13 54 04	7 23E-02	However, SF6 was r		0 07278		
16X	13 54 39	6 29E+01	at start of this event		68 1446		

17X	13 55 19	1 16E+01			11 9147				
18X	13 55 57	1 93E-01			0 19427				
19X	13 56 35	9.72E-02			0 09784				
20X	13 57 10	7.24E-02			0 07288				
21X	13 57 46	7.53E-02			0 0758				
22X	13 58 21	7.89E-02			0 07942				
23X	13 58 56	2.28E-01			0.2295				
24X	13 59 32	6 38E-02			0.06422				
25X	14 00 07	8.26E-02			0 08315				
26X	14 00 43	5 48E-02			0 05516				
27X	14 01 18	7.79E-02			0 07841				
28X	14 01 54	6 70E-02			0 06744				
29X	14 02 29	7.67E-02			0.07721				
30	14 03 24	6 79E-02			0.06835				
31	14 03 59	7.82E-02			0 07872				
32	14 04 34	6 89E-02	Ave	8 26E-02	0 06935	Ave	8 32E-02		
33	14 05 10	5 91E-02	Std Dev	0 040013	0 05949	Std Dev	0.040277		
34	14 05 45	7 32E-02			0 07368	CV	48 43%		
14 06 20	User	Event	Number	2					
35	14 06 20	2 71E+01	In duct #3, 100% SF		28 9042				
36	14 06 58	2 37E+01			25 1775				
37	14 07 34	2 35E+01			24 9583				
38	14 08 09	2 36E+01			25 0679				
39	14 08 44	2 36E+01	Ave	2 37E+01	25 0679	Ave	2 51E+01	1503 463	Mean
40	14 09 20	2 37E+01	Std Dev	0 104881	25 1775	Std Dev	0 11496	1493 688	Min
41	14 09 55	2 38E+01			25.2871	CV	0 46%	1513 367	Max
14 10 31	User	Event	Number	3					
42	14 10 31	2 36E+01	In duct #2, 100% SF		25 0679				
43	14 11 06	2 57E+01			27 3697				
44	14 11 41	2 58E+01			27 4793			Overall	
45	14 12 17	2 57E+01			27 3697			2876 772	Mean
46	14 13 03	2 59E+01			27 5889			2857 336	Min
47	14 13 39	2 58E+01			27 4793			2893 399	Max
48	14 14 14	2 59E+01			27.5889				
49	14 14 49	2 57E+01			27.3697				
50	14 15 25	2 60E+01			27.6985				
51	14 16 00	2 59E+01	Ave	2 56E+01	27.5889	Ave	2.75E+01	1373 309	Mean
52	14 16 36	1 02E+00	Std Dev	0 710243	1 02673	Std Dev	0 119793	1363 648	Min
53	14 17 13	1 55E+01			16 1895	CV	0 44%	1380 031	Max
14 17.51	User	Event	Number	4					
54	14 17 51	3 10E+01	In duct #2, SF6 distn		33 179				
55	14 18 29	2 81E+01			30 0003				
56	14 19 05	2 26E+01			23 9718				
57	14 19 43	2 33E+01			24 739				
58	14 20 19	2 40E+01			25 5063				
59	14 20 54	2 36E+01			25 0679				
60	14 21 29	1 98E+01			20 9027				
61	14 22 05	2 39E+01			25 3967				
62	14 22 40	3 00E+01			32 0829				
63	14 23 49	2 64E+01	Ave	2 49E+01	28 1369	Ave	2 65E+01	96 43%	Mean
64	14 24 27	2 87E+01	Std Dev	3 024927	30 658	Std Dev	3 315622	76 00%	Min

65	14 25 02	2 38E+01			25 2871	CV	12 50%	116 65%	Max
14 25 38	User	Event	Number	5					
66	14 25 38	1.13E+01	In duct #3, SF6 distn		11.5858				
67	14 26 13	1.84E+01			19 3681				
68	14 26 48	2 28E+01			24 191			Overall Capture	
69	14 27 24	1.23E+01			12 6818			81.02%	Mean
70	14 27 59	1.53E+01			15 9702			56 13%	Min
71	14 28 35	1.09E+01			11 1474			112.97%	Max
72	14 29 10	8 58E+00			8 63663				
73	14 29 46	2 57E+01			27.3697				
74	14 30 21	1 05E+01			10 709				
75	14 30 56	1.97E+01			20 7931				
76	14 31 32	1.97E+01	Ave	1 54E+01	20 7931	Ave	1.61E+01	84.15%	Mean
77	14 32 07	9.63E+00	Std Dev	5 457963	9 75534	Std Dev	5 979112	34 38%	Min
78	14 33 02	1.58E+01			16 5183	CV	37 10%	108 94%	Max
14 33 37	User	Event	Number	6					
79	14 33 37	1 31E-01	Background, top of p		0 13186				
80	14 34 15	7 60E-02			0 0765				
81	14 34 51	6 78E-02			0 06825				
82	14 35 26	7 41E-02			0 07459				
83	14 36 02	6 67E-02			0 06714				
84	14 36 37	6 05E-02	Ave	6 62E-02	0 0609	Ave	6 67E-02		
85	14 37 12	6 55E-02	Std Dev	0 007809	0 06593	Std Dev	0 00786		
86	14 37 48	5 31E-02			0 05345	CV	11 79%		

Paver outside, Facing West, Wind 5-10 from NW									
1302 Measure	Roadtec								
1302 Settings									
Compensate for Water Vap Interference				NO					
Compensate for Cross Interference			:	NO					
Sample Continuously		:		YES					
Pre-set Monitoring Period				NO					
Measure									
Gas A Sulfur hexafluoride				YES					
Water Vapour		:		NO					
Sampling Tube Length		:		15 0 ft					
Air Pressure				756 0 mmHg					
Normalization Temperature				88 0 F					
General	Information								
Start	Time		6/6/95	14 48					
Stop	Time		6/6/95	15 24					
Results	Not	Averaged							
Number	of	Event	Marks	5					
Number	of	Recorded	Samples	58					
								SF6 flow	
Paver outside, Facing West, Wind 5-10 from NW								1.07	
								lpm	
					Corrected			Ventilation	
Samp	Time	Gas			concentration			flow rates	
No	hh mm ss	ppm			ppm				
								and	
1	14 49 00	7 17E-02	Background on top		0 072173				
2	14 49 43	7 32E-02	of paver		0 073683			% Capture	
3	14 50 29	5 84E-02			0 058785				
4	14 51 05	5 84E-02	Ave	6 04E-02	0 058785	Ave	6 08E-02		
5	14 51 40	4 05E-02	Std Dev	0 013186	0 040767	Std Dev	0 013274		
14 52 18	User	Event	Number	1		CV	21 82%		
6	14 52 18	6 66E-02	In duct #3, 100% capt		0 06704				
7	14 52 56	2 38E+01			25 28708				
8	14 53 34	2.44E+01			25 94474				
9	14 54 09	2 44E+01			25 94474				
10	14 54 44	2.43E+01			25 83513				
11	14 55 20	2 42E+01	Ave	2 42E+01	25 72552	Ave	2 58E+01	1466 148	Mean
12	14 55 55	2 43E+01	Std Dev	0 225093	25 83513	Std Dev	0 246724	1455 625	Min
13	14 56 30	1 85E-01			0 186221	CV	0 96%	1493 688	Max
14 57 08	User	Event	Number	2					
14	14 57 08	2 58E+01	In duct #2, 100% capt		27 47928				
15	14 57 46	2 59E+01			27 56889				

16	14 58 22	2 60E+01			27 6985				
17	14 58 57	2 60E+01	Ave	2 60E+01	27.6985	Ave	2 77E+01	1365 449	Mean
18	14 59 32	2 60E+01	Std Dev	0 10328	27 6985	Std Dev	0 113205	1358 273	Min
19	15 00 39	2 61E+01			27 80811	CV	0 41%	1374 527	Max
15 01 14 User		Event	Number	3					
20	15 01 14	2 60E+01	In duct #2, SF6 distnb		27 6985			Overall	
21	15 01 50	2 42E-01			0 243597			2831 597	Mean
22	15 02 28	8 69E-02			0 087474			2814 098	Min
23	15 03 03	1 45E+01			15 09335			2868.214	Max
24	15 03 41	1 89E+01			19 91619				
25	15 04 16	8 10E+00			8 07631				
26	15 04 52	1.79E+01			18 82009				
27	15 05 27	1 47E+01			15 31257				
28	15 06 03	2 49E+01			26 49279				
29	15 06 38	2 14E+01			22 65644				
30	15 07 13	1 07E+01	Ave	1 73E+01	10 92817	Ave	1.82E+01	65 82%	Mean
31	15 07 49	1 74E+01	Std Dev	5 558217	18 27204	Std Dev	6 092362	29 20%	Min
32	15 08 24	2 49E+01			26 49279	CV	33 46%	95 77%	Max
15 08 59 User		Event	Number	4					
33	15 08 59	5 15E-01	In duct #3, SF6 distnb		0 518399				
34	15 09 37	1 10E+01			11 257				
35	15 10 34	1 42E+01			14 76452			Overall Capture	
36	15 11 10	1 29E+01			13 33959			80 52%	Mean
37	15 11 45	2 33E+01			24 73903			40 09%	Min
38	15 12 20	1 87E+01			19 69697			114 57%	Max
39	15 12 56	2 73E+01			29 12343				
40	15 13 31	1 77E+01			18 60087				
41	15 14 07	3 19E+01	Ave	2 34E+01	34 16549	Ave	2 48E+01	96 31%	Mean
42	15 14 44	3.24E+01	Std Dev	7 827675	34 71354	Std Dev	8 579915	51 78%	Min
43	15 15 20	3 19E+01			34 16549	CV	34 58%	134 75%	Max
15 15 55 User		Event	Number	5					
44	15 15 55	2 58E+01	In duct #3, SF6 off		27 47928				
45	15 16 33	4 37E+00	SF6 bleeding out of s		4 398842				
46	15 17 09	1 88E-01			0 189241				
47	15 17 47	1 41E-01			0 141931				
48	15 18 22	1 44E-01			0 14495				
49	15 18 57	7 58E-02			0 0763				
50	15 19 33	7 40E-02			0 074488				
51	15 20 19	4 72E+00			4 751152				
52	15 20 57	3.72E+00			3 744552				
53	15 21 33	2 74E+00			2 758084				
54	15 22 10	2 28E+00			2 295048				
55	15 22 46	1.38E+00			1.389108				
56	15 23 21	1.57E+00	Ave	2 73E+00	1 580362	Ave	2 76E+00		
57	15 23 57	1 06E+01	Std Dev	1.762539	10 81856	Std Dev	1 774172		
58	15 24 35	1,31E-01			0 131865	CV	64 24%		

		Calibration data.				
	1302 Measurem	Data				
1302 Settings						
Compensate for Water Vap Interference :			NO			
Compensate for Cross Interference :			NO			
Sample Continuously :			YES			
Pre-set Monitoring Period :			NO			
Measure						
Gas A Sulfur hexafluoride			YES			
Water Vapour :			NO			
Sampling Tube Length			15 0 ft			
Air Pressure			760 0 mmHg			
Normalization Temperature			73 0 F			
General	Information					
Start	Time	5/30/95	14 12			
Stop	Time	5/30/95	15 49			
Results	Not	Averaged				
Number	of	Event	Marks			
Calibration data						Data for chart
					B&K Resp	PPM in bag
					4 01E-03	0
Samp	Time	Gas	A	Gas	1.35E+00	1 35
No	hh mm ss	ppm	ppm	ppm	8.02E+00	8 1
					2.13E+01	22 5
1	14 12 59	5 01E-02	Air in lab		4.55E+01	51 7
2	14 13 42	5 02E-02			7.45E+01	78 8
3	14 14 17	4 73E-02			9 48E+01	101 8
4	14 14 53	4 80E-02				
5	14 15 28	4 42E-02				
6	14 16 04	4.70E-02				
7	14 17.10	4.28E-02				
8	14 17 46	4.37E-02				
9	14 18.21	4 81E-02				
10	14 18 56	4 14E-02	Ave	4 03E-02		
11	14 19 32	1 92E-02	Std Dev	0 01479		
12	14 20 07	1 33E-03				
14 20 43	User	Event	Number	1		
13	14 20 43	5 67E-03	Nitrogen in bag			
14	14 21 18	5 00E-04	0			
15	14 21 53	2 46E-03				
16	14 22 29	-3 42E-04				
17	14 23 04	3 12E-03				

18	14 23 40	7 58E-03		
19	14 24 15	4.99E-03		
20	14 24 51	-1 50E-03		
21	14 25 26	1.79E-03		
22	14 26 01	5 92E-03		
23	14 26 56	6 69E-03		
24	14 27.32	1.34E-04		
25	14 28 07	6 92E-03		
26	14 28 42	-1.30E-04		
27	14 29 18	5 75E-03	Ave	4 01E-03
28	14.29 53	6 04E-03	Std Dev	0 003128
29	14 30 29	3 89E-03		
14 31 04 User		Event	Number	2
30	14 31 04	5 18E-03	Air in lab	
31	14 31 40	3 92E-02		
32	14 32 15	4 04E-02		
33	14 32 51	4 50E-02		
34	14 33 26	4 20E-02		
35	14 34 01	4 54E-02		
36	14 34 37	4 08E-02		
37	14 35 12	3 91E-02		
38	14 35 48	4 62E-02		
39	14 36 34	4 03E-02		
40	14 37 09	4 27E-02		
41	14 37 45	4 26E-02		
42	14 38 20	3 65E-02		
43	14 38 55	4 40E-02		
44	14 39 31	4 45E-02		
45	14 40 06	3 67E-02		
46	14 40 42	4 26E-02		
47	14 41 17	3 97E-02		
48	14 41 53	3 57E-02		
49	14 42 28	4 16E-02		
50	14 43 03	4 36E-02		
51	14 43 39	3 83E-02		
52	14 44 14	4.16E-02		
53	14 44 50	4 43E-02		
54	14 45 25	3 95E-02		
55	14 46 00	3 68E-02		
56	14 47 07	3 66E-02	Ave	4 00E-02
57	14 47 42	4 22E-02	Std Dev	0 002914
58	14 48 18	1 35E+00		
14 48 53 User		Event	Number	3
59	14 48 53	1.36E+00	1 35 in bag	
60	14 49 29	1 35E+00		
61	14 50 04	1.35E+00		
62	14 50 39	1.35E+00		
63	14 51 15	1.35E+00		
64	14 51 50	1 36E+00		
65	14 52 26	1.34E+00		
66	14 53 01	1 33E+00		

67	14 53 36	1 35E+00		
68	14 54 12	4 63E-02		
69	14 54 47	3 77E-02	Ave	1 35E+00
70	14 55 23	3 80E-02	Std Dev	0 00828
71	14 55 58	3 82E-02		
14 56 53	User	Event	Number	4
72	14 56 53	8 17E+00	8 1	in bag
73	14 57 30	7.93E+00		
74	14 58 06	8 03E+00		
75	14 58 41	7.97E+00		
76	14 59 17	8 04E+00		
77	14 59 52	8 04E+00		
78	15 00 27	8 04E+00		
79	15 01 03	7.99E+00	Ave	8 02E+00
80	15 01 38	7.98E+00	Std Dev	0 067805
81	15 02 13	1 16E-01		
15 02 51	User	Event	Number	5
82	15 02 51	1 49E+01	22 5 in bag	
83	15 03 29	2 13E+01		
84	15 04 05	2 12E+01		
85	15 04 40	2 13E+01		
86	15 05 16	2 12E+01		
87	15 05 51	2 13E+01		
88	15 06 37	2 13E+01		
89	15 07 13	2 14E+01		
90	15 07 48	2 14E+01		
91	15 08 23	1 18E-01	Ave	2 13E+01
92	15 09 01	4 55E+01	Std Dev	0 075593
93	15 09 42	4 56E+01		
15 10 17	User	Event	Number	6
94	15 10 17	4 54E+01	51 7 in bag	
95	15 10 53	4 56E+01		
96	15 11 28	4 54E+01		
97	15 12 04	4 55E+01	Ave	4 55E+01
98	15 12 39	4 55E+01	Std Dev	0 083666
99	15 13 14	2 36E-01		
15 13 55	User	Event	Number	7
100	15 13 55	7.43E+01	76 8 in bag	
101	15 14 35	7.51E+01		
102	15 15 10	7.43E+01		
103	15 15 46	7 43E+01		
104	15 16 52	7 44E+01		
105	15 17 28	7.40E+01		
106	15 18 03	7 44E+01		
107	15 18 38	7 42E+01		
108	15 19 14	7 45E+01		
109	15 19 49	7 44E+01		
110	15 20 24	7 53E+01		
111	15 21 00	3 45E-01		
112	15 21 40	8 99E-02	Ave	7 45E+01
113	15 22 16	6 49E-02	Std Dev	0 384944

114	15 22 51	5 81E-02		
15 23 27 User		Event	Number	8
115	15 23 27	1.04E+02	101 5 in bag	
116	15 24 07	1 04E+02	Data was outlier	
117	15 24 42	1.04E+02	and not used in calib	
118	15 25 18	1.04E+02		
119	15 25 53	1.04E+02		
120	15 26 48	1 05E+02		
121	15 27 23	6.38E-01		
122	15 28 04	1.12E-01		
123	15.28 39	8 01E-02		
124	15 29 14	6 69E-02		
125	15 29 50	5 83E-02	Ave	1 04E+02
126	15 30 25	5 86E-02	Std Dev	0 408248
127	15 31 01	5 35E-02		
15 31 36 User		Event	Number	9
128	15 31 36	3 12E-02	Nitrogen in bag	
129	15 32 11	2 62E-02	0	
130	15 32 47	2 57E-02		
131	15 33 22	1 89E-02		
132	15 33 57	2 50E-02		
133	15 34 33	2 95E-02		
134	15 35 08	1 93E-02		
135	15 35 44	2 09E-02		
136	15 36 30	4 81E-02		
137	15 37 05	4 63E-02		
138	15 37 41	4 75E-02		
139	15 38 16	4 59E-02		
140	15 38 51	4 96E-02	Ave	3 40E-02
141	15 39 27	4 04E-02	Std Dev	0 011713
142	15 40 02	5 68E-02		
15 40 38 User		Event	Number	10
143	15 40 38	9 50E+01	101 8 in bag	
144	15 41 18	9 54E+01		
145	15 41 53	9 44E+01		
146	15 42 29	9 48E+01		
147	15 43 04	9 45E+01		
148	15 43 39	9 45E+01		
149	15 44 15	9 49E+01		
150	15 44 50	9 49E+01	Ave	9 48E+01
151	15 45 26	9 47E+01	Std Dev	0 310018
152	15 46 01	5 57E-01		
154	15 47 48	7 50E-02		
155	15 48 24	6 70E-02		
156	15 48 59	6.25E-02		

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0 999497
R Square	0 998995
Adjusted	0 998794
Standard	1 406917
Observati	7

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regressio	1	9833 918	9833 918	4968 092	1 09E-08
Residual	5	9 897077	1 979415		
Total	6	9843 815			

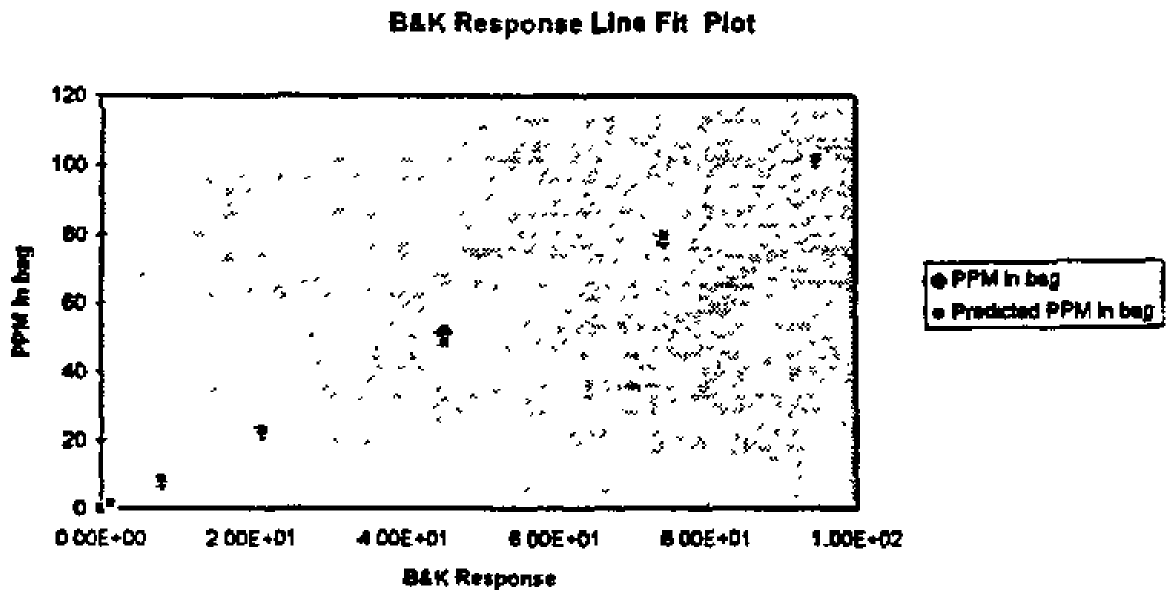
	Coefficient	*andard Err*	*t Stat*	*P-value*	*ower 95%*	*pper 95%*	*wer 95 00*	*Up 95%*
Intercept	0 073723	0 753988	0 097778	0 925907	-1 86446	2 011907	-1 86446	2 011907
B&K Resp	1 074642	0 015246	70 48469	1 09E-08	1 03545	1 113834	1 03545	1 113834

RESIDUAL OUTPUT

bservatio	*ted PPM i*	*Residuals*
1	0 078029	-0 07803
2	1 523296	-0 1733
3	8 693546	-0 59355
4	22 9636	-0 4636
5	48 94844	2 751558
6	80 10524	-1 30524
7	101 9378	-0 13784

Two straight line calibration from Stan Shulman

0 - 9 ppm	y=0 9934 x
9 - 100 pp	y=0 9123 * (x-9) + 0.9934 * 9


B&K Response Line Fit Plot
120
100
80
60
40
20
0
PPM in bag
0.00E+00
2.00E+01
4.00E+01
6.00E+01
8.00E+01
1.00E+02
B&K Response
PPM in bag
Predicted PPM in bag

4.

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0 999496							
R Square	0 998993							
Adjusted	0 832326							
Standard	1 285561							
Observati	7							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regressio	1	9833 899	9833 899	5950 321	6 94E-09			
Residual	6	9 916001	1 652667					
Total	7	9843 815						
	Coefficient	*andard Err*	*t Stat*	*P-value*	*ower 95%*	*pper 95%*	*wer 95 00*	*Up 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
B&K Resp	1 075689	0 009825	109 4819	3 91E-11	1 051657	1 099741	1 051657	1 099741

Calibration