IN-DEPTH SURVEY REPORT:

FIELD EVALUATION OF CATERPILLAR ENGINEERING CONTROLS DESIGNED TO REDUCE OCCUPATIONAL EXPOSURES DURING ASPHALT PAVING OPERATIONS

MANUFACTURER Caterpillar Paving Products
PAVING CONTRACTOR Barriere Construction

PAVING LOCATION New Orleans, Louisiana

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PLANT SURVEYED	Caterpillar Paving Products (Paver Manufacturer) Barriere Construction (Paving Contractor) New Orleans, Louisiana
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DISCLAIMER

EXECUTIVE SUMMARY

On September 9-13, 1996, researchers from the National Institute for Occupational Safety and Health (NIOSH) evaluated a first-generation engineering control designed to capture and remove fugitive asphalt emissions during asphalt paving The Caterpillar 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 conducted the research through an inter-agency agreement with DOT's Federal Highway Administration (FHWA) Industry, labor, and governmental participation in the project was fostered through a research partnership which included NIOSH, FHWA, the National Asphalt Pavement Association (NAPA), the Asphalt Institute, six manufacturers of asphalt paving equipment, the International Union of Operating Engineers (IUOE), the Laborers' International Union of North America (LIUNA), and the Laborers' Health and Safety Fund of North America (LHSFNA)

The asphalt paving engineering control 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 The indoor evaluation used tracer gas analysis techniques to quantify the control's exhaust flow rate and to determine the control's 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 engineering controls under "real-life" paving conditions

Throughout each manufacturer's phase two evaluation, NIOSH researchers focused primarily on each engineering control's ability to capture and remove airborne contaminates generated within the asphalt paver's auger area Secondary measurements were collected at screed and paver operator positions located on the asphalt paver Since no prescribed methods exist to evaluate engineering controls under the unique physical constraints of the asphalt paving environment, the NIOSH researchers developed a multifaceted evaluation strategy that included tracer gas testing, industrial hygiene sampling, and real-time sampling for particulate (PM10), organic vapor, and temperature All of these methods were incorporated into a control-on vs control-off field evaluation protocol in order to quantify the engineering control's performance

The scope of this report is limited to the Caterpillar phase two (field) evaluation of a single engineering control installed on a Caterpillar Model AP-1050 asphalt paving machine The tested design consisted of a single exhaust hood mounted above the auger area A rubber hood, predominantly covering the center auger area between the rear of the tractor and the front of the screed, enclosed about 40 percent of the top of the auger area Airborne contaminants were exhausted from the auger area through the use of a hydraulic exhaust fan located under the paver deck Ducting routed through the rear tractor wall connected the exhaust fan to the hood An exhaust stack, attached to the discharge side of the fan, exited up through the paver deck to a point about 6 feet above the deck and about 12 feet above the ground

Field tracer gas measurement techniques revealed an average exhaust flow of 1130 cubic feet per minute (cfm) from the exhaust fan. Test results indicate that the Caterpillar engineering control design was successful in capturing and removing an average of 60 percent of the asphalt fume released from the auger area. This source reduction led to an average worker-area reduction of 41 percent. One way to circumvent the mathematical impact of background concentrations and the variability resulting from ambient conditions was to evaluate the engineering control's ability to prevent higher-level (top 25%) contaminant concentrations at the screed operator and paver operator positions. Using this approach, the Caterpillar engineering control produced an average reduction in higher-level exposures of 68 percent within these workstations.

The Caterpillar evaluation was the third of six field evaluations to be conducted as part of the engineering controls research partnership. Although the testing methods used had only a minimal history in the challenging environment of asphalt paving, there was sufficient experience to warrant some modifications in the overall testing protocol. Knowledge gained during this evaluation resulted in limited changes to the evaluation protocol and potentially impacted the findings of subsequent performance evaluations. Lastly, many of the environmental and process variables were unique to the Caterpillar evaluation. For example, the Caterpillar field evaluation was the only evaluation conducted while paving city streets. For all of these reasons, the reported performance results should not be used to predict future results under different conditions or to compare performances with those obtained by other paver manufacturers.

The implementation of engineering controls on asphalt paving equipment will continue to be an iterative process. NIOSH encourages Caterpillar to incorporate the following recommendations into their engineering control implementation process: (1) Investigate ways to increase the existing level of auger-area enclosure, especially over the center portion of the auger area. [From the observation standpoint, if HMA is flowing to the end of the auger, intuitively it is flowing at the center as well.], (2) Monitor the worker/contractor acceptance of the current/future auger-area enclosure design and incorporate design changes if undesirable field-modifications are observed, (3) Monitor field conditions of asphalt paver engineering controls to determine how well the control design stands up to the rigorous demands of a paving environment, and, (4) Modify or supplement the existing hood enclosure to minimize escaping fume when the screed is extended beyond the width of the paver.

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 and Physical Hazards Branch (EPHB) (formerly the Engineering Control Technology Branch) of the Division of Applied Research and Technology (DART) (formerly the Division of Physical Sciences and Engineering) has the lead within NIOSH to study and develop engineering controls and assess their impact on reducing occupational illness Since 1976, EPHB 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 September 9-13, 1996, researchers from NIOSH evaluated a first-generation engineering control designed to capture and remove fugitive asphalt emissions during asphalt paving The Caterpillar 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 conducted the research through an inter-agency agreement with DOT's Federal Highway Administration (FHWA) Industry, labor, and governmental participation in the project was fostered through a research partnership which included NIOSH, FHWA, the National Asphalt Pavement Association (NAPA), the Asphalt Institute, six manufacturers of asphalt paving equipment (Barber-Greene/Caterpillar, Blaw-Knox, Cedarapids, Champion, Dynapac, Roadtec), the International Union of Operating Engineers (IUOE), the Laborers' International Union of North America (LIUNA), and the Laborers' Health and Safety Fund of North America (LHSFNA)

The NIOSH contribution to the engineering controls partnership included engineering control design and evaluation assistance to each of the manufacturers during prototype development and a detailed field performance evaluation of each manufacturer's engineering control design during traditional asphalt paving operations Throughout the research partnership, NAPA played a critical role as the industry liaison, facilitating the interactions with each of the manufacturers and coordinating the manufacturer/contractor/researcher requirements necessary for each of the field evaluations. Project participation by IUOE, LIUNA, and LHSFNA rounded out the team effort by facilitating worker participation and buy-in into the engineering controls research effort.

The asphalt paving engineering control study consisted of two major phases. During the primary phase, NIOSH researchers visited each participating manufacturer and evaluated their prototype engineering controls under managed environmental conditions. The indoor evaluation procedure used a tracer gas analysis protocol to quantify each control's exhaust flow rate and determine the capture efficiency.[1] Results and recommendations 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 engineering controls under "real-life" paving conditions.

The Caterpillar phase one evaluation occurred in March 1996. Results and recommendations from the phase one evaluation are published in the NIOSH 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."[2] Since the phase one evaluation was only one portion of the overall development and evaluation of the Caterpillar engineering control, finalization of the Caterpillar phase one report was delayed until the completion and co-release of Caterpillar' phase two report.

The scope of this report is the Caterpillar phase two (field) evaluation of a prototype engineering control installed on a Caterpillar Model AP-1050 asphalt paving machine (see Figure 1). Participating NIOSH researchers included Ken Mead, Mechanical Engineer, Leroy Mickelsen, Chemical Engineer, Scott Earnest, Industrial Engineer, Larry Reed, Aeronautical Engineer, Dan Farwick, Industrial Hygiene Technician, Clint Morley, Intern-Industrial Hygienist all from the Division of Applied Research and Technology (DART), NIOSH and Caroline Portmann, Intern-Industrial Hygienist, from the Division of Surveillance, Hazard Evaluation, and Field Studies (DSHEFS), NIOSH. The NIOSH team was augmented by Tom Brumagin, NAPA's Director of Environmental Services, Keith Schmidt, Caterpillar's Chief Design Engineer, Rob Lobmeyer, Caterpillar Project Engineering Supervisor, Jack Farley, Caterpillar Manager of Customer Support, and Dave Conzelmann, New Orleans Territory Manager for Louisiana Machinery, a Caterpillar equipment dealer. The field evaluation was conducted in coordination with New Orleans, Louisiana, paving contractor, Barriere Construction at two Barriere project sites in New Orleans, Louisiana. Randy Barns, Area Superintendent, represented Barriere Construction.

EVALUATION PROCEDURE AND EQUIPMENT

With the input of its partners, NIOSH researchers developed an evaluation protocol that focused on each engineering control's ability to capture and remove airborne contaminates generated within the asphalt paver's auger area.[3] Secondary measurements were collected at screed and paver operator positions located on the asphalt paver. The primary focus was the control of asphalt fume, a particulate with a diameter of about 1.0 micrometer (1×10^{-6} meters) and smaller

Figure 1. Caterpillar Model AP-1050 Asphalt Paving Machine undergoing field testing of prototype engineering controls The testing site was a city street paving project in New Orleans, Louisiana

A secondary focus was on the control of organic vapors originating from the hot mix asphalt (HMA) Since no prescribed methods existed to evaluate engineering controls under the unique physical constraints of the asphalt paving environment, a multifaceted protocol using multiple evaluation methods was developed to quantify each engineering control's performance (Appendix A) Each of the evaluation methods within the protocol has inherent advantages and disadvantages, some of which can have an effect on the calculated results An additional advantage of using multiple evaluation methods was that at times, the harsh environment led to equipment malfunctions and the loss of important data The impact of these losses was lessened by the presence of multiple evaluation tools It was anticipated that some of these methods would work better than others and that as the overall project progressed, adjustments would be made to the selection and application of the evaluation methods based upon prior experiences A listing and description of the evaluation methods follows

Tracer Gas For the phase two (field) evaluations, the tracer gas evaluation technique from phase one was modified for use during actual paving operations The method to calculate total exhaust flow of the engineering control did not deviate from the phase one tracer gas method However, the capture efficiency SF_6 dosing technique required modification for use when paving Instead of supplying SF_6 to the auger area via a distribution plenum under the auger, the SF_6 was supplied through four medical-quality 20-gauge injection needles, uniformly distributed across the width of the auger The intent of this dosing system was to deliver the SF_6 into the open head space near the top of the auger area (above the fresh HMA and between the front of the screed and the rear of the tractor) The four needles were positioned at a level approximate to the top of the screed and pointed downward towards the auger's center shaft In this manner, the SF_6 was injected in uniform amounts across the four dosing points, into the flow of fume and vapors convectively raising out of the auger head space For the Caterpillar evaluation, the total dosing flow of SF_6 was approximately 0 1 liters per minute (lpm) for each needle (0 2 lpm per side) Multiple tests were conducted during each control-on test period Difficulties encountered with the field tracer gas method included maintaining the injection needles at the prescribed locations, preventing needle obstruction due to occasional contact with the HMA, and maintaining a steady supply of 120V electrical current to the dosing and sampling equipment

Industrial Hygiene Sampling Industrial hygiene (IH) sampling trains were configured for use with two analytical sampling methods The first method quantified the total particulate drawn into a filter cassette then determined what portion of the collected particulate was benzene soluble This method is often referred to as the Benzene Soluble Fraction (BSF) method Due to anticipated detection limitations, this method was only used at sampling locations directly above the auger The second IH sampling method was a new analytical method developed by NIOSH research chemists The new method quantified concentrations of total polycyclic aromatic compounds (PACs) and was reportedly more sensitive than the asphalt fume sampling method previously described Due to the increase in sensitivity, the total PAC method was used for sampling both above the auger and at each of the asphalt paver's workstations Each of these methods is described in detail in the NIOSH Manual of Analytical Methods (NMAM)[4] At the auger area, four general area (GA) sampling locations were uniformly distributed across the width of the auger Additional GA sampling locations included the right and left paver operator positions and the right and left screed operator positions Lastly, breathing zone (BZ) samples were collected from the paver operator (PO), right screed operator (RSO), and the left screed operator (LSO) In order to establish the control-on vs control-off performance ratio, each sampling position (GA or BZ) was assigned two sampling trains (one for control-on and one for control-off) for each sampling method used The same personal sampling pump was used to pull air through each of the two sampling trains For each day of testing, one sampling train was used during all of the control-on periods and the other was used during all of the control-off periods In this manner, there was only one IH performance ratio per day established for each of the sampling locations Difficulties encountered with the IH evaluation method included (1) Filter loss into the asphalt, (2) IH pump battery faults due to long days of use under hot conditions, (3) Area contamination from non-paving sources of PACs such as diesel fuel openly used for solvent (see Figure 2), diesel leaks and fires from the screed heater, diesel exhaust from the tractor, aerosolized hydraulic fluid from exhaust fan failures, cigarette smoking, and, (4) Non-auger sources of asphalt fume associated with the material transfer vehicle (Shuttle Buggy)

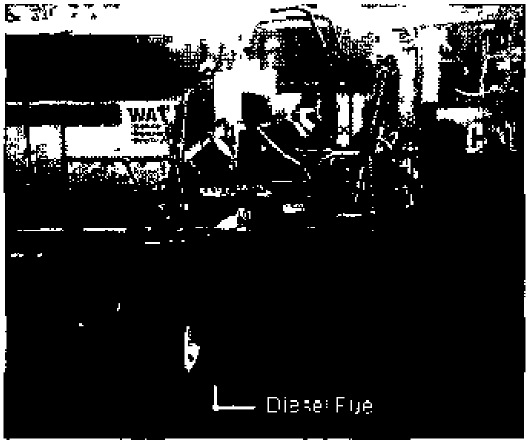

Figure 2: Photograph showing open bucket of diesel fuel adjacent to the right screed operator's work station Non-paving sources of aromatic compounds such as diesel fuel may have adversely affected the measured exposure reductions at paver workstations

Real-Time Aerosol Monitoring: Two types of direct-reading aerosol monitors were used to measure airborne particulate concentrations To reduce the impact of naturally-occurring environmental particulate upon the data results, each of the aerosol monitors was configured to limit recorded measurements to particles with an aerodynamic equivalent diameter of 10 micrometers or less (calibrated to Arizona Red Road Dust) The sampling inlet for one of the particulate monitors, a DataRAM Aerosol Monitor (MIE Inc , Billerica, MA), was positioned in the center of the auger area with the sampling head located 12-15 inches above the top of the auger blade In this position, the DataRAM could measure particulate escaping directly from the auger area Sample frequency for the DataRAM was once every 6 seconds The other two aerosol monitors were Grimm Dust Monitors (Grimm-Labortechnik, Germany) One Grimm was positioned adjacent to one of the paver operator positions while the other was positioned adjacent to a screed operator position The minimum sample frequency option for the Grimms was once every 6 seconds However, the Grimm internally averages the individual readings over a prescribed sample period and reports only the maximum, minimum, and average concentrations for that period For the field paving evaluations, the minimum available sample period of 1-minute was selected for these instruments Uncertainties associated with the aerosol monitoring included the unknown effects of varying humidity and instrument vibration The DataRAM sample inlet included an in-line heater which helped to reduce variation due to humidity The Grimms did not have the in-line heater option Vibration isolators were used with all of the aerosol monitors in an effort to minimize vibrational error Both types of aerosol monitors included an internal warning feature for excessive vibration, however, it is unknown how much error can occur before these warnings are activated

Real-Time Organic Vapor Monitoring: Real-time monitoring of total organic vapor was conducted using two TVA 1000 Toxic Vapor Analyzers (Foxboro, Foxboro, MA) Each TVA contained both a Flame Ionization Detector (FID) and a Photo Ionization Detector (PID) for the detection of volatile organics Both the FID and PID detectors were used in each TVA and were programmed to record measurement responses once every 4 seconds The sample inlet to one TVA was located above the auger and adjacent to the DataRAM inlet The second TVA inlet location alternated between the screed operator position and the paver operator position (adjacent to the respective Grimm Dust Monitors) The alternation pattern was randomly generated prior to the start of the field evaluation Difficulties encountered with the TVAs included mechanical breakdowns, suspected to result from elevated humidity and temperature levels, unknown response variation due to humidity, instrument drift, airborne concentrations of hydraulic fluid aerosolized by a leaking connection at the exhaust fan, and the previously described work practices associated with the use of diesel fuel These difficulties posed a much greater dilemma as the measured concentrations approached the predominant background levels Due to its increased sensitivity over the PID, only the FID measurements were used to determine the organic vapor control efficiency as detected above the auger The PID measurements were available as a backup, in the event of FID failure Many of the instrument observations collected for the paver and screed operator positions were not greatly distinguishable from the background concentration measured during non-paving activities This observation remained true during both control-on and control-off conditions

Wind Speed And Temperature: Two portable Hygro-thermo Anemometers, Model HTA 4200 (Pacer Industries, Chippewa Falls, WI), were used to measure and log the cross-wind (wind blowing perpendicular to the paver's direction of travel) velocity As an added benefit, these instruments also recorded the temperature The HTAs were positioned to sample from the screed and paver operating positions with one HTA adjacent to each of the Grimm Dust monitors The wind velocity and temperature were sampled once every 4 seconds

All of the evaluation methods were incorporated into a control-on vs control-off field evaluation protocol in order to quantify the engineering control's performance Due to the nature of the engineering control design, switching between a control-on and a control-off test setting was limited to activating and deactivating the exhaust fan There was no feasible way to remove and reattach the exhaust hoods and enclosure hood when switching between control settings Thus, any control effect (good or bad) created by the mere presence of the engineering control would have affected the overall performance evaluation results Since the control settings were alternated, the only condition that was randomized was the initial setting for the given day However, the evaluation plan also specified that if day 1 started with control-on then the following day would start with control-off and vice-versa The third day of sampling was different in that only short-term sampling (no industrial hygiene sampling) was carried out by randomizing control-on and control-off settings in pairs Further details concerning the statistical design and randomization strategy for the real-time and industrial hygiene samples are included in Appendix B

An indeterminate variable for all of the direct-reading instruments was the impact of background concentrations and environmental variables The Caterpillar field evaluation was unique in that it was the only evaluation to be conducted within an urban area, primarily on a major city street Intuitively, higher background concentrations of PACs and aerosols associated with vehicle engines would be expected To compound the matter, large portions of the street were significantly covered by an overhead canopy of very large trees Fume and other contaminants from sources other than the paving machine could buildup within the canopy and generate an increased background concentration (see Figure 3)

One way to minimize the unknown variable effects is through shorter sample periods collected closer in time In this way, any background and environmental effects would be more likely to influence the control-on and control-off testing scenarios in a similar manner In a unique modification to the evaluation protocol, day 3 of the Caterpillar field evaluation was dedicated solely to short-term sampling This change was done at the cost of losing a day of industrial hygiene sampling

Figure 3: Non-paver sources of asphalt fume such as that generated by the MTV, were occasionally contained by canopies of large trees, thus increasing background concentrations

ENGINEERING CONTROL DESIGN DESCRIPTION

The Caterpillar phase two (field) evaluation was conducted on a single engineering control installed on a Caterpillar Model AP-1050 asphalt paving machine The tested design consisted of a single exhaust hood mounted above the auger area A rubber partition, covered a portion of the center auger area between the rear of the tractor and the front of the screed, enclosing about 40 percent of the top of the auger area Airborne contaminants were exhausted from the auger area through the use of a hydraulic exhaust fan located under the paver deck Ducting routed through the rear tractor wall connecting the exhaust fan to the hood An exhaust stack, exited up through the paver deck to a point about 6 feet above the deck and about 12 feet above the ground

The Caterpillar design focused primarily at enclosing the center of the auger area directly above the point where HMA from the slat conveyors is dumped in front of the auger blades Towards the ends of the augers, the level of enclosure diminished When the available paving width needed to be increased, the ends of the screed were extended beyond the width of the tractor In this position, the extended portion of the screed had minimal enclosure, fumes and vapors near the end of the auger were minimally controlled and ambient winds had an increased opportunity to disrupt fume containment throughout the auger area

DATA RESULTS

Wind Speed and Temperature

The HTA instruments that recorded wind speed and temperature were located at the screed operator and paver operator locations Although there was some indication of general trends associated with wind speed (i e , higher wind speeds may have led to lower concentrations at the screed and operator positions), there was no determinable correlation between the measured wind speeds and the exposure concentrations observed by the direct reading instruments Little difference (less than 1/5 degree F) in average temperature was found between control-on and control-off settings when 5-minute periods (before and after a control setting change) were studied This estimate is based on 5-minute segments since temperature differences should develop quickly

SF_6 Determinations

There were a total of ten control-on runs in which SF_6 determinations were made Multiple determinations were conducted and averaged within each run, resulting in a total of ten average efficiency estimates The average of these was a 93 percent reduction The lower 95 percent confidence point for the true efficiency was 91 percent Thus, for the SF_6 determinations, the true efficiency of the engineering control can be said to be greater than 91 percent with 95 percent confidence The SF_6 evaluations were treated as a separate experiment Due to its reduced variability, the 95 percent lower confidence limits (LCL) were used as opposed to the 80 percent limits used when evaluating reductions in environmental contaminants

Environmental Contaminants

Roughly 200,000 data points were statistically evaluated as a result of the four-day paving evaluation Tables I and II below summarizes the results of the evaluation A more complete description of the evaluation methods may be found in Appendix B

General Comment: Equipment failures for the TVA located at the auger lead to erroneous data which were not used in Table II DataRam and Grimm (medians) were higher for day 3 than for other days For the Grimm data, the upper 25 percent determinations did not indicate higher reduction than for all medians Vapor data away from the auger did not indicate a reduction

Table I
Engineering Control's Airborne Contaminant Control Efficiencies
(All Periods)

	SAMPLES ABOVE AUGER					SCREED/PAVER OPERATOR SAMPLES					
	DataRam (Aerosol)	TVA (Vapor)	IH (Total PACs)	IH Total Part	IH Benz Sol Part	Grimms (Aerosol)	Grimms Upper 25%	TVA (Vapor)	TVA Upper 25%	IH (Total PACs)	IH Upper 25%
Reduction Estimate	45	46	63	69	73	33	66	3	7	48	70
Individual LCL[1]	39	33	57	64	69	23	60	1	3	40	59
Simultaneous LCL[2]	29	0	41	50	58	3	48	0	0	19	33

Note 1: When the intent is to quote results for just one kind of sample (e g , aerosols above auger) then the Reduction Estimate and Individual Lower Confidence Limit (LCL) for that individual sample type are appropriate

Note 2: When the intent is to quote an overall picture of all sample types (aerosol/vapor, real-time/IH) then the Reduction Estimates and Simultaneous LCLs are appropriate

Table II
Engineering Control's Airborne Contaminant Control Efficiencies
Day 3: Short Periods Only

	SAMPLES ABOVE AUGER		SCREED/PAVER OPERATOR SAMPLES			
	DataRam (Aerosol)	TVA (Vapor)	Grimms (Aerosol)	Grimms Upper 25%	TVA (Vapor)	TVA Upper 25%
Reduction Estimate	81	_	62	72	3	5
Individual LCL[1]	78	_	57	66	2	0 3
Simultaneous LCL[2]	70	_	42	51	0	0

Note 1: When the intent is to quote results for just one kind of sample (e g , aerosols above auger) then the Reduction Estimate and Individual Lower Confidence Limit (LCL) for that individual sample type are appropriate

Note 2: When the intent is to quote an overall picture of all sample types (aerosol/vapor, real-time/IH) then the Reduction Estimates and Simultaneous LCLs are appropriate

DATA DISCUSSION

The asphalt paving engineering controls project was an experiment that established new ground in the application and performance evaluation of engineering controls As such, there were no regulatory, consensus, or industry standards by which to perform the evaluation The hot mobile environment of asphalt paving work was an additional obstacle Given these limitations, and in consideration of the time and resource constraints associated with each field evaluation, NIOSH and its partners developed a "shotgun" approach to quantifying engineering control efficiency during asphalt paving The general concept was to use multiple evaluation techniques in a statistically designed testing strategy of control-off and control-on periods It was anticipated that some techniques may perform better than others and for that reason, redundant approaches were incorporated into the evaluation protocol Furthermore, new variations of the sampling protocol, such as Day 3's short-term sampling periods, were developed as the field evaluations progressed The Caterpillar evaluation was the third field evaluation of asphalt paving engineering controls A discussion of each evaluation technique, its results, and its usefulness to the Caterpillar engineering control evaluation is discussed below

Wind Speed and Temperature

The lack of an identified numerical correlation between the wind speed and observed concentrations, regardless of the status of the engineering control, appears to indicate that there are additional variables that play a role in determining individual exposure concentrations In considering wind velocity, related variables such as wind direction, adjacent geographic features, and the paver's own profile could easily contribute to the exposure quantity

The evaluation of temperature reductions due to the engineering controls was not an original objective of the field evaluation protocol After qualitative observations at an early field evaluation indicated that temperature reductions were a potential fringe benefit, the temperature probe on the HTA turning vane anemometer was identified to record any temperature reduction due to the engineering controls While the observed reductions in temperature are minimally existent, there are some potential explanations

1 Since the HTA's temperature sensor is partially shielded by the airfoil encircling the rotating vane anemometer, the recorded temperature may more accurately reflect that of the ambient cross-winds as opposed to the convective currents raising from the HMA in the auger area

2 The extended screed design used with the evaluated paving machine appears to position the screed operators further behind the auger area than some other screed designs The increased distance from the HMA in the auger would likely reduce the auger-source temperature effects felt by the screed operators Thus, partial reductions of convective currents escaping the auger area may not be significantly detectable at the screed operator positions

Given these considerations, the reported values for temperature reductions due to the control should be considered as only cursory observations If Caterpillar determines that a more detailed quantification of temperature reductions due to the engineering controls is desired, a separate evaluation that focuses specifically on this issue is recommended

SF_6 Determinations

The result of the SF_6 evaluation procedure ($\eta = 93\%$ capture efficiency) reveals that the engineering control performed very well at capturing the tracer gas supplied into the auger area It is important to note, however, that the SF6 testing protocol allows the observer to identify performance reductions under short-term, ideal conditions which are very close in time This generally produces performance data whose results are more optimistic than the protocol's other evaluation methods By comparison, the SF_6 results are roughly twice the performance results for the overall reductions of real-time measurements collected above the auger [Table I DataRam ($\eta = 45\%$), TVA ($\eta = 46\%$)] However, when compared with data that were similarly collected under short-term sampling periods conducted closer in time, the results are similar [Table II DataRam ($\eta = 81\%$)] Another issue to consider when evaluating the tracer gas results is that these values solely reflect the engineering control's ability to control airborne contaminants at the four points of SF_6 injection into the auger area By comparison, the other evaluation methods detect airborne contaminant concentrations regardless of their source The collection of fume and vapor that were generated and released during extended screed paving, for example, could not be represented by these tracer gas performance results

Environmental Contaminants

Auger Area--

The results depicted in Table's I and II indicate that the engineering control captured and removed on average 60 percent of the asphalt fume (DataRAM, PAC and BSF samples) generated within the auger area The discrepancies between the real-time and IH samples over the auger (Table I) could reflect the differences associated with sampling positions as well as the previously mentioned difficulties with using real-time sampling over the longer sample periods The section "IH Samples" in Appendix B contains additional discussion of differences in estimated reduction of particulate by real-time and industrial hygiene methods The improved performance results shown in Table II are especially encouraging since the short-term sampling method increases the likelihood that any observed differences are primarily due to the engineering control When evaluated collectively, the short-term results and the results from the IH samples collected over the auger indicate that the engineering control prevented the majority of asphalt fume from escaping the auger area

The results for controlling organic vapor (TVA) also show a significant reduction in escaping contaminant, although not as impressive as the short-term DataRam and the IH results Unfortunately, the TVA at the auger malfunctioned during the day of short-term sampling so no short-term paired reductions are available Interestingly, the long-term TVA results at the auger ($\eta = 46\%$) are very similar to the long term DataRam results at the auger ($\eta = 45\%$) The same sampling location (single point over center of auger area) was used for both of these instruments Thus the discrepancy between these two results may partially reflect a different level of control at this individual location, than the control level observed across the four sampling locations used for the IH sampling

Screed/Paver Operator--

Due to the lower number of samples at the screed and paver operator positions and the increased variability at these distances from the engineering control, all samples (includes GA and BZ Total PAC samples) collected at the non-auger positions were evaluated collectively according to sample type Even with the increased pool of data, the variability at these positions is noticeably reflected in the reduced confidence limits

The engineering control source reduction lead to an operator and screed worker average reduction of 41 percent, based on the average reduction for Grimm and total PAC samples Since the concentrations observed at the non-auger locations averaged roughly 17-fold lower than those observed immediately above the auger (based upon comparison of IH Total PAC results), the lower control efficiency at the non-auger positions was believed to partially result from the natural control-effects produced by environmental factors In other words, when the wind and environmental factors effectively reduce contaminant concentrations, there is less opportunity for the engineering control to affect exposures When the environmental factors are less effective in controlling the removal of auger source emissions, such as during a stagnant wind condition, the worker-area concentrations increase Under these conditions, the contribution of the engineering control becomes more important As a follow-up to this concept, the data were analyzed to determine what contribution the engineering control provided when the environmental factors were not as effective (i e , when work area exposures were at their highest) For this analysis, the data were analyzed to determine the engineering control's efficiency at reducing the occurrence of the highest 25 percent of fume exposure concentrations These results (see Table I) indicate that the presence of the engineering control effectively reduced the occurrence of higher-level concentrations at the screed and paver operator positions by 68 percent (average upper 25 percent reduction for particulate and total PAC's) Since, by design, the engineering control only captures fumes originating from the auger area, this analysis appears to verify that the auger area was the major contributing source of higher-level asphalt fume exposures

Interpreting the results for the TVA at the non-auger positions is a more difficult task In prior field evaluations, overall values at the screed and paver operator positions were indiscernible from a zero response, with values often fluctuating above and below the theoretical zero position In the New Orleans evaluation, there appeared each day to be a persistent background concentration regardless of paving or non-paving status The source of the background is uncertain and could be associated with the urban environment, excessive humidity, or some other source of organic vapor Since the FID detector is a non-specific detector, (i e , the same concentration of two different organics can generate dramatically different instrument responses) It is not possible to determine the source, identity, or actual concentration of the background contaminant given the available data In an effort to evaluate the control reduction without the impact of ambient PAC background concentrations, "background-corrected" reductions were calculated after subtracting the lowest determinable background concentration from all of the control-on data recorded for each day of sampling Ideally, the true background would have been determined through direct measurement at some point away from the paving activity In this regard, the "corrected" data may slightly overestimate the actual background concentration The reduction results reflecting the background-compensated data are shown in Table III

Table III
Background-Corrected Results for TVA at Non-Auger Positions

	Over All Days		Short-term (Day 3)	
	TVA (Vapor)	TVA Upper 25%	TVA (Vapor)	TVA Upper 25%
Reduction Estimate	16	22	24	18
Individual LCL	6	0	9	0
Simultaneous LCL	0	0	0	0

Given the obvious inconsistencies between the TVA data and those observed using the Total PAC method and the physical characteristic differences between the organic vapor monitored by the TVA and the asphalt fume particulate, NIOSH considers the TVA results at the non-auger positions to be non-representative of the exposure reductions to asphalt fume at these positions

CONCLUSIONS AND RECOMMENDATIONS

The scope of this report is limited to the Caterpillar phase two (field) evaluation of a single engineering control installed on a Caterpillar Model AP-1050 asphalt paving machine On average, the Caterpillar design was successful in capturing and removing 60 percent of the asphalt fume (DataRam, PAC, and BSF samples) originating from the auger area A special short-term sampling method conducted on day 3 of the field evaluation indicated that the engineering control was capable of controlling as much of 80 percent of the asphalt fume originating from the auger area The engineering control's success in capturing fumes at the auger was reflected in reductions of worker exposures (GA & BZ) as well Over all days, the average worker-area reductions were 41 percent with an average 68 percent reduction during the highest exposure conditions During the short-term day of sampling, these results improved to average reductions of 62 percent overall and 72 percent during the highest exposure conditions

The Caterpillar evaluation was the third of six field evaluations to be conducted as part of the engineering controls research partnership Although the testing methods used had only a minimal history in the challenging environment of asphalt paving, there was sufficient experience to warrant some modifications in the overall testing protocol Knowledge gained during this evaluation resulted in limited changes to the evaluation protocol for subsequent field evaluations and potentially impacted their results Lastly, many of the environmental and process variables were unique to the Caterpillar evaluation For all of these reasons, the reported performance results should not be used to predict future results under different conditions or to compare performances with those obtained by other paver manufacturers

In almost any industrial process, the design and implementation of engineering controls becomes an iterative exercise The Caterpillar field evaluation completed an important step in this process by successfully demonstrating significant fume reductions due to the engineering control Effective July 1, 1997, Caterpillar began providing engineering controls as standard equipment on all of their new highway-class pavers As the Caterpillar engineering control is adopted into the industry, NIOSH recommends the following (1) Investigate ways to increase the existing level of auger-area enclosure, especially over the center portion of the auger area [From the observation standpoint, if HMA is flowing to the end of the auger, intuitively it is flowing at the center as well], (2) Monitor the worker/contractor acceptance of the current/future auger-area enclosure design and incorporate design changes if undesirable field-modifications are observed, (3) Monitor field conditions of asphalt paver engineering controls to determine how well the control design stands up to the rigorous demands of a paving environment, and, (4) Modify or supplement the existing hood enclosure to minimize escaping fume when the screed is extended beyond the width of the paver If desired, NIOSH engineers are available to assist in the design or design review of any of these recommendations

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APPENDIX A

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

PHASE TWO (FIELD) EVALUATION PROTOCOL

ASPHALT PAVING FIELD EVALUATION PROCEDURE

The field evaluations of the paving equipment manufacturers' engineering control designs will attempt to characterize the control performance of each prototype design during normal paving operations The field evaluation techniques are designed to minimize interference with the paving process During the field evaluations, the paver will alternate between "engineering controls on" (controlled) and "engineering controls off" (uncontrolled) conditions The duration of each condition will depend on the difficulty in transitioning between controlled and uncontrolled scenarios Initially, the duration for each condition will be two hours Time duration modifications will be made in the field as dictated by the equipment design, preliminary data analysis, and the paving process

__Safety__ In addition to following the safety procedures established by the host contractor at the field site, the following cautions and procedures will be exercised at each testing site

1 Orange safety vests will be worn by all persons when working on or near roads

2 Yellow warning lights will be operating on each vehicle during field testing

3 All compressed gas cylinders will be transported, handled, and stored in accordance with the safety recommendations of the Compressed Gas Association

4 The Threshold Limit Value for sulphur 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 during use 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

Three evaluation methods will be used during the prototype evaluations __Method A__ is a tracer gas method which will only occur during "controlled" paving conditions In this method, sulfur hexafluoride (SF_6) is injected into the auger region behind the tractor and in front of the screed Air samples are taken within the engineering control's exhaust duct(s) to determine what percentage of the surrogate "contaminant" was captured and removed by the engineering control A modified version of Method A will also be used to quantify the engineering control's exhaust volume For __Method B__, organic vapors, respirable aerosol, wind velocity and temperature are measured at point locations with real-time instruments during both controlled and uncontrolled paving conditions The data are downloaded to a computer and analyzed to determine the concentration of airborne contaminants, the environmental conditions, the effect of the wind, and the effect of the engineering controls For __Method C__, personal and area samples are collected on sampling media throughout the day Two sets of sampling media will be used at each sampling location One set will be used to sample during controlled paving, and the other will be used during uncontrolled paving Each sample will be color coded to identify it as a controlled or uncontrolled sample At each sampling location, the two sampling trains will lead to a single sampling pump The controlled vs uncontrolled paving scenario will dictate which of the two sampling trains will be actively connected to the sampling pump When in an inactive status, the sampling train will be capped at the inlet and outlet to avoid vapor migration

Field Set-up The following field setup and evaluation method descriptions are based on our understanding of the field environment at most asphalt paving sites The field evaluation protocol may vary slightly due to unforeseen conditions at some field sites

Evaluation Method A (Tracer Gas) The tracer gas evaluations will occur twice a day, morning and afternoon These evaluation periods will correspond with paving periods which utilize the engineering controls For this evaluation, we release a known quantity of sulphur hexafluoride (SF_6) into predetermined locations, then measure the amount of SF_6 captured and removed through the engineering control's exhaust duct The SF_6 release is controlled by three mass flow controllers which are each calibrated for a predetermined flow rate of 99 98 percent SF_6 Each controller is connected to a PTFE distribution tube One tube feeds SF_6 into each side of the paver's auger area, and the third tube feeds SF_6 directly into the engineering control's exhaust hood

A hole, drilled into the engineering control's exhaust duct, allows access for a multi-point monitoring wand The location for this hole is selected to allow for thorough mixing of the exhaust air stream The monitoring wand is oriented so that the perforations are perpendicular to the moving air A sample tube connects the wand to a Bruel & Kjaer (B&K) Model 1302 Photo-acoustic Infra-red Multi-gas Monitor positioned on the paver deck 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 analyze an air sample approximately once every minute

To determine the total exhaust volume of the engineering control, a known SF_6 supply will flow through a single mass flow controller and directly into the engineering control's exhaust hood, thus creating a 100 percent capture efficiency The mean concentration of SF_6 measured in the exhaust stream will be used to calculate the volume of air exhausted by the engineering control The equation for determining the exhaust volume in cubic feet per minute (cfm) is

$Q_{(exh)} = [Q_{(SF6)}/C_{(SF6)}] \times 10^6$

where $Q_{(exh)} =$ volume of air exhausted through the engineering control (cfm)

$Q_{(SF6)} =$ volume of SF_6 (cfm) introduced into the system The flow rate in liters per minute (lpm) must be divided by 28 3 liters/cubic foot to convert the units to cfm

$C_{(SF6)} =$ concentration of SF_6 (parts per million (ppm)) detected by the B&K 1302

When the engineering control design uses a dual exhaust system, each side of the exhaust system will be evaluated separately Quick-connect fittings will be used as required to assist the evaluation of both hoods The results can then be summed to obtain the engineering control's total exhaust volume

During the capture efficiency evaluations, a known supply of SF_6 will be released through two mass flow controllers One mass flow controller will feed a calibrated flow of SF_6 to the right auger area, the other controller will feed the left auger area Within each auger area, two PTFE distribution tubes will be strategically positioned for releasing the SF_6 This results in a total of four SF_6 distribution tubes within the two auger areas These will be labeled R-In, R-Out, L-In, L-Out Figure 1 shows the planned distribution tube locations Using quick-connect fittings, the engineering control capture efficiency evaluations will be conducted for both the inner auger areas (SF_6 released through R-In and L-In) and the outer auger areas (SF_6 released through R-Out and L-Out)

As the engineering control exhaust hood captures all or part of the released SF_6, the diluted SF_6 concentrations will be monitored in the same manner as stated for the exhaust volume evaluations Monitoring will continue for about 10 minutes or until approximate steady-state concentrations appear The measured concentration will be multiplied by the exhaust volume of the exhaust hood(s) in order to calculate the total volume of SF_6 captured by the engineering control The amount of captured SF_6 will be compared to the known release rate of SF_6 to determine the engineering control's capture efficiency

The sequence from a complete tracer gas evaluation run is outlined below

- Calibrate the B&K gas analyzer <u>before going to the field</u> with SF_6 concentrations ranging from 0 to 100 ppm (5 points)
- Position and secure the power supply, B&K, SF_6 gas cylinder, and mass flow controllers on the paver deck so that they are immobile and are not in the paver operator's way
- Based on engineering control exhaust volumes provided by each manufacturer, calculate the flow rate of SF_6 required to create an SF_6 concentration approximating 15 parts per million (ppm) during the 100 percent capture evaluations Calibrate one of the three mass flow controllers at this calculated SF_6 flow rate
- Assuming an engineering control capture efficiency of 50 percent, calibrate the remaining two mass flow controllers such that the measured SF_6 concentration will approximate 15 ppm during the engineering control SF_6 capture efficiency evaluations
- Position the inner and outer pairs of PTFE distribution tubes within the right and left auger areas Have a paver operator raise and lower the screed to verify that the distribution tubes and connections do not interfere with the paving mechanisms
- Position a distribution tube within the engineering control's exhaust hood(s)
- Drill an access hole in the engineering control's exhaust duct(s) and position the sampling wand into the hole, with perforations oriented perpendicular to the exhaust flow
- Turn on the B&K gas analyzer and input the ambient temperature and pressure
- After the paving process has begun, activate the mass flow controllers which supply SF_6 to the inner auger positions and adjust to the desired flow rate

- Measure the diluted SF_6 concentration within the engineering control's exhaust duct for 10 minutes or until steady-state conditions are approximated (Note For dual duct designs, this measurement period will occur twice, once for each exhaust duct)
- Switch the SF_6 supply to the two outer auger positions and repeat the previous measurement step
- Measure the temperature and pressure within the engineering control's exhaust duct(s) (These will later be used to convert SF_6 concentration readings in the exhaust duct from ambient temperature and pressure to actual temperature and pressure)
- At the end of the sampling period, while controlled paving is still in progress, deactivate the SF_6 flow to the auger area and activate the SF_6 flow into the engineering control's exhaust hood Monitor the diluted concentrations of SF_6 in the exhaust duct to determine the engineering control's exhaust volume flow rate (Note For dual duct designs, this measurement period will occur twice, once for each exhaust duct)
- Turn off SF_6 delivery Continue to sample background readings for 2 minutes
- Deactivate B&K sampling and store data in internal memory
- Repeat the process each time the engineering control is in use
- At the end of each day, remove the B&K from paver, and download stored data to a computer

Evaluation Method B Real-time Monitoring (Wind, Temperature, Organic Vapor, Aerosol and Video Recording) Real-time monitoring will be conducted using five types of instruments and a hand-held video camera, each synchronized to the internal clock of a notebook computer Video recordings of the paving process will be taken during the data collection process to document traffic and for use in real-time monitoring The angle for most of the video recording will be from behind and to one side of the paver so that the screed area and the presence of asphalt delivery vehicles should be in view Figure 2 contains information on the placement of each real-time instrument Each instrument is identified below with its brief operating sequence

1 Wind, Temperature (dry bulb (db)) Two portable Pacer Hygro-thermo Anemometers will log the cross-wind (wind blowing perpendicular to the paver's direction of travel) velocity and the temperature at the screed control panel and at the unused paver operator position The velocity will be averaged and recorded every 4 seconds

For each Hygro-thermal Anemometers

- Change all batteries before going to the survey site
- Locate positions at the down-wind screed control panel and the unused paver operator chair to locate the portable anemometers Orient the anemometers to measure the cross-wind velocity component (wind blowing from side-to-side across the paver)
- Clear the memory of the anemometer's internal data loggers
- Set data recording frequency and annotate the equipment start time
- Place the anemometers on the paver and annotate the wind direction

2 <u>Organic Vapor</u> Two Foxboro, TVA 1000s with flame ionization and photo ionization detectors (FID & PID) will measure and record the total organic vapor concentration every 4 seconds One TVA 1000 will be permanently located to monitor above the center of the auger area, 3-6 inches above the height of the screed The second TVA 1000 will alternate 15 minute sampling periods between the unoccupied paver operator position and the downwind screed control panel

For each Foxboro TVA 1000

- Locate a source of hydrogen near the field site for filling the FID flame fuel tanks of both TVA 1000s <u>before going on the survey</u>
- Charge the TVA 1000 batteries <u>before going to the survey site</u>
- Fill the H_2 tanks
- Set each TVA 1000 auto logging rate to 4 seconds
- Synchronize TVA 1000 clocks to computer time
- Ignite the FID flames
- Calibrate the TVA 1000 with zero air and span gas

3 <u>Aerosols</u> The MIE, Inc , DataRAM Real-time Aerosol Monitor and two Grimm Dust Monitors will measure and record respirable (less than or equal to (≤) 10 microns aerodynamic equivalent diameter) aerosol concentrations every 4-6 seconds One Grimm will be placed near the unused paver operator position The second Grimm will be near the downwind screed operator position The DataRAM will monitor with the TVA 1000 over the center of the augers, 3-6 inches above the height of the screed

DataRAM

- Charge the DataRAM battery <u>before going to the survey site</u>
- Change the backup filter in the DataRAM <u>before going to the survey site</u>
- Calibrate the DataRAM using the internal reference calibration standard
- Install the temperature conditioning heater to the DataRAM Inlet
- Install the PM10 (Verify that 2 5 micron nozzle is not installed in the PM10 inlet head) inlet head to the temperature conditioning heater
- Install the flexible sampling hose on the inlet to the PM10
- Install the omnidirectional sampling head to the free end of the flexible sampling hose
- Set the DataRAM to sample every 4 seconds Set pump flow rate to 2 0 lpm
- Synchronize DataRAM clock to the computer clock
- Locate a secure place to mount the DataRAM onto the paver and position the omni-directional sampling head at the identified monitoring position

For each Grimm

- Charge the Grimm battery and backup batteries before going to the survey site
- Replace the internal PTFE filter prior to going to the survey site
- Remove the black protection cap from the air inlet
- Synchronize the Grimm's date and time with the notebook computer clock

- Insert the Grimm's memory card
- Set the dust measurement mode to particles ≤ 10 microns
- Set the particle count to particles ≤ 10 microns
- Position the Grimm in the desired monitoring position

Evaluation Method C (Total Polycyclic Aromatic Compounds-BZ & GA Samples) There will be 11 sampling locations for each day of paving during the engineering control study field study Eight of these locations will use GA samples, the other three locations will be personal BZ samples mounted on the paver operator and both the screed operators (See Figure 3 for a schematic of the planned sampling locations) Each of the 11 sampling positions will have two sampling trains, one for the controlled paving and one for the uncontrolled paving The sampling pumps will be calibrated to a flow rate of 2 lpm For this evaluation method, a switch from one controlled sampling condition to another will proceed as follows

1 Both an active sample and an idle sample will be co-located at a single sampling position (Applies to either general area (GA) samples or personal breathing zone (BZ) samples)
2 At the identified transition time, the inlet cap will be removed from the "idle" sampling media
3 At the pump inlet, the hose from the active sample will be disconnected and replaced by the hose from the idle sample The time of day for this transition will be annotated for both samples
4 The previously active sample (now idle) will be capped at the cassette inlet and at the sampling hose outlet
5 This process will be repeated as transitions are made between controlled and uncontrolled paving conditions

At the end of each day, all samples will be collected, capped, and stored in a chilled environment until future delivery at an analytical laboratory for analysis Analysis of these samples will be conducted using the Total Polycyclic Aromatic Compound (PAC) method recently developed by the National Institute for Occupational Safety and Health, Division of Applied Research and Technology (DART) (formerly the Division of Physical Sciences and Engineering), Chemical Exposure and Monitoring Branch (CEMB) (formerly the Methods Research Support Branch) See Attachment 1 for a descriptive overview of this analysis

Integrated personal and area samples will be collected using PTFE filters followed by sorbent tubes A summary of activities associated with this sampling method is listed below

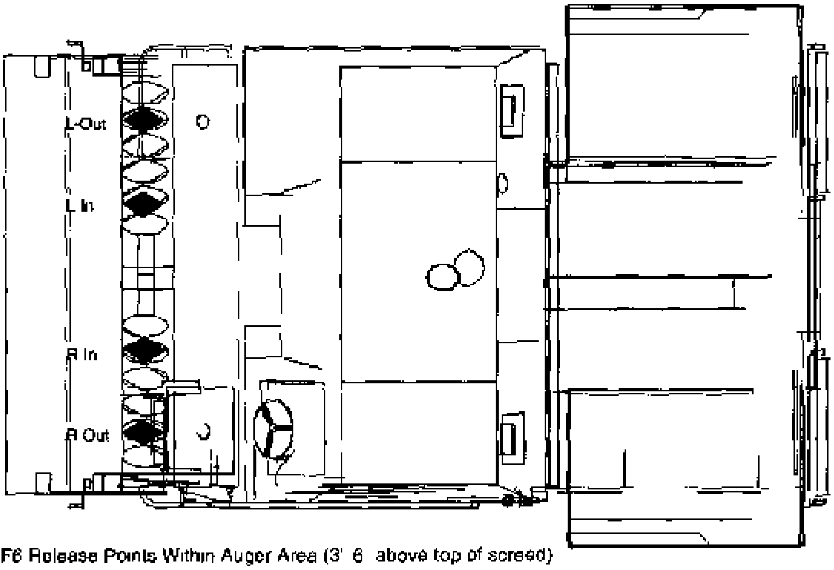
- Calibrate sampling pumps to flow at 2 lpm
- Construct pairs of sampling trains for eight area and three personal sampling positions (total of 22 samples per day)
- Color code each sampling train red=uncontrolled, blue=controlled sampling scenario
- Assign one red and one blue sampling train to each sampling pump, and record the pump number-sample media assignments

- Place five area and three personal samplers Remove filter caps, start pumps, record time, pump number, location/person, and filter number
- Run personal and area samplers for the full working shift
- Post-calibrate sampling pumps and record information on data sheets
- Inventory samples, prepare field blanks, and pack collected samples on ice
- Deliver samples to NIOSH analytical laboratory for total PAC analysis at the end of the survey

Additional Measurements

- Ambient temperature and asphalt application temperature will be measured during each controlled/uncontrolled paving scenario Ambient pressure will be obtained through local weather data sources
- Any down time of more than 5 minutes will be recorded
- The arrival/departure times and the HMA payload (tons) will be recorded for each HMA delivery vehicle
- The crude oil source, supplier, and mix design will be recorded
- The paver model number, any modifications to the paver, and engineering control system dimensions will be recorded

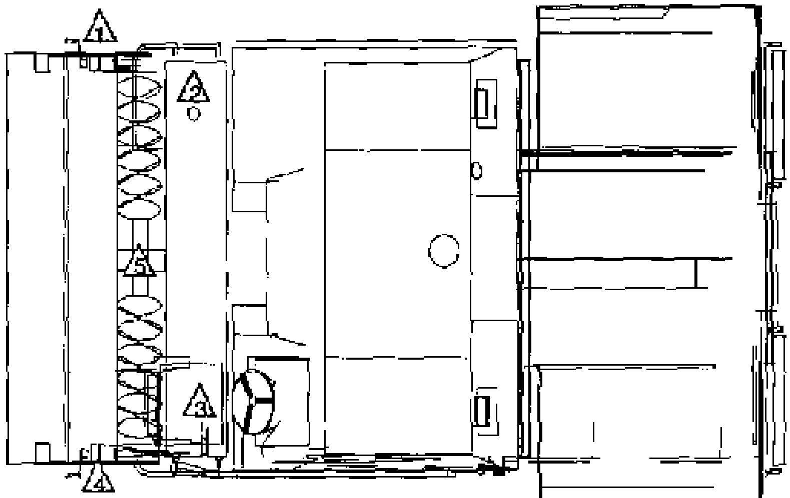
Figure 1 Tracer Gas Dosing And Sampling Locations



◆ SF6 Release Points Within Auger Area (3' 6 above top of screed)

○ B&K Monitoring Point Within Engineering Control Exhaust Stack

Figure 2 Real-Time Sampling Locations



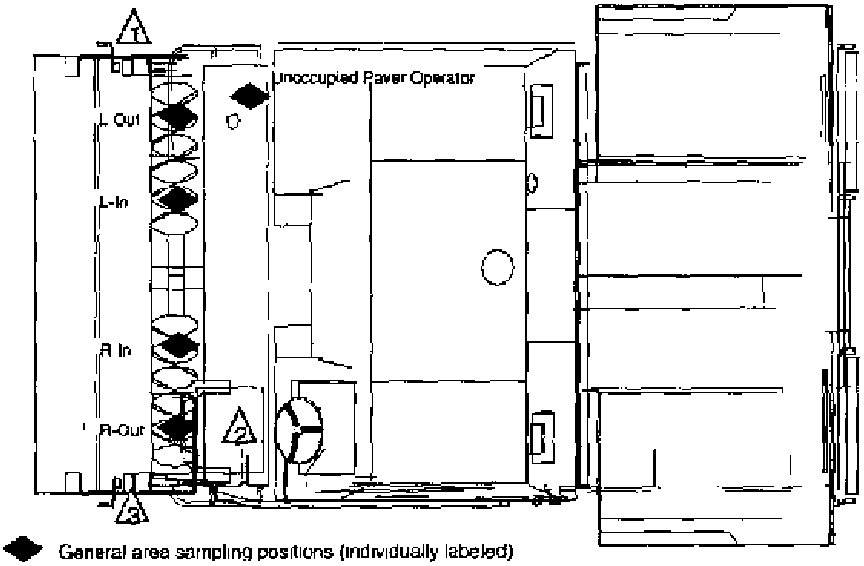
△ Real Time Sampling Locations

1 LHS Screed Operator
2 Unoccupied Paver Operator
3 Occupied Paver Operator
4 RHS Screed Operator
5 Center Auger Position

Equipment	Position
TVA 1000(x 2)	(1 2) 5
Grimm(x 2)	1 2
DataRAM	5
Wind Temp (x 2)	1 2
Noise (x 2)	(1 2) (3 4)
Heat Stress	(1 2 3 4)

Parenthesis denotes rotation among multiple positions

Figure 3 Total-PAC Sampling Locations



◆ General area sampling positions (individually labeled)

△ Personal breathing zone and general area sampling positions
1 - LHS Screed Operator
2 Paver Operator
3 - RHS Screed Operator

ATTACHMENT A

POLYCYCLIC AROMATIC COMPOUNDS AS A CLASS PROCEDURE

Analytical Overview

The Polycyclic Aromatic Compounds (PACs) are extracted from the sampling media with 4 milliliter (mL) of hexane Using a Zymark Benchmate II, the sample solution is fractionated into an aliphatic, an aromatic, and a polar fraction Two mL of the sample solution is eluted through a cyano-solid phase extraction (SPE) column while the remaining 2 mL is retained for additional analyses such as sulfur compounds An additional 2 mL of hexane is used to wash the SPE column and collected with the previous hexane eluate The polar compounds remain on the column while the aliphatic and aromatic compounds are collected in the 4 mL of hexane eluate Four mL of DMSO is added to the hexane eluate and agitated The aliphatic fraction remains in the hexane layer while the aromatic compounds migrate into the DMSO layer during this liquid/liquid extraction The DMSO layer is transferred into a High Performance Liquid Chromatography (HPLC) auto-sampler tube for flow-injection analysis Flow-injection analysis uses the same equipment and data reduction as an HPLC analysis except no attempt is made to separate the compounds into discreet peaks By removing the column, the equipment is used to deliver the sample as a single peak, monitored spectrofluorometrically, and quantitated as ug/sample of PACs as a class The samples are normalized using a Supelco QTM PAH mixture

TOTAL PAC PROCEDURE

Sample Fractionation

1 Remove filters and tubes from refrigerator and allow to come to room temperature

2 Place filter, front section, and back section of tube in separate 16 x 100 screw-cap culture tubes (Daigger Cat#LX23607B) Discard the o-rings from the cassette The front glass wool is added to the front sorbent culture tube section Add the middle and back glass wool to the back sorbent culture tube section

3 Add 4 mL of hexane (Burdick and Jackson 216-1) to each culture tube

4 Cap the threaded tube with the PTFE-faced cap and rotate overnight (Labquake Shaker)

5 Using a Pasteur pipet, remove the hexane from the threaded tube and place in a 16 x 100 mm straight walled disposable culture tubes (CMS 339-309) This transfer is necessary because I could not figure a way to modify the threaded tube to hold the SPE holder on the Benchmate Let me know if you find a way!

6 Place the straight walled tube in the first rack of the Benchmate II with the SPE tube (Supelco LC-CN SPE #5-7013) Place a threaded tube with a sleeve made of plastic or Tygon tubing over the threads in the second rack of the Benchmate II This sleeve allows the Benchmate arm to control the tube

7 Fill the Benchmate reservoirs with hexane, DMSO, methylene chloride, and methanol (All Burdick and Jackson HPLC Grade)

8 Run the weight calibration and purge programs to prepare the Benchmate

9 Run the attached Benchmate program

10 When finished, about 2 mL of the original hexane extract will remain in the first culture tube Transfer this solution to an amber 4-mL autosampling vial (Kimble 60884A-1545) and cap with solid PTFE-faced cap (Qorpak 5200/100) Analyze this solution for sulfur PACs and benzathiozol Discard the SPE tube

11 The second culture tube will contain about 4 mL of hexane and 4 mL of DMSO Remove the sleeve, cap the tube, and rotate the sample overnight to allow liquid/liquid extraction of the PACs into the DMSO layer.

12 Transfer the DMSO layer (bottom) to an amber autosampling tube for HPLC analysis

Flow Injection Analysis

Equipment Waters 600-MS System Controller, Thermo Separations Group Membrane Degasser, Waters 715 Ultra WISP, two (2) Shimadzu RF-535 HPLC Fluorescent Detectors, and a Dionex AI-450 Laboratory Automation System One of the detectors is set at 254 nm excitation and 370 nm emission while the other is set at 254 nm excitation and 400 emission A flowrate of 1 5 mL of 100 percent acetonitrile is used to carry the sample to the detectors The injection volume is 25 uL The runtime programed into the data acquisition method allows four injections of the same sample A purge of 1 minute was programed into the WISP to allow time for the method start and injection start to coordinate

Standards Supelco QTM PAH test mixture (4-7930) is used as the standard It contains 2000 ug/mL of 16 individual PACs, therefore, this bulk standard contains 32,000 ug/mL of total PACs The working standards (ug of total PACs/mL) are serial dilutions in DMSO

Since the samples contain a large range of concentrations and the limited linearity of the fluorescent detectors, multiple runs had to be made of the samples

Run 1 Initially, the samples are run with the detector set in the low sensitivity mode Typically, the calibration curve ranges from 0 5 to 15 0 ug/mL Samples bracketed within this calibration curve are quantitated using a least squares program

Run 2 Sample areas exceeding the highest standard of Run 1 are diluted with DMSO and reanalyzed The majority of the dilutions are required for the 254/400 setting but both must be checked

Run 3 Samples below the lowest standard of Run 1 are reanalyzed with the detector set in the high sensitivity mode The highest standard must overlap the first calibration curve and the LOD associated with this procedure is typically around 0 01 ug/mL

Calculations

The areas of the four replicate injections are averaged The calculated values are in ug/mL Calculation of the final concentration must take into account that 4 mL of DMSO was used in the fractionation and that only half of the sample was fractionated, therefore, the conversion factor from ug/mL to ug/sample is 8

ug/sample = 8 x ug/mL

APPENDIX B

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

CATERPILLAR PHASE TWO FIELD EVALUATION

STATISTICAL DESIGN AND DATA ANALYSIS

CATERPILLAR (NEW ORLEANS)

EXPERIMENTAL DESIGN

The data were collected in periods that included **two kinds of randomization** See **Figure 1** for the randomization that was used during the experiment There was randomization of shorter length time periods and randomization of longer length time periods Both kinds of randomization were required, since the **longer periods were needed for the industrial hygiene** samples, and **the shorter length periods** were required to increase the precision of the difference between the control-on and control-off periods **for the real-time samplers** A period consisted of a randomized pair (control-on, control-off) For purposes of TVA sampling at the screed and operator, the periods in the short-term were designated as either screed or operator samples Since only one TVA instrument was available for sampling at these two locations, the inlet to the TVA was placed either at the screed or operator according to the randomization scheme In the long-term periods, the TVA was randomized between screed and operator sampling, even though the control setting was unchanged

Although we call the periods either 'short' or 'long,' **short periods were not all of the same length and long periods were not all of the same length** The short periods varied in length between 5 minutes and 15 minutes Notice that whereas days 1 and 2 had two long-time periods, day 4 had three long-time periods

METHODS FOR DATA ANALYSIS

1 Since these data were collected in batches of control-on and control-off, **it is not appropriate to treat the measurements individually when** making comparison of control-on and control-off settings The reason is that the variability of measurements made in batches is usually different (smaller) from that of measurements which are collected in a randomized fashion Since the randomization used in the study is within the periods, it makes sense to **calculate one number for each control-on and control-off setting within each period** Since **the median** is not sensitive to measurements from the center of the distribution, the median is used in the analyses of all the real-time measurements (These included vapor and particulate at the auger and away from the auger)

For the **industrial hygiene samples**, each of which is collected for a relatively long period of time, the average of each type of sample was used, rather than the median **Because each sample is a time-weighted average over a relatively long period of time, the sample determinations themselves adjust for extreme values that occur in the course of sampling, and the average rather than the median seems appropriate.** This average was taken over all locations sampled during the control setting The industrial hygiene samples included total PAC at the auger (four locations), total PAC away from the auger (two or three personal samples and four area samples), and total particulate/benzene soluble fraction (BSF) analyses for samples at the auger (four locations)

2 An early analysis question was which measurements to use in computation of the median For short-time periods, it makes sense to use all measurements For long-time periods there are trends in the data that indicate it is unwise to use the entire set of data at one control setting Consider Figure 2, a plot of the medians of sequential measurements by the DataRam (DRAM) particulate monitor Each plotted value is a median of over 100 determinations Comparisons of control-on and control-off depend upon which medians are actually paired For instance, if we compare the last transition from control-off to control-on at a little after hour 15 in Figure 2, we see that there is some difference in the control-off and control-on medians (42 percent reduction due to control) Near the bottom of the figure are the medians on the log scale for all measurements at each control setting in each period If we compare the median value for the last period control-off setting with that for the last period control-on setting we find a huge difference, an 85 percent reduction due to the control Since we ourselves have no control over environmental changes, it makes sense to compare control-on and control-off determinations that are close together in time **In other words, we will compare medians of measurements after a change point from one control setting to the other for the long-time periods.**

3 Another question concerns **how many measurements to use before and after a change point** Our thinking is that **determinations close together in time are more similar in the uncontrollable variables** We must determine how far in time before and after a control setting change we must include data for computation of the medians We must decide what duration should be taken for each period Comparisons of control effectiveness were done for different length time periods **The number of minutes was always a function of absolute clock time (from the start of the period), since the idea is that it is important to be close together in time to allow for better comparability of the determinations. The periods are constructed with respect to the last measurement before a control setting change or the first measurement after such a change.** For instance, if the last control-off determination before a change occurred at 10 a m , then the 15 minute interval would include measurements between 9 45 and 10 a m If the first control-on determination was made at 10 45 a m , then the 15 minute determinations would include measurements between 10 45 and 11 00 a m The comparisons indicate that by approximately a half-hour the estimated effectiveness of the control is stable, and does not change much after that **For the results presented here, half-hour periods are used. Additional explanation is provided in the statistical appendix.**

4 Day 4 of sampling differed from the first three days in that trucks were used for delivery of the asphalt On the previous three days, the laying of asphalt was largely a continuous process due to the use of a material transfer vehicle On day 4, **there were many stops in-between trucks.**

On the other hand, it seems sensible to introduce a break where none is present, since it may take a while to reach an equilibrium For instance, data in Figure 3 from the day of short-time sampling suggest some drift at the beginning of a new control setting - often upward for control-off and downward for control-on Also, **because there may be uncertainty about the exact time that paving start or stops, ½ minute of measurements were deleted after the time**

indicating the start of a new control setting or after the time indicating resumption of paving after a break of at least 25 seconds in paving activity, and analogously for the paving before the control setting change or before the 25 second stoppage in paving. This deletion policy applies to all days of data collection **This was done for all real-time determinations except the GRIMMs, which were used for particulate measurements away from the auger.** The choice of a ½ minute is somewhat arbitrary Some series are relatively short, and we do not want to exclude too much data By deleting a half minute of 4-second measurements, we are deleting seven or eight measurements The GRIMMS are different because they record a determination every minute With so few determinations for the relatively short periods of this study, it makes sense to **use all the GRIMM data that we can for those measurements which have at least half their minute sampling time in the particular control setting under consideration.**

5 Another issue concerned **drift in the FID determinations** The TVAs were spanned with samples containing no analyte and with samples containing analyte that should have given 100ppm readings for FID This spanning was carried out both at the beginning of the day and at the end of the day **The instruments are assumed to have linear relation to the true concentration. Drift in the 100ppm determinations was assumed to be linear between the two endpoints.** This assumption allowed for determination of a factor for converting the 100ppm responses at a particular sampling time t to the equivalent responses at the initial 100ppm spanning time (t=0) **Thereby, changes in readings over time to the same air concentration would be corrected** Because zero span gas determinations were not recorded, a similar correction could not be made for any potential drift in the zero

6 For the real-time data, **ln (median)s were analyzed via analysis of variance methods**, in order to obtain an estimate of the ratio of control-on to control-off (by exponentiating the estimated difference [ln(control-on) - ln(control-off)]) The quantity of interest is 1 minus the estimated ratio, which is the estimated reduction due to the control-on, or (control-off median - control-on median)/(control-off median), which is converted to percent reduction by multiplying by 100 The models used are different for different kinds of measurements **For the real-time particulate at the auger and for vapor determinations, the models include terms for day-to-day differences, pair of (control-on, control-off) within day, and interaction between day and control differences The particulate determinations away from the auger, measured at both the screedman and operator locations, are averaged to obtain one average measurement at each setting at each time, since the two different locations are sampled simultaneously and are correlated.**

In the analysis of the total PAC data, the response is the average (on the natural log scale) over the different locations sampled simultaneously of the same sample type For the total PAC away from the auger, both area and personal samples are included in the average Because the industrial hygiene samples (total PAC or weighing samples) were long-time samples done simultaneously, it was possible to carry out a combined analysis of these data **The control effectiveness was estimated by including all sample types in the same split-plot analysis,**

and obtaining a separate estimate for each sample type, but pooling the residual variances so as to use a better estimate of the sub-plot variance, with more degrees of freedom This seemed acceptable, since the bulk of the variability of the measurements is sampling variability, which was thought to be similar, even though the total PAC and the weighing methods are quite different The whole plot error is due to the variability of control setting differences over mixes The sub-plot error is due to variation unexplained after adjustment for sample type differences and sample type differences over control settings

7 As might be expected, reduction due to the control is greatest for the auger samples A suggested alternative for the non-auger particulate samples, both real-time and total PAC, was carried out **This was to estimate the percent reduction for the periods with the highest 25 percent control-off values** For the total PAC these are the highest 25 percent of the individual location total PAC control-off determinations away from the auger For the real-time particulate or vapor, these are the highest 25 percent of the control-off medians, where operator and screedman locations are treated individually **The data are analyzed as a split-plot kind of design. The standard deviation for the control-on effectiveness for the highest 25 percent can be obtained from the split-plot error. For the total PAC data the split-plot error is due to the variability of control effectiveness over mixes; for the real-time data it is due to the variability of control effectiveness over pairs within mixes.** The results from these analyses can be interpreted as follows Since the observed reduction is confounded with uncontrollable factors such as wind speed and direction, the highest control-off measurements may occur where such factors are not effective in reducing the contaminant Thus, **the reduction here is of interest, since it may indicate what can be expected when environmental control is not present.** Why choose 25 percent? Why not 30 or 50 percent cutoff point? Because the choice is arbitrary, we will present results based on the upper 25 percent, but will also discuss results for the upper 50 percent control-off values

8 For many of the comparisons that follow, the aim was **to establish confidence limits that hold simultaneously for all comparisons at the 80 percent confidence level at the auger and at the non-auger locations and also for the IH samples. Thus, for all comparisons simultaneously we can say that the error rate is 20 percent.** The probability that any confidence interval statements are in error is no more than 20 percent **Altogether if eight comparisons were allowed for, then each would be allowed a 2.5 percent error rate. Since the error rates add, the overall error rate will then be no more than 20 percent** The choice of an overall 20 percent error rate is somewhat arbitrary although 20 percent might be thought to be acceptable since many factors in this study are not controlled The reason to control for the overall error rate is that, although the measurements may each be of a considerably different nature, they are all correlated, since they are all taken at the same time Together they present different aspects of the workplace exposure to the particulate and vapor produced by the paving process **Alternatively, we could consider each comparison of control-on versus control-off as a separate test In a less ambitious evaluation, only one kind of measurement might be taken or only one kind of measurement might be of interest. For this consideration, we have also calculated individual 80 percent confidence bands for each determination.** The

above approach regarding confidence bands was used for tests of control effectiveness for particulate and vapor **In addition, NIOSH conducted separate investigations whose efficiency confidence limits were calculated independently from the vapor and particulate samples.** These included **tracer gas effectiveness**, for which 95 percent confidence limits were produced, and **evaluation of temperature differences** between control-on and control-off, for which 80 percent confidence bands were calculated

9 In a study such as this, there are different choices as to how to view the days included in the study To generalize the results for the single paving machine evaluated here to any days and locations on which that paver might be used, we would want to regard the days of sampling used in the study as a random sample This generalization is a more ambitious goal than we think is warranted by the data collected for this study Only a small sample of possible paving sites is used and variation in ambient conditions (weather or habitat) is limited Also only a single paving machine was evaluated For all of these reasons it makes sense to **treat the days studied as having fixed means, rather than as a random sample of all possible days**

SF_6 DETERMINATIONS

The average SF_6 efficiency is 92.78. The estimated variance is 11 34 With ten measurements, this yields a standard deviation of the mean of 1 065 **The 95 percent lower confidence limit on the true efficiency is 92.78 - 1.833 (1.065) = 90.83**, where 1 833 is the 95th percentile of the Student's t distribution with 9 degrees of freedom **Thus, the true efficiency can be said to be >90 percent, with 95 percent confidence.**

EFFECTIVENESS OF CONTROL AT AUGER

The results for the TVA analyses of vapors at the auger and of the DataRam measurements at the **auger** are shown in Figure 4 Results are presented as **percent reduction of the control-on relative to the control-off.** The percent reduction is given separately by day and by average over all days for the real-time vapor and particulate samples

The percent reduction varied considerably over days both for vapor and particulate **For all days the percent reduction based on RAM (particulate) data was about 45 percent. The lower confidence limit for simultaneous comparisons was about 29 percent and for individual comparisons was about 39 percent. For the vapor the overall reduction was about 46 percent, with a lower confidence limit for simultaneous comparisons of about 0 percent (thus, no reduction) and for individual comparisons of about 33 percent** Note that for vapor data only two days of data were available, and only two pairs on the last day could be used

EFFECTIVENESS OF CONTROL AT SCREED AND OPERATOR POSITIONS

The results for the vapor and particulate measurements at the screed and operator locations are plotted by day in Figure 5 The results for vapors are the averages over the screed and operator locations **There is about 3 percent reduction for vapor measurements, with lower confidence limit of 0 for simultaneous comparisons and about 1 percent for individual comparisons. For the particulate there is estimated 33 percent observed reduction with a lower confidence limit of 3 percent for simultaneous comparisons and about 23 percent for individual comparisons.**

The analysis of the upper 25 percent particulate data yields a reduction of about 66 percent, with a lower confidence limit of about 48 percent for simultaneous comparisons and about 60 percent for individual comparisons For these results, medians are used from both the operator and the screed locations Only those medians are included which have the control-off medians in the upper 25 percent of all control-off medians The estimated reduction depends somewhat on the terms that are included in the statistical model An alternative estimate, based on a somewhat different model, yields an estimated 56 percent reduction Given the variability in the data, the difference between 66 and 56 percent is not great, and we use the higher figure for our summary statistic When the analysis is carried out for the upper 50 percent control off median pairs, the reductions are only a little smaller - estimated 49 percent reduction Since we are not using many measurements for the upper 25 percent comparisons, it is reassuring to see that the other comparison also indicates large reductions For the vapor, the estimated reduction for the upper 25 percent comparisons is about 7 percent, with lower (simultaneous) confidence limit showing no reduction, and lower(individual) confidence limit showing about 3 percent reduction Results change little from the analyses based on the medians

Figure 6 plots the geometric means for the particulate analyses **The GRIMM (particulate) data were not low compared to the RAM (particulate) auger data** In fact, for some days and sampling locations the GRIMM geometric means exceeded the geometric means of the DataRAM data These are two different kinds of instruments, and one would not necessarily expect GRIMM means to always be less than DataRAM means The GRIMM data are somewhat different from all the other data collected As was mentioned above, they were 1-minute averages of determinations made every 6 seconds There was no way to examine the ten determinations that went into each of these averages

IH SAMPLES

Figure 7 is a plot of the percent reduction due to the control, based on the total PAC industrial hygiene sample data (the sum of the 370nm and 400nm wavelengths) and gravimetric samples determined from filters, either total particulate or benzene soluble fraction of the total particulate The gravimetric and total PAC samples were all collected at the auger There were also total

PAC samples collected in screedman and operator breathing zones as well as area samples corresponding to these breathing zone locations

All the auger samples - total PAC, total particulate, benzene soluble - show reductions of at least 60 percent, though the estimates differ somewhat, respectively, 63, 69, and 73 percent. The lower 80 percent (simultaneous) confidence limits are, respectively, 41, 50, and 58 percent.

The individual 80 percent confidence limits are, respectively, 57, 64, and 69 percent.

The particulate estimates differ considerably between real-time and industrial hygiene - **the real-time indicate about 45 percent reduction, the IH samples over 60 percent reduction.** In fact, this figure underestimates the difference in the estimates, since IH samples were not taken on the third day of sampling, the most effective day for the real-time samples It might seem that the difference in the estimates is due to the use of 30 minute periods for the real-time samples, compared with the entire period for the IH samples However, the results for 120 minute data with short-time sampling excluded, shown in the "Statistical Section - Determining Length of Period," indicate reduction less than 40 percent, much lower than the greater than 60 percent estimates obtained from the industrial hygiene samples The reason for the difference appears to be that the industrial hygiene samples provide time-weighted averages over all control-on determinations and over all control-off determinations, one determination by each method over all occurrences of each control setting per day **When the real-time samples are averaged in the same manner, the resulting average estimate indicates a 57 percent reduction, just a little lower than the average of the three industrial hygiene determinations (68%). Should we be concerned about the different results, which depend on the way that we average the real-time data?** As indicated in Figure 1, both days 2 and 4 of sampling began with control-off samples Both days have decreasing amounts of particulate over the course of the day (see Figure 2 for day 4 data) Because of the order (control-off followed by control-on), combining over all occurrences of a setting increases the size of the reduction due to control-on On the other hand, **since we expect the measurement level to attain a stable value fairly quickly, the larger differences associated with the full-day time weighted average may have more to do with environmental trends than with reduction due to the control. There is no way to prove this, and using the average of the four auger particulate determinations, and the average of the two non-auger particulate determinations is a compromise procedure.**

Because the control effectiveness for the **non-auger** area samples and personal samples is quite similar for all three days of sampling, they are combined **They average about 48 percent reduction due to the control, with 80 percent lower simultaneous confidence limits indicating at least 19 percent reduction due to the control, and lower individual confidence bands of about 40 percent.**

The pairs of non-auger PAC data that included the **highest 25 percent of control-off determinations** were also analyzed for control effectiveness (see Figure 8) For these data, the estimated effectiveness was 70 percent and **a lower (simultaneous) confidence limit of**

33 percent and a lower (individual) confidence limit of 59 percent. For the upper 50 percent control-off pairs, the estimated reduction was about 62 percent The lower confidence limits are 30 percent (simultaneous) and 52 percent (individual) The reason for the change when 50 percent is used can be found in Figure 8 Including the 50 percent highest control-off pairs includes one low value, which decreases the overall effectiveness and increases the standard error of the estimate However, the estimate from the upper 50 percent control-off pairs also suggests higher reduction than the estimate for all data

Figure 9 gives the daily geometric means of the total PAC breathing zone and non-auger samples, by type (area or personal samples) and by control setting The geometric means for the breathing zone samples, whether control-on or control-off, do not change much from day-to-day The geometric means for the area samples, control-off, do change considerably

Figure 10 shows a relationship between benzene soluble determinations and total PAC determinations at the auger A relationship can be developed because there were filter samples (for BSF method analysis) paired with the total PAC samples at the auger **The approximate straight line relationship allows a crude conversion from the total PAC method to gravimetric units. The conversion results must be interpreted loosely, since there is no certainty that the PACs measured at the worker positions are 100 percent identical to those at the auger. However, the conversion is still useful since the only IH samples taken away from the auger were total PAC samples. All but three of the non-auger total PAC samples yield benzene soluble "equivalent" determinations less than 0 mg/cu. m.** Since the benzene method is gravimetric, it is difficult to interpret negative values Because the total PAC non-auger samples show reduction not inconsistent with that at the auger, and since there is no reason to think that the conversion from total PAC away from the auger should differ much from that near the auger, it appears that the gravimetric samples are not as sensitive as the total PACs

The IH data do allow us to make another estimate of the efficiency of the control for vapors The filters that were used for gravimetric analyses had tube backups These tubes collected only vapor, since the particulate was extracted by the filters Thus, the efficiency of the control can be estimated by both the backup tube data (vapors) and the filter data (particulate) The accompanying Figure 11 displays the efficiency by sampling day **On average the reduction due to the control based on the tube data is about 60 percent compared to about 70 percent for that based on the filter data. The difference between tube and benzene soluble results is significant at the 5 percent level.** This could be taken as another estimate of the efficiency of the control for vapors, although there is the possibility that the heat in the material on the filters produced additional vapor

WIND AND TEMPERATURE MEASUREMENTS

The HTA instruments were located at the screedman and operator locations **Little difference (less than 1/5 degree F) in average temperature was found between control-on and control-off when 5-minute periods (before and after a control setting change) were studied** Five minute periods were used here rather than the 30 minute periods used above, since we believe that temperature differences should show up quickly As in the other comparisons, median temperatures were used for this comparison, based on the pairing scheme described above

Median wind speeds were calculated for each control setting used in the randomization These determinations and the temperature determinations were made by two HTA instruments, located near the GRIMMs at either the screed positions or the operator positions No wind measurements were taken on day 1 of sampling **Day 4 was the windiest day.** There is no clear association between wind speed and level of contaminants

CONCLUSIONS

Reductions Given in Percent

	Part auger Real time	Vapor auger Real time	Total PAC auger Indus Hygiene	Benz Sol Auger	Total Part - Auger	Part non auger Real time	Part non auger upper 25%	Vapor non auger Real time	Vapor non auger upper 25%	Total PAC non auger Indus Hyg	Total PAC non auger upper 25%
EST	45	46	63	73	69	33	66	3	7	48	70
Indiv LCL	39	33	57	69	64	23	60	1	3	40	59
Simul LCL	29	0	41	58	50	3	48	0	0	19	33

The results are summarized in the above table An obvious question is **which kind of confidence interval to rely on.** If the basic aim is to quote results for just one kind of sample, say real-time particulate at the auger, then it is appropriate to quote the point estimate and the **individual lower confidence limit** for that sample type. If the aim is to obtain an overall picture of all matrices (particulate and vapor) or all types of samples (real-time and industrial hygiene), then the **simultaneous confidence intervals** are the correct ones to use

STATISTICAL SECTION - DETERMINING LENGTH OF PERIOD

For the DataRAM data, results are presented both with and without the one day of short time sampling For the FID at the auger, there were no results for the short-time sampling day Results are given as [ln(con-off)-ln(con-on)]

Nominal	DRAM	DRAM	FID-auger (no short time available)
Time	Exclude short time	Include short time	
15 min	0 319(0 196)	0 659(0 143)	0 286(0 162)
30 min	0 240(0 128)	0 60(0 116)	0 614(0 212)
45 min	0 236(0 111)	0 596(0 111)	0 645(0 264)
60 min	0 222(0 258)	0 586(0 17)	0 645(0 263)
120 min	0 425(0 266)	0 738(0 173)	0 626(0 264)

For the FID, the main difference is between the 15 minute results and the longer times For 15 minutes, the estimated difference [ln(con-off)-ln(con-on)] at 15 minutes is 0 286 (reduction due to the control is about 25 percent) compared to a difference at 30 minutes of about 0 614 (reduction due to control about 46 percent) The simultaneous lower confidence bands are, respectively 0 and 0 percent, and the lower confidence bands for individual comparisons are 12 and 33 percent, respectively

For the DataRAM the main difference is between the 120 minute results and those for the earlier times When the 30 minute and 120 minute results are compared for the DataRam (including short-term), the estimated difference for the 120 minute data is 0 738 (reduction about 52 percent) and 0 596 for the 30 minute data (reduction about 45 percent) Lower simultaneous confidence limits are 29 percent for 120 minute data and also 29 percent for 30 minute data (because of the difference in the standard errors) The individual lower confidence bands are 44 and 39 percent, respectively

(Excluding the short-term data considerably lowers the estimates - estimated difference of about 0 24 (21 percent reduction) for the 30 minute data and about 0 425 (35 percent reduction) for the 120 minute data

We will use the 30 minute results in the report. The reason is the FID data. There is no way to say which duration gives the "right" estimate, but we can see that estimates of duration between 30 and 60 minutes are relatively stable for both vapor and particulate.

We should recall that the FID is based on only two days of data, and all are long-time periods. The DataRAM includes three days of long period samples, and one day of short period samples The short periods varied in length between from 5 minutes to less than 15 minutes of continuous paving **There is no problem in combining results from periods of different lengths. whether 5, 10, or 30 minutes in length**

LIST OF FIGURES

FIGURE 1.RANDOMIZATION SEQUENCE

THREE DAYS OF LONG TIME PERIODS, ONE DAY OF SHORT TIME PERIODS

	DAY 1	DAY 2	DAY 3	DAY 4
PERIOD 1	L ON	L-OFF	S	L-OFF
PERIOD 2	L-OFF	L-ON		L-ON
PERIOD 3	L-ON	L OFF		L OFF
PERIOD 4	L-OFF	L ON		L-ON
PERIOD 5				L OFF
PERIOD 6				L ON

S=SHORT-TIME PERIOD CONSISTING OF 9 RANDOMIZED PAIRS
L=LONG-TIME PERIODS FIRST CONTROL SETTING IN EACH DAY RANDOMLY SELECTED
OFF=VENTILATION CONTROL OFF, ON=VENTILATION CONTROL ON

FIGURE 2 LOGS OF MEDIANS OF PARTICULATE DATA FROM DAY 4

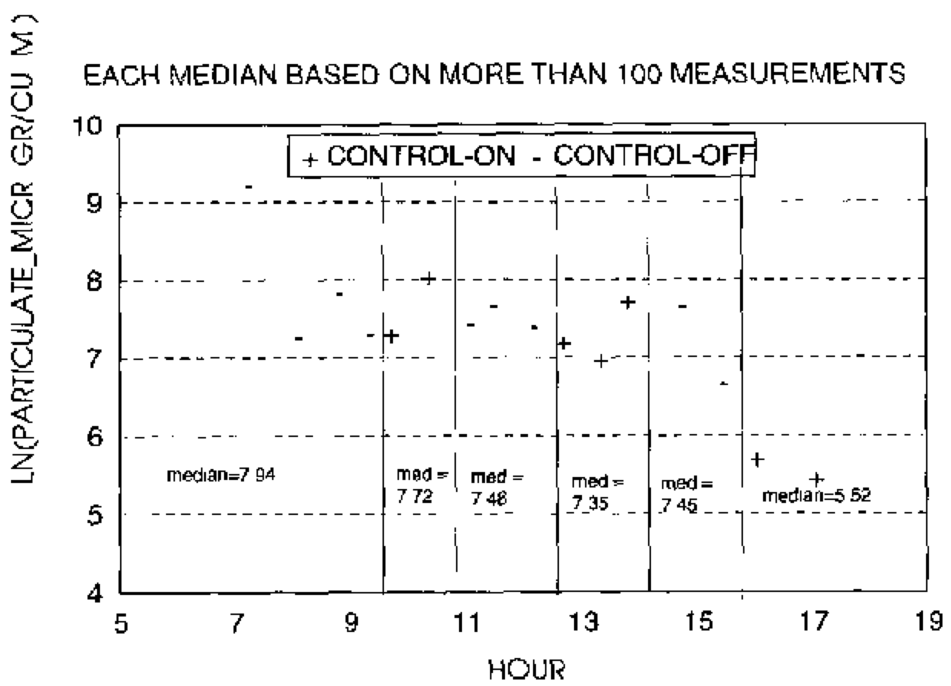
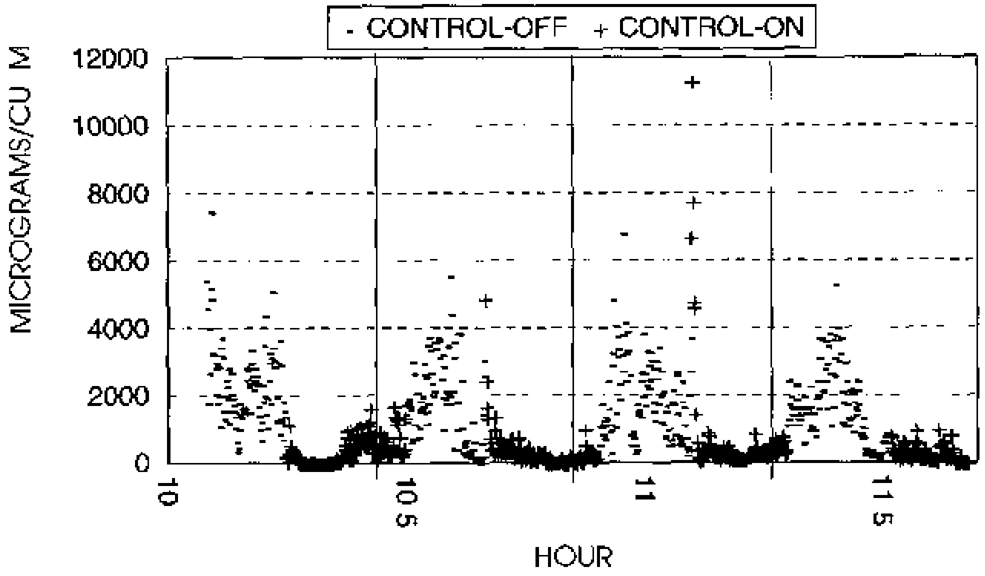


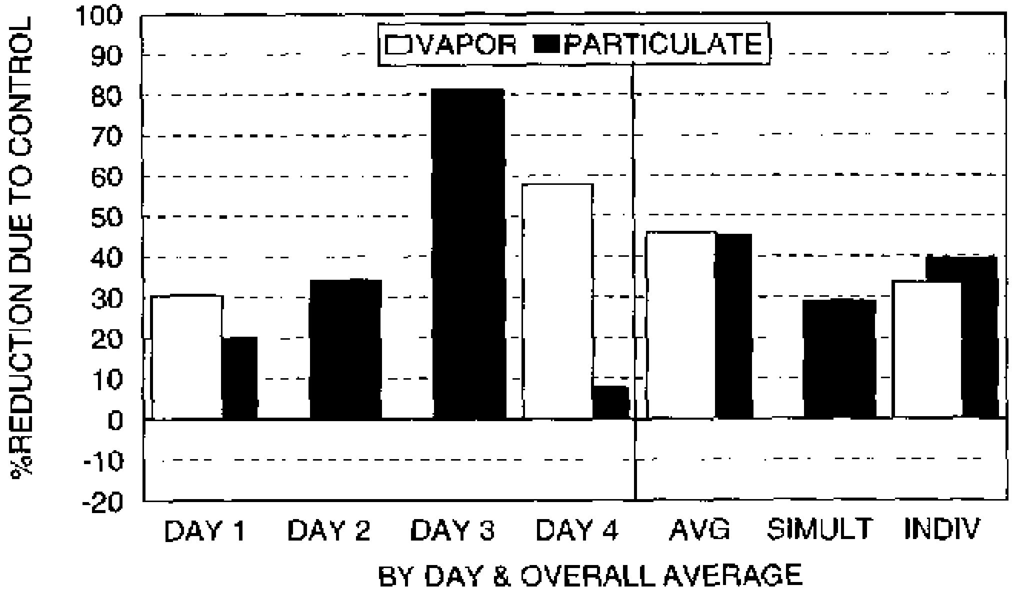
FIGURE 3 PARTICULATE DETERMINATIONS AT AUGER FROM DAY 3, SHORT-TIME SAMPLING



FOR THE FOUR PAIRS SHOWN RANDOMIZATION PRODUCED SAME CONTROL-OFF CONTROL-ON SEQUENCE LINES SEPARATE RANDOMIZED PAIRS

FIGURE 4: AUGER: %REDUCTION BY DAY & OVERALL AVERAGE

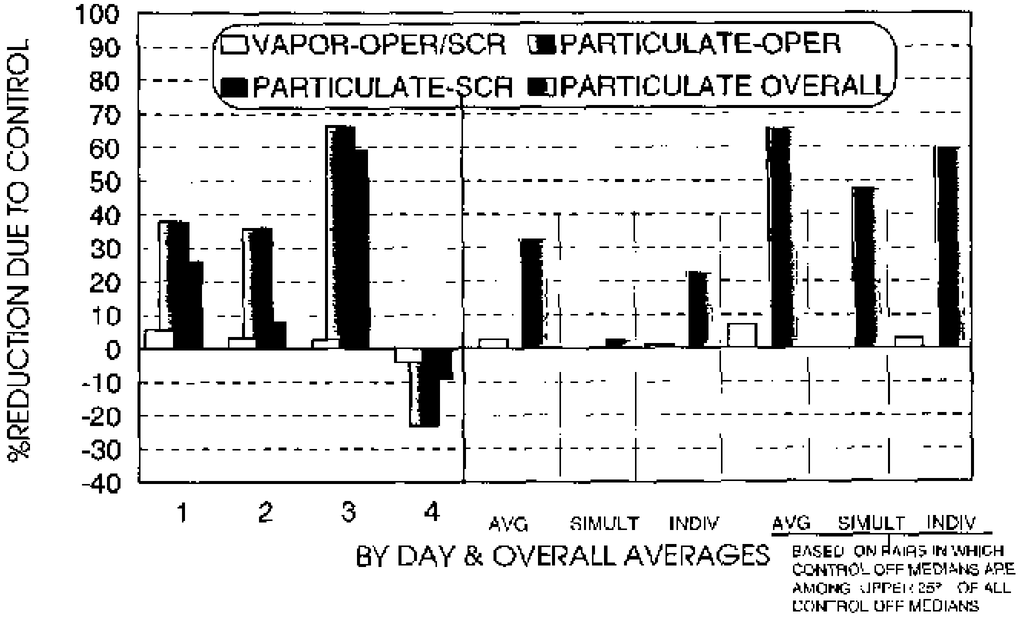
LOWER 80% CONFIDENCE LIMITS, SIMULTANEOUS & INDIVIDUAL VAPOR & RAM



NO VAPOR SAMPLES FOR DAYS 2 & 3

FIGURE 5: AWAY FROM AUGER: %REDUCTION BY DAY & OVERALL, BASED ON SAMPLE MEDIANS

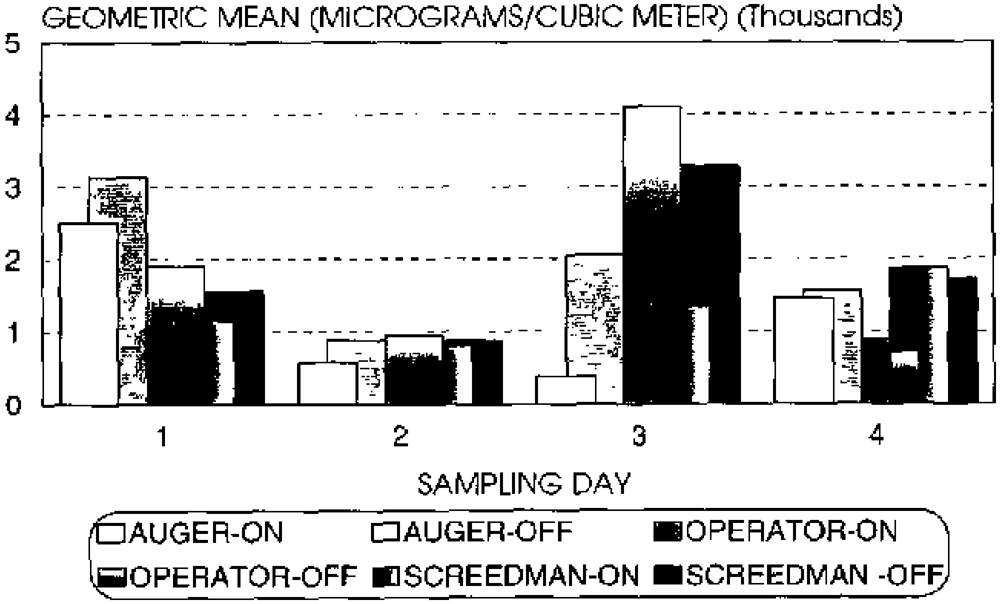
LOWER 80 % CONFIDENCE LIMITS FOR VAPOR AND PARTICULATE GIVEN FOR BOTH SIMULTANEOUS AND INDIVIDUAL INFERENCE ALSO COMPARISONS FOR PARTICULATE FOR PAIRS CONTAINING UPPER 25% CONTROL OFF MEDIANS



VAPOR CLs CLOSE TO 0 AVERAGES FOR VAPOR ARE LOWER THAN AT AUGER DAY 4 PRODUCED VERY DIFFERENT RESULTS FOR PARTICULATE. SIMULTANEOUS CLS 0 FOR VAPOR

FIGURE 6:REAL-TIME PARTICULATE GEOMETRIC MEANS

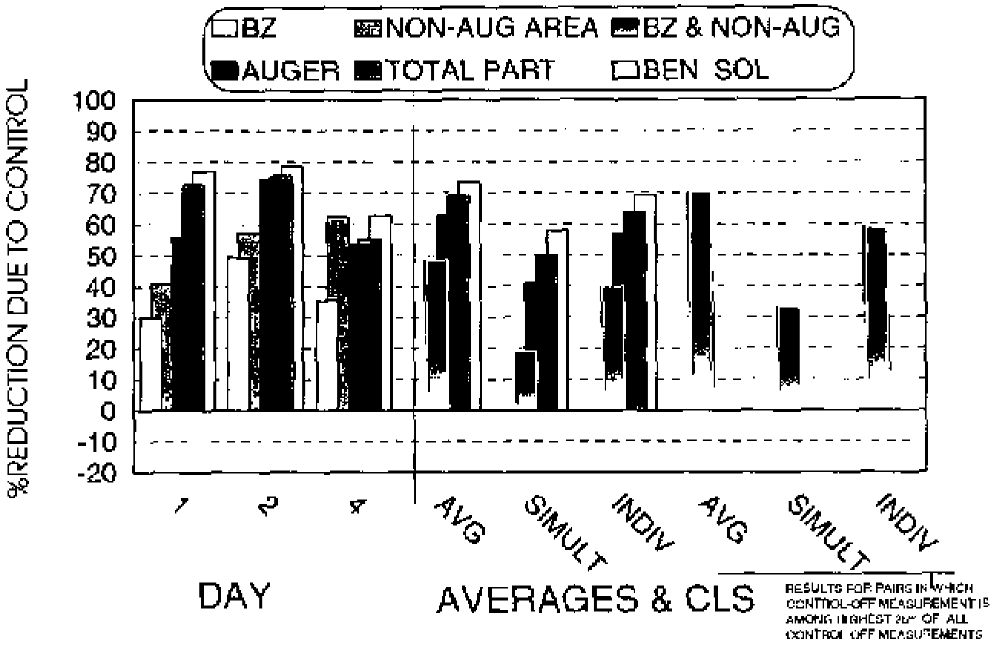
AUGER MEASUREMENTS VIA DATARAM, NON-AUGER VIA GRIMMS



ON MEANS 'CONTROL ON', OFF MEANS 'CONTROL OFF', HIGHEST EFFECTIVENESS ON DAY 3, SHORT-TIME SAMPLING

FIG. 7: INDUSTRIAL HYGIENE SAMPLES: %REDUCTION BY DAY

80% CONFIDENCE LIMITS, SIMULTANEOUSLY & INDIVIDUALLY FOR NON-AUGER TOTAL PAC,
ESTIMATES AND CLS GIVEN ALSO FOR UPPER 25% CONTROL OFF PAIRS



%REDUCTIONS BASED ON GEOMETRIC MEANS OF SUMMED 370nm AND 400nm DETERMINATIONS FOR AVERAGES & CONFIDENCE LIMITS BR ZONE AND NON AUGER PACS ARE COMBINED

FIGURE 8: % REDUCTION FOR LOWEST 75% CONTROL-OFF VERSUS HIGHEST 25% CONTROL-OFF PAIRS

FOR TOTAL PAC AREA & BREATHING ZONE SAMPLES AWAY FROM AUGER

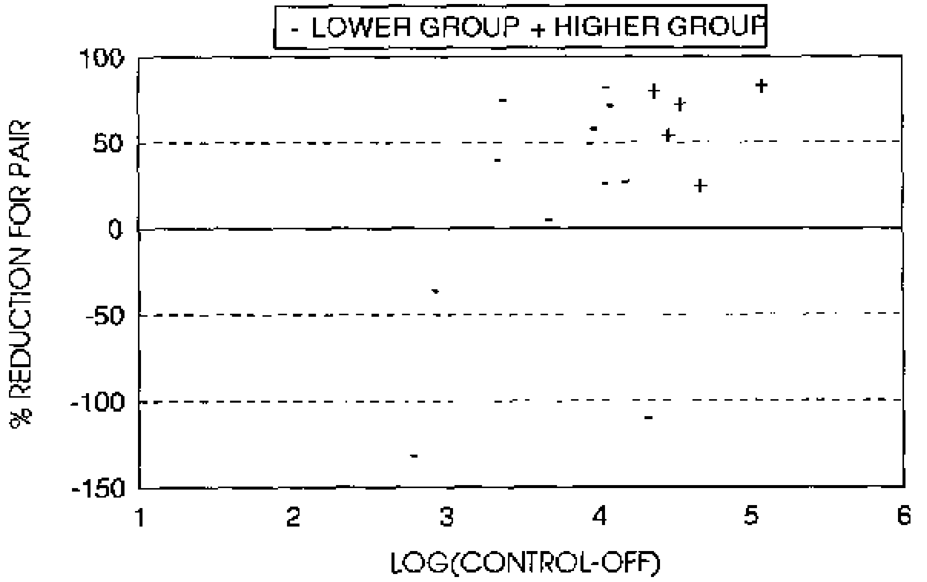
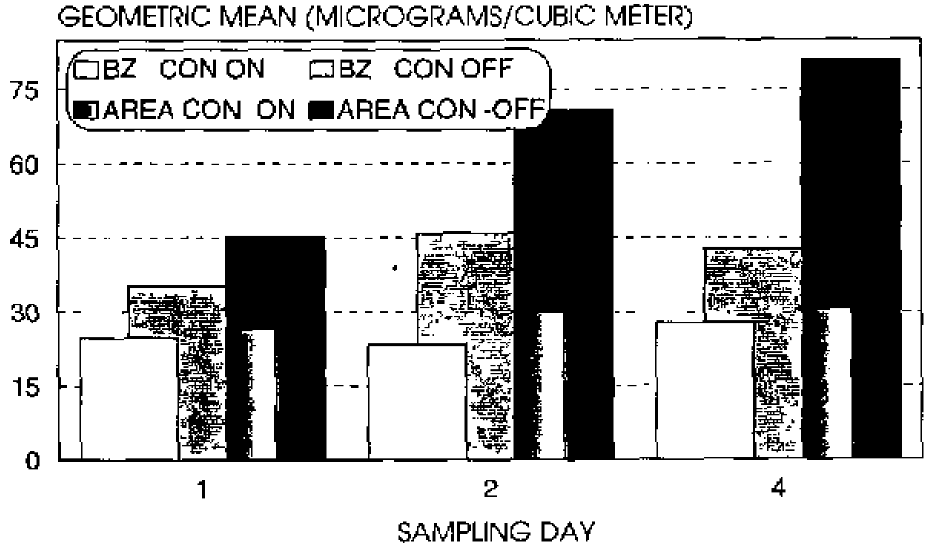
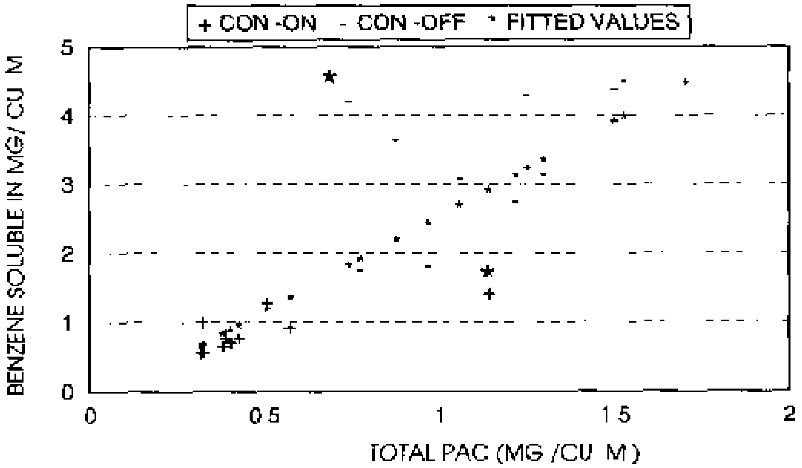


FIGURE 9:TOTAL PAC GEOMETRIC MEANS:BREATHING ZONE SAMPLES & AREA SAMPLES AWAY FROM AUGER



NO IH SAMPLES TAKEN ON DAY 3, 370nm and 400nm DETERMINATIONS ARE SUMMED

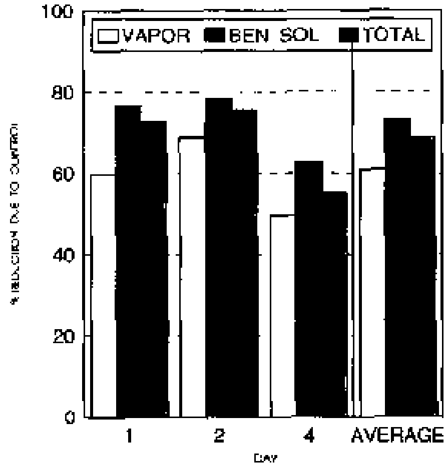
FIGURE 10 AUGER BENZENE SOLUBLE VS SUM OF INSTRUMENTAL RESPONSES (370NM + 400NM)



THE TWO STARRED VALUES ARE FROM SAME LOCATION ON SAME DAY

FIGURE 11 REDUCTION DUE TO CONTROL AT AUGER

TUBE SAMPLES(VAPOR) VS FILTER SAMPLES (BENZENE SOLUBLES & TOTAL PARTICULATE)



ON AVERAGE REDUCTION IS ABOUT 60% FOR VAPOR COMPARED TO ABOUT 70% FOR FUME DIFFERENCE BETWEEN TUBE AND BEN SOL STATISTICALLY SIGNIFICANT AT 5% LEVEL