IN-DEPTH SURVEY REPORT:

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

MANUFACTURER Cedarapids, Inc
PAVING CONTRACTOR Milestone Contractors

PAVING LOCATION Tippecanoe County, Indiana

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PLANT SURVEYED	Cedarapids Inc (Paver Manufacturer) Milestone Contractors (Paving Contractor) Tippecanoe County, Indiana
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EXECUTIVE SUMMARY

On June 17-21, 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 Cedarapids engineering control evaluation was completed as part of a Department of Transportation (DOT) project to evaluate the effectiveness of engineering controls on asphalt paving equipment NIOSH researchers conducted the research through an inter-agency agreement with DOTs 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, 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 Cedarapids phase two (field) evaluation of a single engineering control installed on a Cedarapids Model CR411 asphalt paving machine The tested design consisted of two exhaust hoods (one per side) mounted above the auger area A single rubber flap attached to the rear edge of both exhaust hoods and extended over the remaining auger area between the paver and the screed Two exhaust fans (one per hood) removed air from the enclosed auger area The captured air was discharged within a hot-gas mixing box (muffler), where it combined with hot exhaust from the paver engine prior to exiting through a single paver exhaust stack

Field tracer gas measurement techniques revealed an average combined exhaust flow of 736 cubic feet per minute (cfm) from the two exhaust fans Test results indicate that the Cedarapids engineering control design was successful in capturing and removing an average of 95 percent of the asphalt fume released from the auger area This source reduction led to an average worker-area reduction of 44 percent The lower efficiency at the non-auger positions is believed to result from a natural control-effect created by environmental factors such as the wind 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 auger source emissions, such as during a stagnant wind condition, the worker-area concentrations increase (in the absence of an engineering control) Under these conditions, the presence of the engineering control became more important This was evidenced by an average control efficiency of 75 percent when it came to preventing the accumulation of higher contaminant concentrations (upper 25 percent of all control-off observations) within the workers' work areas

The Cedarapids evaluation was the first of six field evaluations to be conducted as part of the engineering controls research partnership Many of the testing methods had not previously been applied to environments as unique and physically demanding as an asphalt paving environment 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 Cedarapids 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

The implementation of engineering controls on asphalt paving equipment will continue to be an iterative process NIOSH encourages Cedarapids to incorporate the following recommendations into their engineering control implementation process (1) Monitor the worker/contractor acceptance of the current auger-area enclosure design and incorporate design changes if undesirable field-modifications are observed, (2) 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, (3) Modify or supplement the existing hood enclosure to minimize escaping fume when the screed is extended beyond the width of the tractor

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 June 17-21, 1996, researchers from NIOSH evaluated a first-generation engineering control designed to capture and remove fugitive asphalt emissions during asphalt paving The Cedarapids engineering control evaluation was completed as part of a Department of Transportation (DOT) project to evaluate the effectiveness of engineering controls on asphalt paving equipment NIOSH researchers conducted the research through an inter-agency agreement with DOTs 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 Cedarapids phase one evaluation occurred in April 1995 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 Cedarapids Incorporated, Cedar Rapids, Iowa "[2] Since the phase one evaluation was only one portion of the overall development and evaluation of the Cedarapids engineering control, finalization of the Cedarapids phase one report was delayed until the completion and co-release of Cedarapids' phase two report

The scope of this report is the Cedarapids phase two (field) evaluation of a prototype engineering control installed on a Cedarapids Model CR411 asphalt paving machine (see Figure 1) Participating NIOSH researchers included Ken Mead, Mechanical Engineer, Leroy Mickelsen, Chemical Engineer, Stan Shulman, Statistician, Chuck Hayden, Mechanical Engineer, Clint Morley, Intern-Industrial Hygienist, and Jack Hill, Intern-Industrial Hygiene technician, all from the Division of Applied Research and Technology (DART), NIOSH The NIOSH team was augmented by Tom Brumagin, NAPA's Director of Environmental Services. Joseph E Musil, Cedarapids' Director of Research and Development, and Bill Rieken, Cedarapids Engineering Technician The field evaluation was conducted in coordination with Indiana paving contractor, Milestone Contractors' Inc at a Milestone project site in Tippecanoe County, Indiana Representatives from Milestone Contractors included John Spangler, President, Doc Ernst, Milestone's Lafayette Operations Manager, and Don Meyer, Paving Crew Foreman

Figure 1. Cedarapids Model CR411 Asphalt Paving Machine undergoing field testing of prototype engineering controls Hot mix asphalt was delivered to the paver by dump truck

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 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 selection and application of the evaluation methods based upon prior experiences A listing and description of the different 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 Cedarapids evaluation, the total dosing flow of SF_6 was 0 1 liters per minute (lpm) for each needle (0 2 lpm per side) Since each side of the auger had its own exhaust fan and duct, each side was analyzed independently and the results were subsequently combined (exhaust flow) or averaged (capture efficiency) 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 and preventing needle obstruction due to occasional contact with the HMA

Industrial Hygiene Sampling Industrial hygiene (IH) sampling trains were configured for use with a new analytical method developed by NIOSH research chemists The new method quantified concentrations of total polycyclic aromatic compounds (PACs) and was more sensitive than the traditional asphalt fume sampling methods (total particulate followed by the benzene soluble fraction of total particulate) [4] At the auger area, four general area (GA) sampling positions were uniformly distributed across the width of the auger area Additional GA sampling positions 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 of the eight GA and three BZ sampling positions were assigned two sampling trains per day 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 positions Difficulties encountered with the IH evaluation method included potential non-paving sources of PACs such as diesel fuel, diesel exhaust, hydraulic fluid, and cigarette smoking, as well the occasional loss of filters into the asphalt due to the vigorous vibrations and jolting of the paver

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 approximately 12–15 inches above the top of the auger drive gear (equivalent to approximately 6 inches above top of auger blade) In this position, the DataRAM could measure particulate escaping directly from the auger area Sample frequency for the DataRAM was once every 4 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 minium 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 Both types of aerosol monitors included an internal warning feature to indicate when excessive vibration occurred, 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 with 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 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 the effect of relative humidity (i e humidity changes throughout a pair of long sampling periods could potentially affect the recorded values at low concentrations), instrument drift, and the work practice of using diesel fuel as a cleaning agent and as a release agent to prevent HMA buildup within the paver's feed path 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 barely distinguishable from a zero-concentration response This condition occurred during both control-on and control-off conditions Since there was insufficient confidence in the accuracy of these measurements at such low values, no performance ratio for the screed and paver operator positions was established using the TVA data

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 required 30 to 45 minutes to reconfigure the paver This constraint greatly limited the number of opportunities to switch between control-on and control-off settings Since the control settings were alternated, the only condition that was randomized was the initial setting for the given day 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 However, because of some technical problems, only one day, the second day of sampling, started with control-off Further details concerning the statistical design and randomization strategy for the real-time and industrial hygiene samples is included in Appendix B

ENGINEERING CONTROL DESIGN DESCRIPTION

The Cedarapids phase two (field) evaluation was conducted on a single engineering control installed on a Cedarapids Model CR411 asphalt paving machine The tested design consisted of two exhaust hoods (one per side) mounted above the auger area Each hood was approximately 8 inches deep and extended from the auger gear box to the outside edge of the paver, thus running the full width of each side of the auger area A single rubber flap attached to the rear edge of both exhaust hoods and extended over the remaining auger area between the paver and the screed Two exhaust fans (one per hood) removed air from the enclosed auger area The captured air was discharged within a hot-gas mixing box (muffler), where it combined with hot exhaust from the paver engine prior to exiting through a single paver exhaust stack

The Cedarapids design was very effective at enclosing the auger area across the width of the tractor When the ends of the screed were pulled in close to the tractor, there was near-total enclosure of the auger area However, when the ends of the screed were extended beyond the edge of the tractor to increase the available paving width, the extended portion of the screed had minimal enclosure (see Figure 2) In this position, fumes and vapors within the extended area were virtually non-controlled and ambient winds had an increased opportunity to disrupt fume containment within the auger area

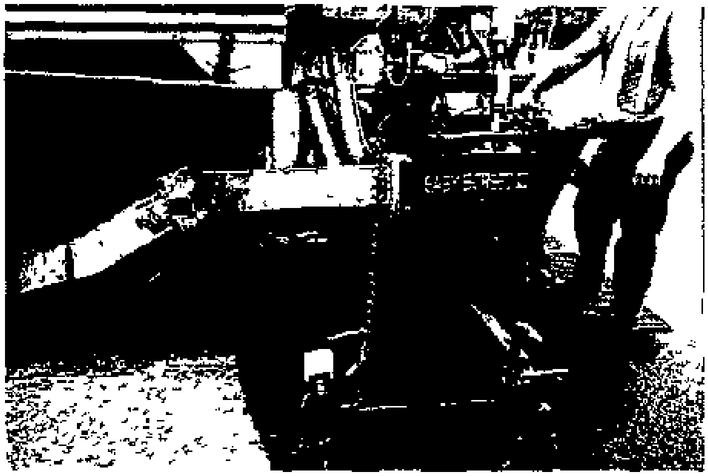

FIGURE 2. Photograph shows left screed gate extended to increase paving width In this position, fumes are uncontrolled and may enter workers' breathing zones

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 Median wind speeds were calculated for each control setting used in the randomization There was no determinable correlation between the measured wind speeds and the exposure concentrations observed by the direct reading instruments The long time delays required to change between control-on and control-off conditions hampered the ability to obtain appropriate temperature comparisons Given this limitation, the overall average temperature was about 1 26 degrees F lower for control-on than for control-off The individual 80 percent confidence limit is 0 31 degrees F and the simultaneous is zero degrees F reduction This estimate is based on 5-minute segments chosen analogously to the 25 minute segments since temperature differences should be quickly observed after a change in control setting

SF_6 Determinations

There were a total of six control-on runs in which SF_6 determinations could be made Multiple determinations were conducted and averaged within each run, resulting in a total of six average efficiency estimates The average combined exhaust flow rate was 736 cubic feet per minute (cfm) from the two exhaust fans The average of these was a 94 percent reduction The lower 95 percent confidence point for the true efficiency was 92 percent Thus, for the SF_6 determinations, the true efficiency of the Indiana equipment can be said to be greater than 92 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 250,000 data points were statistically evaluated as a result of the four-day paving evaluation Table I below summarizes the results of the evaluation A more complete description of the evaluation methods may be found in Appendix B

Table I
Engineering Control's Airborne Contaminant Control Efficiencies

	SAMPLES ABOVE AUGER			SCREED/PAVER OPERATOR SAMPLES			
	DataRam (Aerosol)	TVA (Vapor)	IH (Total PACs)	Grimms (Aerosol)	Grimms Upper 25%	IH (Total PACs)	IH Upper 25%
Reduction Estimate	96%	81%	93%	31%	79%	56%	70%
Individual LCL[1]	95%	78%	89%	17%	70%	47%	60%
Simultaneous LCL[2]	91%	71%	66%	0%	48%	20%	41%

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 is 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 evaluate the engineering controls 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 A discussion of each evaluation technique and its usefulness to the Cedarapid's 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 a preliminary 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. The observed temperature reductions, due to control, are not as large as anticipated. Since the HTAs temperature sensor is partially shielded by the airfoil encircling the rotating vane anemometer, it is possible that the recorded temperature may more accurately reflect that of the ambient cross-winds as opposed to the convective currents rising from the HMA in the auger area.

Given these considerations, the reported values for temperature reductions, due to the control, should be considered as only cursory observations. 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 (η = 94% 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 SF_6 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. 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. The fact that the SF_6 results correspond well with both the DataRAM (η = 96%) and Total PAC (η = 93%) observations above the auger are probably related to the good enclosure provided by the Cedarapids' design. In this regard, users of this engineering control should be cautioned that removal of this enclosure will likely degrade the engineering control's capture efficiency in the absence of other design upgrades.

Environmental Contaminants

Auger Area--

The results depicted in Table I indicate that the engineering control performed very well in controlling the escape of asphalt fume (DataRAM and IH samples) from the auger area The consistency in results between the two evaluation methods and the high values reported in the confidence limits indicate that the engineering control prevented almost all of the asphalt fume from escaping the auger area

The results for controlling organic vapor (TVA) also show a significant reduction in escaping contaminant although moderately less than the DataRAM and IH results Intuitively, one would expect vapor originating within the auger area to follow the same path, or air currents, as the asphalt fume The discrepancy in performance results could be due to several factors

- The frequent use of diesel fuel as a cleaning solvent contaminated the testing area and became a non-auger source for organic vapor
- The screed removal and re-attachment associated with each change in control setting was observed to regularly release hydraulic fluid at the rear of the tractor (near the TVA inlet) This could have produced an additional source of uncontrolled organic vapor
- The long sample periods combined with an unknown rate of instrument drift could have had an undesirable effect upon data results Once this concern became apparent, subsequent field evaluations with other paver manufacturing partners incorporated a series of multiple, short-term control-on/off pairs with more frequent span checks in order to reduce this uncertainty

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 Even with the increased pool of data, the variability at these positions is noticeably reflected in the reduced confidence limits

Since the concentrations observed at the non-auger locations averaged roughly 20-fold lower than those observed immediately above the auger (based upon comparison of IH 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 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 for those control-on periods that correspond to the highest 25 percent of control-off 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 75 percent Since, by design, the engineering control only captures fumes originating from the auger area, this analysis also served to verify that, under the observed test conditions, the auger area was the major contributing source of higher-level asphalt fume exposures

CONCLUSIONS AND RECOMMENDATIONS

The scope of this report is limited to the Cedarapids phase two (field) evaluation of a single engineering control installed on a Cedarapids Model CR411 asphalt paving machine On average, the Cedarapids design was successful in capturing and removing 95 percent of the asphalt fume (real-time and total PAC) originating from the auger area, resulting in an average reduction of 44 percent within the screedman and paver operator work areas During those periods when environmental factors were not as effective in reducing area concentrations (i e , when work area exposures were at their highest), the engineering control provided an average fume exposure reduction of 75 percent These performance values represent an achievable level of performance by the evaluated engineering control operated under the conditions observed during the Cedarapids engineering control evaluation The Cedarapids evaluation was the first of six field evaluations to be conducted as part of the engineering controls research partnership Many of the testing methods had not previously been applied to environments as unique and physically demanding as an asphalt paving environment 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 Cedarapids 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 Cedarapids field evaluation completed an important step in this process by successfully demonstrating a 95 percent capture of the auger-source asphalt fume and significantly reducing workers' exposures by 44 percent Effective July 1, 1997, Cedarapids began providing engineering controls as standard equipment on all of their new highway-class pavers As the Cedarapids engineering control is adopted into the industry, NIOSH recommends the following (1) Monitor the worker/contractor acceptance of the current auger-area enclosure design and incorporate design changes if undesirable field-modifications are observed, and, (2) 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 Provide design modifications and maintenance recommendations as necessary to maintain the protective viability of the engineering control

As future modifications to the Cedarapids engineering control occur, NIOSH recommends that design engineers incorporate protective features that 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 these features

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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

<u>Safety</u> 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 <u>Method A</u> 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 <u>Method B</u>, 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 <u>Method C</u>, 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 Organic Vapor 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 before going on the survey
- Charge the TVA 1000 batteries before going to the survey site
- 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 Aerosols The MIE, Inc , DataRAM Real-time Aerosol Monitor and two Grimm Dust Monitors will measure and record respirable (less than or equal to ($\leq$) 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 before going to the survey site
- Change the backup filter in the DataRAM before going to the survey site
- 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

<u>Evaluation Method C (Total Polycyclic Aromatic Compounds-BZ & GA Samples)</u> 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

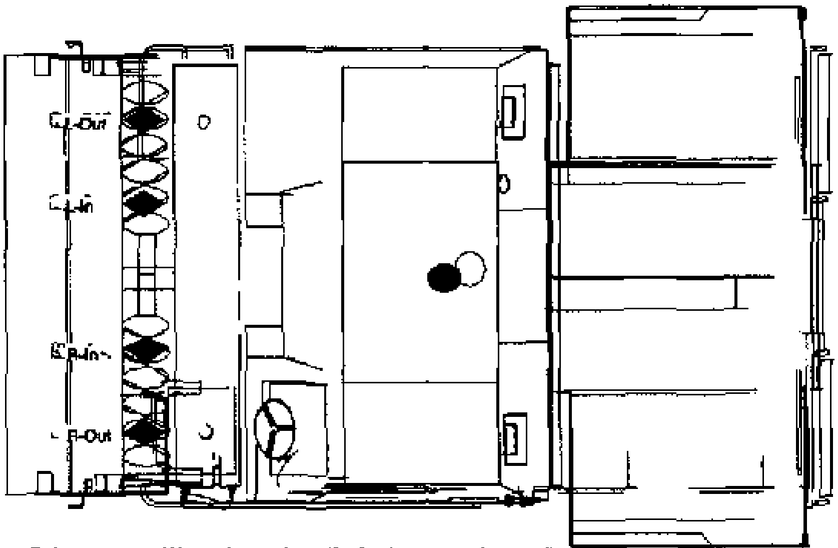
- Calibrate sampling pumps to flow at 2 lpm
- Construct pairs of sampling trains for eight area and three personal sampling positions (total of 22 samples per day)
- Color code each sampling train red=uncontrolled, blue=controlled sampling scenario
- Assign one red and one blue sampling train to each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

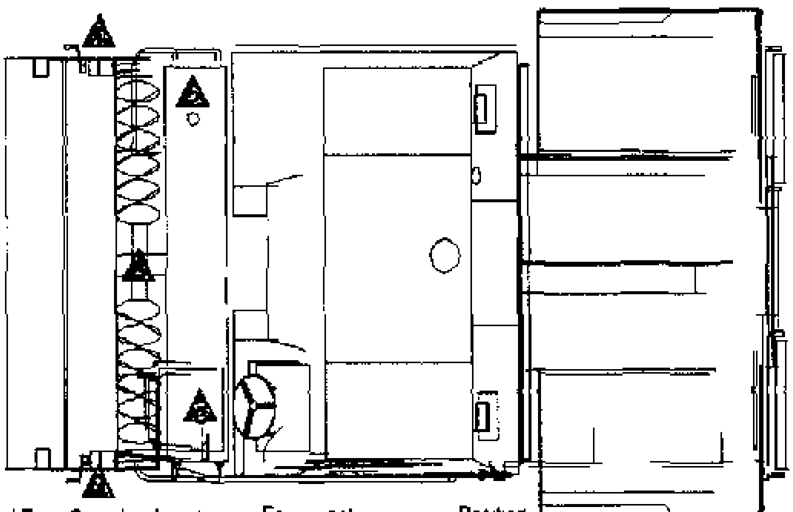
Figure 1 Tracer Gas Dosing And Sampling Locations



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

B&K Monitoring Point Within Engineering Control Exhaust Stack

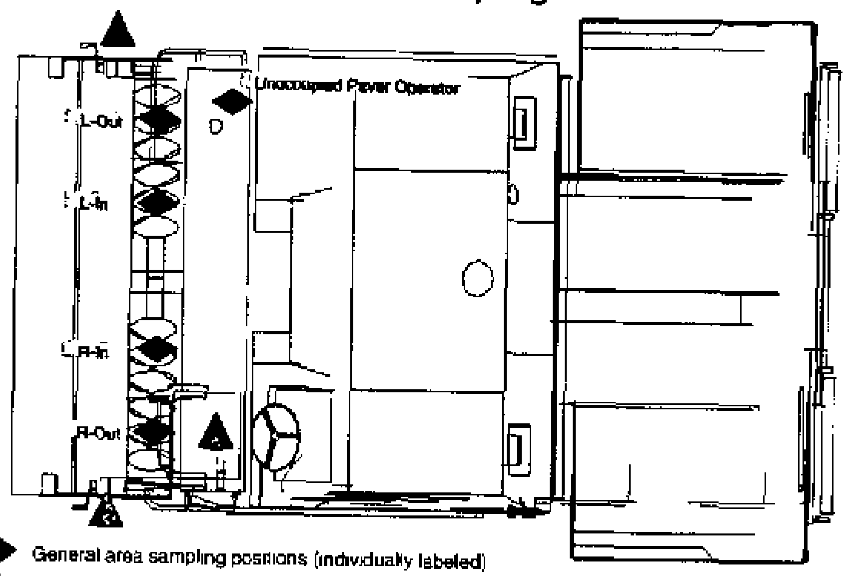
Figure 2 Real-Time Sampling Locations



Real Time Sampling Locations	Equipment	Position
1 LHS Screed Operator	TVA 1000(x 2)	(1,2) 5
2 Unoccupied Paver Operator	Grimm(x 2)	1 2
3 Occupied Paver Operator	DataRAM	5
4 RHS Screed Operator	Wind Temp (x 2)	1 2
5 Center Auger Position	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

<u>Analytical Overview</u>
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.

$$\text{ug/sample} = 8 \times \text{ug/mL}$$

APPENDIX B

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

CEDARAPIDS' PHASE TWO FIELD EVALUATION

STATISTICAL DESIGN AND DATA ANALYSIS

CEDAR RAPIDS (INDIANA)

EXPERIMENTAL DESIGN

The data were collected in long time periods See **Figure** 1 for the randomization followed **The requirements for industrial hygiene samples determined the period length.** Real-time samples have no requirement like this, but the design deemed necessary for the industrial hygiene samples was imposed on them too

Comparisons were to be based on pairs (control-on, control-off) Since the control settings were alternated, **the only condition that was actually randomized was the initial setting for the given day.** However, the design also specified that if day 1 started with control-on then day 2 would start with control-off, and vise-versa The same randomization approach was used for days 3 and 4, though due to practical problems both days began with control-on For industrial hygiene samples, at any given sample location, the same sample media were used for both periods of the particular control setting (on/off) during a given day This ensured that enough material would be collected on the sample media Thus, for each industrial hygiene sampling location, there is really just one pair (control-on, control-off) for each day

For the real-time samples, averages can be obtained for each control setting shown in Figure 1. Note that there were actually three control periods on each day except for the first day It was difficult to obtain an additional period because it took over half an hour to remove or attach the enclosure that was part of the control Whereas for the industrial hygiene data, there are no decisions to make about grouping of the data For the real-time samples, there are many decisions to make Since most of these instruments make their determinations every 4 seconds, we can use just a portion of the results for a given control setting if we think that leads to more precise comparison of control-off with control-on How we choose the portion is discussed in the next section

Only one TVA instrument was available to sample organic vapor concentrations at the screed and paver operator locations To accomplish sampling at these two positions, the sample inlet to the TVA was alternated between the screed or paver operator positions according to a randomization scheme that was independent of the engineering control test setting

METHODS FOR DATA ANALYSIS

Some of the considerations involved in handling of the real-time data are the following

1 Since these data were collected in batches of control-on and control-off, **it is not appropriate to treat the measurements individually** when comparing control-on and control-off settings The reason is that the variability of measurements made in batches is usually different (smaller) than that of measurements which are collected in a randomized fashion See Figure 2 for vapor data from day 2 of the study Since the only randomization involves ordering control-on and

control-off settings, it makes sense to **calculate one number for each control-on and control-off setting within each pair** Since **the median** is not sensitive to measurements far from the center of the distribution, the median is used for the real-time measurements This includes real-time measurements for both particulate and vapor

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, 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) and total PAC away from the auger (two or three personal samples and four area samples)

2 **For long-time periods there are trends in the data that indicate it may be unwise to use the entire set of data at one control setting.** These trends may be short-time trends or long-time trends Consider Figure 2 again Although there is no apparent trend for the control-on determinations, the control-off determinations seem to increase during the time period shown These measurements are taken from a larger collection, shown in Figure 3, as the medians of large batches of particulate measurements Each plotted value is a median of over 40 vapor determinations Note that the set 1 data shown in Figure 2 are marked in Figure 3

Comparisons of control-on and control-off depend on the data used to compute the medians If we compare the median of the entire first setting of control-on with that of the entire first setting of control-off, we may get quite different results than if we compare the medians shown in set *1* Since we 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 before and after a change point from one control setting to the other.**

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 should include data for computation of the medians Figure 2 (control-off) indicates that as we increase the length of time from the control setting change for inclusion of points, the medians used in the comparison can become quite different

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 half an hour, the estimated effectiveness of the control is stable and does not change much in the next half hour **For the results presented here, 25 minute periods are used. Additional explanation is provided in the section of this appendix entitled, "Determining Length of Period."**

4 Trucks were used for delivery of the asphalt for each day **Consequently there were stops, especially when there were delays in truck arrival** If there is a long break, environmental differences can affect estimates of the difference between the two control settings The times without measurements plotted in Figure 2, control-on setting, are due to stops in truck delivery An important consequence of the delivery by trucks is made clear in Figure 4 That figure has the same control-on measurements as Figure 2, but in addition, has the vapor determinations when there is no paving We might expect lower measurements during such intervals, but in Figure 4 the measurements tend to increase when paving stops When paving resumes, the measurements shown in Figure 4 decrease It is often true that after a change in control setting and after a stop in paving activity, there is a period of time during which the measurements change their means **Because of this tendency, we have deleted a half minute of real-time measurements before and after a period of no paving. 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 half 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 **There were problems with downloading the particulate data collected in the auger area for the first three days of this study. This was due to a "handshaking" error between the DataRAM and the computer.** The problems resulted in incomplete data transfer for some of the readings Identification of the affected readings was obvious and the following rules were devised for removing faulty data Since each reading was to have included a minimum, maximum, and average value for the 4 second interval, the record is deleted if any of these were missing If the maximum exceeded 9 times the average or the minimum is less than 1 times the average, then the record is deleted Approximately one of every four determinations was removed **These deletions result in reasonable looking data, which were used for the subsequent analyses.**

6 Another issue concerned **drift in the FID determinations** As the TVAs sampled through the day's paving, the "zero point" tended to drift upward Ideally, recalibration or multiple spans of zero gas could have been recorded However, the definition of sets used here does not require

such span data concerning drift, since the matched data in a set are close together in time, and we would not expect much difference in their drift

7 Data are analyzed by taking the natural log of the median for the particular control setting for the real-time data, and the natural log of the determinations at each control setting for the industrial hygiene data These **ln (median)s are then 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 and vapor, 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 (Grimm), measured at both the screedman and paver 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. For the same reason, averages (of the natural logs of measurements) are used in analysis of the total PAC data** sampled simultaneously from four locations above the auger and also for the analysis of the total PAC samples collected away from the auger For the latter, both area and personal samples are included in the average **For the industrial hygiene samples, the terms in the models are just day and control setting, since there is just one sample mean at each control setting on each day.**

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, 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 days; for the real-time data it is due to the variability of control effectiveness over pairs within days.** 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. 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 Twenty 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 fumes 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

Rather than work with the individual efficiency determinations, we average the efficiencies estimated during the same control-on run, resulting in six average efficiency estimates The average of these is 94 36 percent reduction The estimated variance is 7 201 The variance of the mean value is obtained by dividing 7 201 by 6 to get 1 200 Since the Student's t 95 percentage point with 5 degrees of freedom is 2 015, **the lower 95 percent confidence point for the true efficiency is: $94.36 - (1.2)^{0.5}(2.015) = 92.154$ percent. Thus, for the SF_6 determinations, true efficiency of the Indiana equipment can be said to be above 92 percent with 95 percent confidence. As was mentioned above, we treat this as a separate experiment and use 95 percent limits here as opposed to the 80 percent limits used below.**

EFFECTIVENESS OF CONTROL AT AUGER FOR REAL-TIME DETERMINATIONS

The results for the DataRAM determinations at the **auger** and for the vapor determinations by the TVA are given in Figure 5 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 vapor and particulate samples

The percent reduction is consistent over days both for vapor and particulate **The average percent reduction for particulate data was about 96 percent. The lower 80 percent confidence limits were 91 percent (simultaneous) and 95 percent (individual). For the vapor, the overall reduction was about 81 percent with 80 percent lower confidence limits of 71 (simultaneous) and 78 percent (individual).**

EFFECTIVENESS OF PARTICULATE AT OPERATOR AND SCREED POSITIONS FOR REAL-TIME DETERMINATIONS

The results for the particulate measurements at the screed and operator locations are plotted by day in Figure 6 **The average reduction, over all days and locations, is about 31 percent, the lower (simultaneous) confidence limit is less than 0, and the 80 percent (individual) lower confidence limit is about 17 percent.**

Figure 7 plots the geometric means for the particulate analyses on the log scale The Grimm geometric means are much lower than the DataRAM geometric means as is expected.

An alternative approach is used to study the **effectiveness of the reduction in particulate at the highest 25 percent of control-off measurements of particulate away from the auger** When the medians of these measurements are compared with the medians of the control-on measurements in the same matched set, bigger reductions are seen -- **estimated reduction of about 79 percent and lower (simultaneous) confidence limit on the reduction of about 48 percent (see Figure 6). The lower (individual) confidence limit is 70 percent. When the upper 50 percent control-off pairs are evaluated, the estimated reduction is also 79 percent.**

INDUSTRIAL HYGIENE SAMPLES

Figure 8 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) collected as either area samples above the auger or near the screedmen and paver operator working locations, or as breathing zone samples attached to the screedman or paver operator Throughout the evaluation, the auger sample reductions were larger than the non-auger reductions For the non-auger samples, the reductions are averaged (data treated first on log scale) over all days and over both area samples and breathing zone samples **For the auger samples, the overall average**

reduction is about 93 percent, with a lower confidence limit (simultaneous) of about 66 percent, and a lower confidence limit (individual) of about 89 percent **For the non-auger samples, the average reduction is about 56 percent**, the lower (simultaneous) confidence limit is about 20 percent, and the lower (individual) confidence limit is about 47 percent

Figure 9 shows the daily geometric means of the total PAC breathing zone and area samples There are no consistent biases between the breathing zone and the non-auger area samples

Just as for the particulate data away from the auger, an alternative approach was attempted to study the **effectiveness of the reduction in total PACs at the highest 25 percent of control-off measurements away from the auger** When these highest measurements are compared with the control-on measurements in the matched pair at the same sampling location on the same day, bigger reductions are seen -- **estimated reduction of about 70 percent and lower confidence limits of 41 percent (simultaneous) and 60 percent (individual).** Figure 10 presents the data used in estimating this reduction The reductions for the high point group and the non-high point group are plotted versus the natural logs of the control-off determinations Seven of the 26 measurements are in the high point group For any one day, all samples are collected simultaneously so that environmental factors should be similar for all samples **The data suggest that at the highest control-off loadings, the engineering control produced much higher reductions than the average taken over all loadings.** Thus, use of the upper 25 percent may indicate the best that the control can do away from the auger **When the control effectiveness estimate is made for the upper 50 percent control-off pairs, the reduction is about 54 percent, about the same as that based on all the data.**

WIND AND TEMPERATURE MEASUREMENTS

The HTA instruments were located at the screedman and operator locations On average, the temperature is about 1 26 degrees F lower for control-on than for control-off This estimate is based on 5-minute segments The individual 80 percent lower confidence limit is 0 31 degrees F lower for control-on than control-off, and the simultaneous 80 percent lower confidence limit indicates no reduction

Median wind speeds are calculated for each control setting used in the randomization These determinations and the temperature determinations were made by the two HTA instruments, located near the GRIMMs at either the screed positions or the operator positions **The vapor data were examined to see how the effectiveness of the control in the matched 25 minute pairs varied with the ratio of the median wind speeds in these pairs Because of limited numbers of pairs, however, it is difficult to assess the results.**

CONCLUSIONS

	Part auger Real-time	Vapor-auger Real time	Total PAC auger Indus Hygiene	Part non auger Real-time	Part nonauger upper 25%	Total PAC non auger Indus Hygiene	Total PAC non auger upper 25%
Estimate	96%	81%	93%	31%	79%	56%	70%
Indiv LCL	95%	78%	89%	17%	70%	47%	60%
Simult LCL	91%	71%	66%	0%	48%	20%	41%

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

Determining Length of Period

The data in this study were collected in periods of several hours at each control setting This was true for both real-time and industrial hygiene samples **Whereas for the industrial hygiene samples, we must use the measurement of each sample. For the real-time samples, we can choose which samples we might use. Why choose? The reason is that we believe that samples closer together in time and geographical location are more likely to be subject to the same environmental factors.** Thus, by choosing samples from the paired control settings that are close together, we hope to obtain more precise comparisons of control effectiveness **Another reason to choose subsets of the longer periods is that we expect that control effectiveness will show up over a short period.** For the data studied here, the approach used was to study the effectiveness of the control as estimated from samples of different time length selections We considered periods of 15, 30, 45, 60, and 120 minutes after a control setting change and before a control setting change The estimates of control effectiveness are given for the auger measurements, both particulate and vapor These are given as **average [ln(control-off)-ln(control-on)], plus the standard error:**

	Particulate		Vapor	
Time	Estimate	Standard Error	Estimate	Standard Error
15 min	3 30	0 45	1 53	0 25
30 min	3 40	0 33	1 68	0 17
45 min	3 31	0 31	1 64	0 19
60 min	3 22	0 30	1 60	0 18
120 min	3 00	0 27	1 61	0 22

The larger the estimate, the more effective is the control **For times greater than 15 minutes, the estimates do not change much** The 15 minute estimate indicates lower effectiveness for the control for the vapor – estimated difference 1 53 (78% reduction) at 15 minutes versus a difference of 1 68 (81% reduction) at 30 minutes For both particulate and vapor, there is an indication that sequences of control-off determinations tend to increase during the first 15 minutes of sampling and be more stable after that Thus, the 15 minute estimates indicate less effectiveness than the longer time durations **The time period of 25 minutes is used in the text, which is close to the 30 minutes that the above table might suggest** In choosing the almost half-hour duration, we are allowing for the possibility that a short period of time may be needed to attain some stability in the estimated control effectiveness Had a longer time period been used, the estimate of control effectiveness would have been about the same, but the confidence limits would have been wider For particulate, the 30 minute estimate of 3 40 shown above corresponds to 97 percent reduction, and for vapor, the 30 minute estimated reduction is 81 percent

LIST OF FIGURES

FIG. 1. RANDOMIZATION SEQUENCE

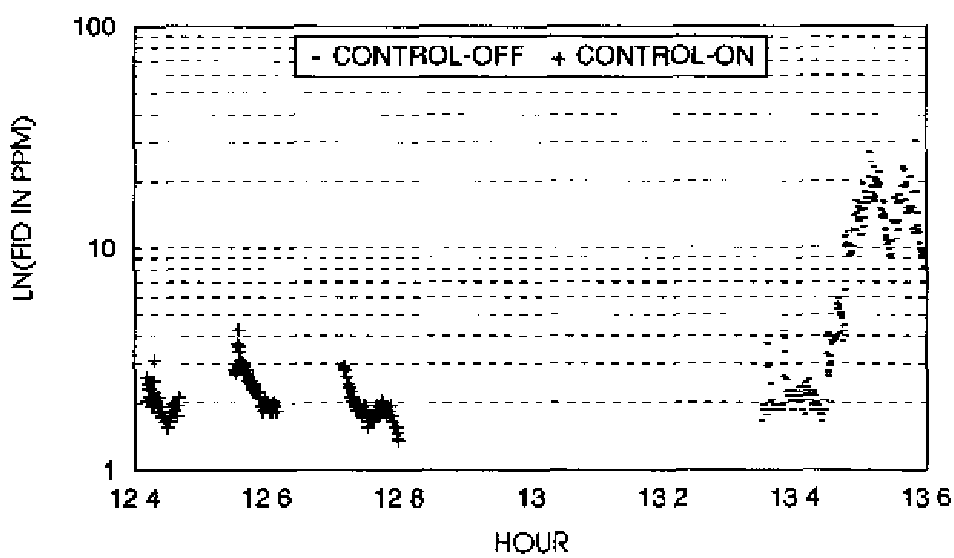
FOUR DAYS OF LONG-TIME PERIODS

	DAY 1	DAY 2	DAY 3	DAY 4
PERIOD 1	L- ON	L-OFF	L-ON	L-ON
PERIOD 2	L-OFF	L-ON	L-OFF	L-OFF
PERIOD 3		L-OFF	L-ON	L-ON

L ON INDICATES CONTROL ON L OFF INDICATES CONTROL-OFF

FIG 2 VAPOR(FID) DETERMINATIONS FROM SET 1, DAY 3

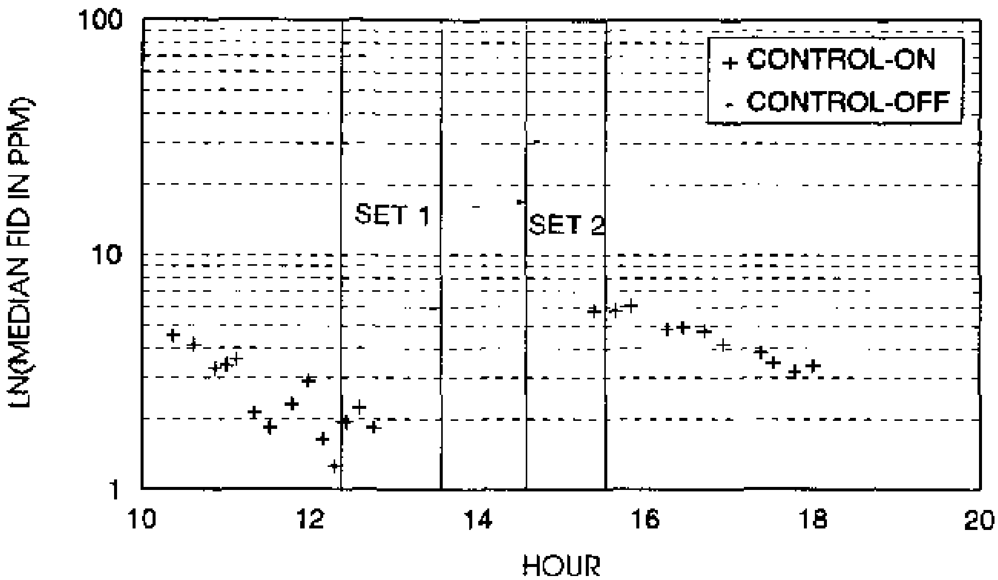
NATURAL LOG SCALE



SHIFT IN MEAN FOR CONTROL OFF INTERRUPTIONS FOR CONTROL ON

FIG. 3: VAPOR(FID) MEDIANS FOR DAY 3

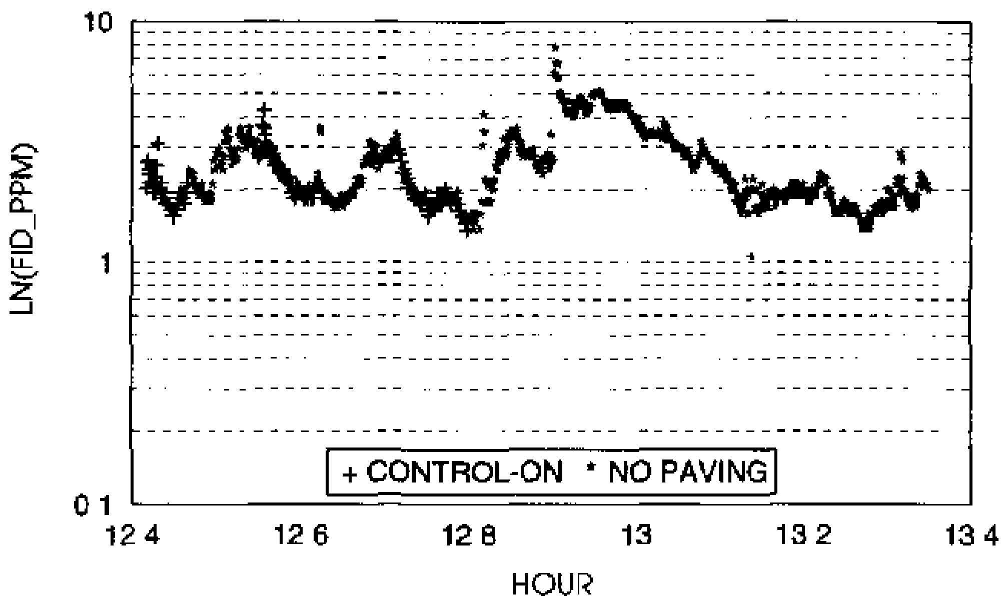
EACH MEDIAN BASED ON AT LEAST 40 MEASUREMENTS



UPWARD TREND FOR CONTROL-OFF & DOWNWARD TREND FOR CONTROL ON

FIG. 4: VAPOR(FID) AT AUGER- SET 1,DAY 3: CONTROL-ON & NO PAVING

NATURAL LOG SCALE



INTERRUPTIONS FOR CONTROL ON FID DETERMINATIONS TEND TO INCREASE DURING NO-PAVING PERIODS SHOWN HERE DURING OTHER NO PAVING TIMES TRENDS MAY DIFFER

FIG. 5: AUGER: %REDUCTION BY DAY & OVERALL AVERAGE

LOWER 80% CONFIDENCE LIMITS(CL) SIMULTANEOUS & INDIVIDUAL VAPOR & PARTICULATE

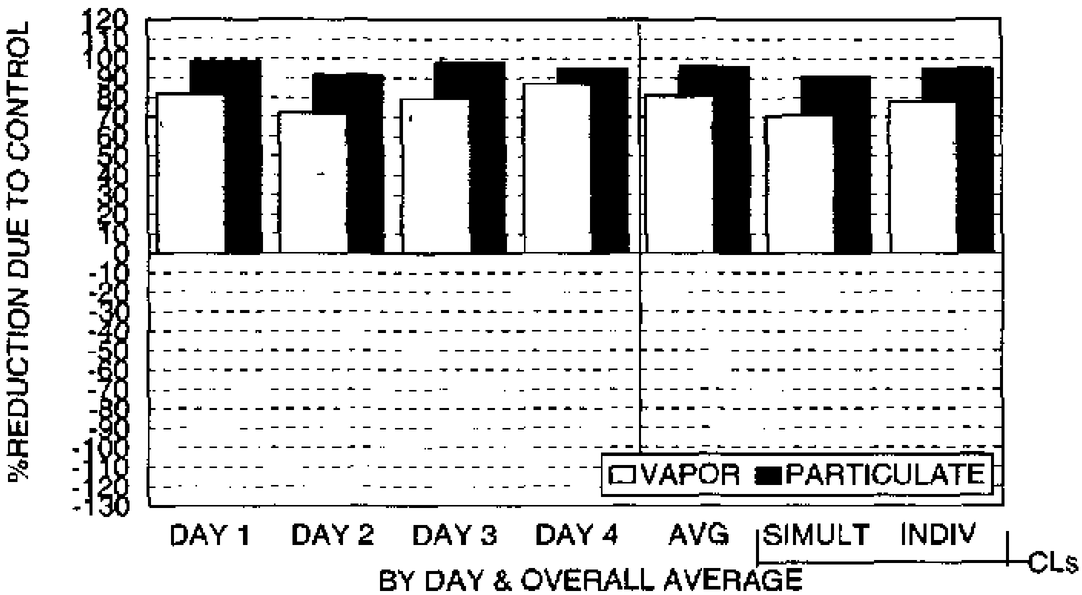
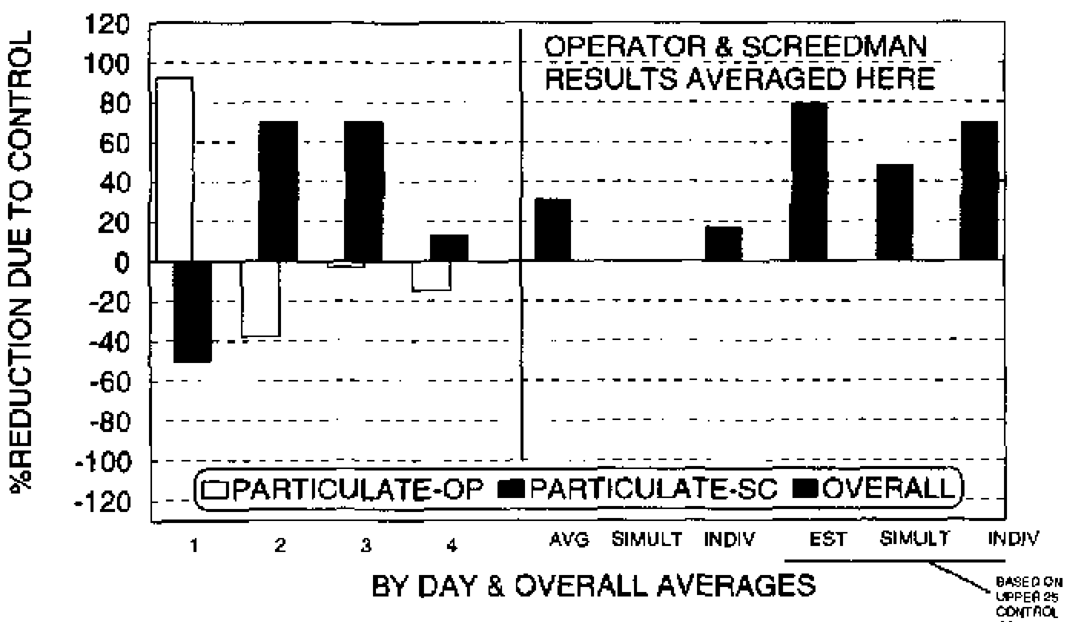


FIG. 6: NOT AUGER: %REDUCTION BY DAY & OVERALL, BASED ON SAMPLE MEDIANS

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



AVERAGE & CONFIDENCE LIMIT TAKEN OVER BOTH LOCATIONS LOWER SIMULTANEOUS CONFIDENCE LIMIT FOR AVERAGE IS LESS THAN 0 AND IS PLOTTED AS 0

FIG. 7:REAL-TIME PARTICULATE GEOMETRIC MEANS

AUGER MEASUREMENTS VIA DRAM NON-AUGER MEASUREMENTS VIA GRIM

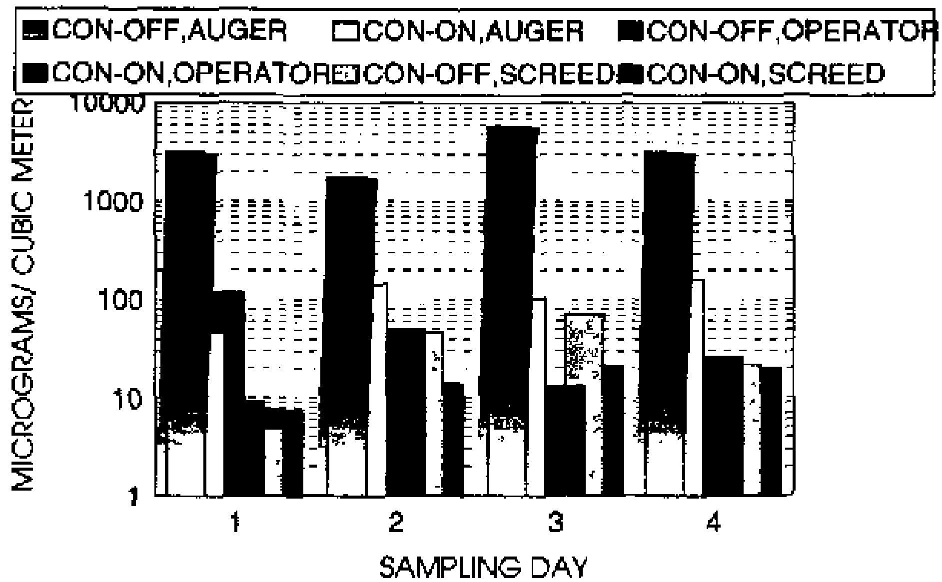
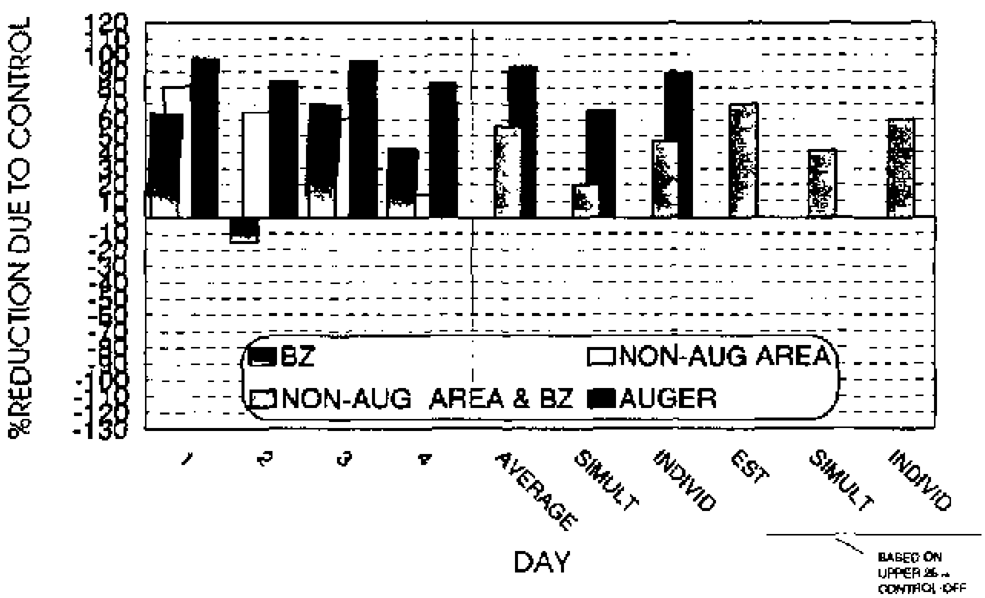


FIG. 8: INDUSTRIAL HYGIENE SAMPLES: %REDUCTION BY DAY

80% CONFIDENCE LIMITS SIMULTANEOUSLY & INDIVIDUALLY



%REDUCTIONS BASED ON GEOMETRIC MEANS OF SUMMED 370nm AND 400nm DETERMINATIONS AVERAGE FOR NON AUGER SAMPLES COMBINES AREA & BREATHING ZONE SAMPLES AVERAGES COMPUTED AS AVERAGE OF LN(CONTROL ON) LN(CONTROL OFF) AND EXPONENTIATED TO OBTAIN AVERAGE REDUCTION

FIG. 9: INDUSTRIAL HYGIENE GEOMETRIC MEANS

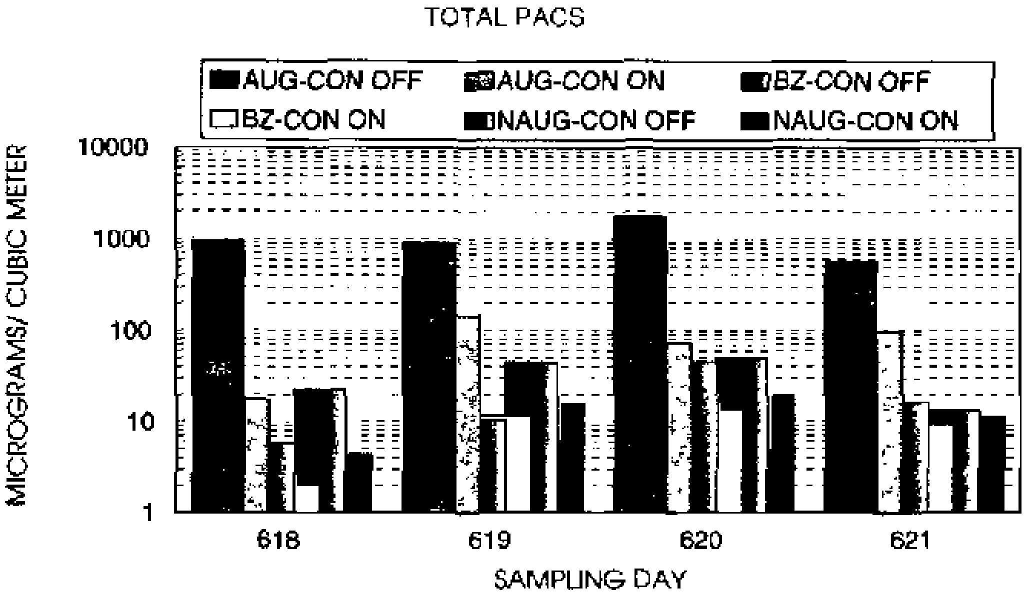
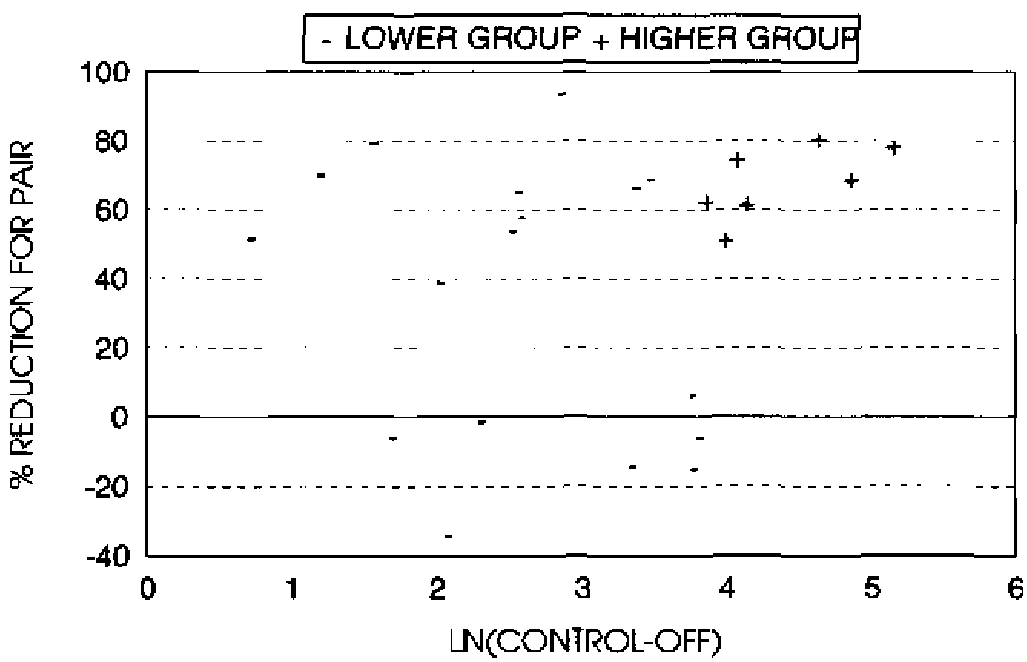


FIG. 10: % REDUCTION FOR LOWEST 75% CONTROL-OFF VERSUS HIGHEST 25% CONTROL-OFF PAIRS

FOR TOTAL PAC AREA & BREATHING ZONE SAMPLES AWAY FROM AUGER



HIGHER GROUP HAS LARGER REDUCTION