IN-DEPTH SURVEY REPORT:

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

MANUFACTURER Champion Road Machinery, Inc

PAVING CONTRACTOR Rea Construction

PAVING LOCATION Ridgeland, South Carolina

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PLANT SURVEYED:	Champion Road Machinery (Paver Manufacturer) Rea Construction (Paving Contractor) Ridgeland, South Carolina
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DISCLAIMER

EXECUTIVE SUMMARY

On December 9-14, 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 Champion engineering control evaluation was completed as part of a Department of Transportation (DOT) project to evaluate the effectiveness of engineering controls on asphalt paving equipment NIOSH researchers conducted the research through an inter-agency agreement with DOT's Federal Highway Administration (FHWA) Industry, labor, and governmental participation in the project was fostered through a research partnership which included NIOSH, FHWA, the National Asphalt Pavement Association (NAPA), the Asphalt Institute, six manufacturers of asphalt paving equipment, the International Union of Operating Engineers (IUOE), the Laborers' International Union of North America (LIUNA), and the Laborers' Health and Safety Fund of North America (LHSFNA)

The asphalt paving engineering control study consisted of two major phases During the primary phase, NIOSH researchers visited each participating manufacturer and evaluated their engineering control designs under managed environmental conditions The indoor evaluation used tracer gas analysis techniques to quantify the control's exhaust flow rate and to determine the control's capture efficiency Results from the indoor evaluations provided equipment manufacturers with the necessary information to maximize engineering control performance prior to the second phase of the study, performance evaluation of the engineering controls under "real-life" paving conditions

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

The scope of this report is limited to the Champion phase two (field) evaluation of a single engineering control installed on a Champion Model 1110T asphalt paving machine The tested design consisted of a single exhaust hood running the full width of the tractor and located above the augers The size, shape, and orientation of the hood resulted in enclosing about 50 percent of the top of the auger area within the width of the tractor The plenum takeoff from the exhaust hood routed the exhaust air through the rear tractor wall and up through the paver deck A heavy-strength flexible duct completed the connection to a hydraulic exhaust fan located on the paver deck An exhaust stack, attached to the discharge side of the fan, discharged the captured fumes at a point about 5 feet above the deck and about 10 feet above the ground

Field tracer gas measurement techniques revealed an average exhaust flow of 1700 cubic feet per minute (cfm) from the exhaust fan Test results indicate that the Champion engineering control design was successful in capturing and removing an average of 83 percent of the asphalt fume released from the auger area This source reduction led to an average worker-area reduction of 49 percent One way to circumvent the mathematical impact of background concentrations and the variability resulting from ambient conditions was to evaluate the engineering control's ability to prevent higher-level (top 25%) contaminant concentrations at the screed operator and paver operator positions Using this approach, the Champion engineering control produced an average reduction in higher-level exposures of 74 percent within these workstations

The Champion evaluation was the fifth of six field evaluations to be conducted as part of the engineering controls research partnership Although the testing methods used had a minimal history in the challenging environment of asphalt paving, there was sufficient experience to warrant some modifications in the overall testing protocol Knowledge gained during this evaluation resulted in limited changes to the evaluation protocol and potentially impacted the findings of the subsequent performance evaluation Lastly, many of the environmental and process variables were unique to the Champion evaluation For example, the Champion field evaluation was the only evaluation conducted during the new construction of a major highway 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 Champion to incorporate the following recommendations into their engineering control implementation process (1) Investigate ways to increase the existing level of auger-area enclosure, especially over the center portion of the auger area [From the observation standpoint, if HMA is flowing to the end of the auger, intuitively it is flowing at the center as well], (2) Monitor the worker/contractor acceptance of the current/future auger-area enclosure design and incorporate design changes if undesirable field-modifications are observed, (3) Monitor field conditions of asphalt paver engineering controls to determine how well the control design stands up to the rigorous demands of a paving environment, and, (4) Modify or supplement the existing hood enclosure to minimize escaping fume when the screed is extended beyond the width of the 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, ECTB has conducted a large number of studies to evaluate engineering control technology based upon industry, process, or control technique The objective of each of these studies has been to identify or design engineering control techniques and to evaluate their effectiveness in reducing potential health hazards in an industry or at specific processes Information on effective control strategies is subsequently published and distributed throughout the affected industry and to the occupational safety and health community

BACKGROUND

On December 9-14, 1996, researchers from NIOSH evaluated a first-generation engineering control designed to capture and remove fugitive asphalt emissions during asphalt paving The Champion engineering control evaluation was completed as part of a Department of Transportation (DOT) project to evaluate the effectiveness of engineering controls on asphalt paving equipment NIOSH researchers conducted the research through an inter-agency agreement with DOT's Federal Highway Administration (FHWA) Industry, labor, and governmental participation in the project was fostered through a research partnership which included NIOSH, FHWA, the National Asphalt Pavement Association (NAPA), the Asphalt Institute, six manufacturers of asphalt paving equipment (Barber-Greene/Caterpillar, Blaw-Knox, Cedarapids, Champion, Dynapac, Roadtec), the International Union of Operating Engineers (IUOE), the Laborers' International Union of North America (LIUNA), and the Laborers' Health and Safety Fund of North America (LHSFNA)

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

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

The Champion phase one evaluation occurred in November 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 Champion Road Machinery, Shippensburg, Pennsylvania "[2] Since the phase one evaluation was only one portion of the overall development and evaluation of the Champion engineering control, finalization of the Champion phase one report was delayed until the completion and co-release of Champion's phase two report

The scope of this report is the Champion phase two (field) evaluation of a prototype engineering control installed on a Champion Model 1110T asphalt paving machine (see Figure 1) Participating NIOSH researchers included Ken Mead, Mechanical Engineer, Leroy Mickelsen, Chemical Engineer, Dan Farwick, Industrial Hygiene Technician, Stan Shulman, Statistician, all from the Division of Applied Research and Technology (DART), Greg Kinnes, Industrial Hygienist, from the Division of Surveillance, Hazard Evaluation, and Field Studies (DSHEFS), and Jeff Bryant, Industrial Hygienist, from the Education and

Figure 1. Champion Model 1110T Asphalt Paving Machine undergoing field testing of prototype engineering controls The test site was a new highway project leading into Hilton Head, South Carolina

Information Division (EID) The NIOSH team was augmented by Tom Brumagin, NAPA's Director of Environmental Services, and Champion Design Engineers Ron Scheffler and George Reed The evaluation was conducted in coordination with South Carolina paving contractor Rea Construction at a new construction project near Hilton Head, South Carolina

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 the selection and application of the evaluation methods based upon prior experiences A listing and description of the evaluation methods follows

Tracer Gas For the phase two (field) evaluations, the tracer gas evaluation technique from phase one was modified for use during actual paving operations The method to calculate total exhaust flow of the engineering control did not deviate from the phase one tracer gas method However, the capture efficiency SF_6 dosing technique required modification for use when paving Instead of supplying SF_6 to the auger area via a distribution plenum under the auger, the SF_6 was supplied through four medical-quality 20-gauge injection needles, uniformly distributed across the width of the auger The intent of this dosing system was to deliver the SF_6 into the open head space near the top of the auger area (above the fresh HMA and between the front of the screed and the rear of the tractor) The four needles were positioned at a level approximate to the top of the screed and pointed downward towards the auger's center shaft In this manner, the SF_6 was injected in uniform amounts across the four dosing points, into the flow of fume and vapors convectively raising out of the auger head space For the Champion evaluation, the total dosing flow of SF_6 was approximately 0 9 lpm evenly distributed among the four dosing needles Multiple tests were conducted during each control-on test period Difficulties encountered with the field tracer gas method included maintaining the injection needles at the prescribed locations, preventing needle obstruction due to occasional contact with the HMA, and maintaining a steady supply of 120V electrical current to the dosing and sampling equipment

Industrial Hygiene Sampling Industrial hygiene (IH) sampling trains were configured for use with two analytical sampling methods The first method quantified the total particulate drawn into a filter cassette then determined what portion of the collected particulate was benzene soluble This method is often referred to as the Benzene Soluble Fraction (BSF) method Due to anticipated detection limitations, this method was only used at sampling locations directly above the auger The second IH sampling method was a new analytical method developed by NIOSH research chemists The new method quantified concentrations of total polycyclic aromatic compounds (PACs) and was reportedly more sensitive than the asphalt fume sampling method previously described Due to the increase in sensitivity, the total PAC method was used for sampling both above the auger and at each of the asphalt paver's workstations Each of these methods is described in detail in the NIOSH Manual of Analytical Methods (NMAM)[4] At the auger area, four general area (GA) sampling locations were uniformly distributed across the width of the auger Additional GA sampling locations included the right and left paver operator positions and the right and left screed operator positions Lastly, breathing zone (BZ) samples were collected from the paver operator (PO), right screed operator (RSO), and the left screed operator (LSO) In order to establish the control-on vs control-off performance ratio, each sampling position (GA or BZ) was assigned two sampling trains (one for control-on and one for control-off) for each sampling method used The same personal sampling pump was used to pull air through each of the two sampling trains For each day of testing, one sampling train was used to sample with the engineering control activated and the other was used when the control was deactivated In this manner, there was only one IH performance ratio per day established for each of the sampling locations Difficulties encountered with the IH evaluation method included (1) Filter loss into the asphalt, (2) Area contamination from non-paving sources of PACs such as cigarette smoking, diesel fuel openly used for solvent (see Figure 2), diesel exhaust from the tractor, and, (3) Non-auger sources of asphalt fume associated with the material transfer vehicle (Shuttle Buggy - day 5 only)

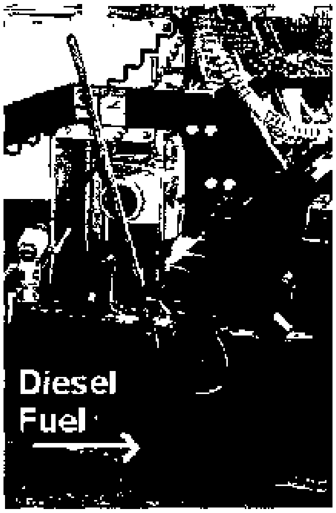

Figure 2: Photograph showing open bucket of diesel fuel adjacent to the left screed operator's workstation Non-paving sources of aromatic compounds such as diesel fuel may have adversely affected the measured exposure reductions at paver workstations

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

Real-Time Organic Vapor Monitoring Real-time monitoring of total organic vapor was conducted using two TVA 1000 Toxic Vapor Analyzers (Foxboro, Foxboro, MA) Each TVA contained both a Flame Ionization Detector (FID) and a Photo Ionization Detector (PID) for the detection of volatile organics Both the FID and PID detectors were used in each TVA and were programmed to record measurement responses once every 4 seconds The sample inlet to one TVA was located above the auger and adjacent to the DataRAM inlet The second TVA inlet location alternated between the screed operator position and the paver operator position (adjacent to the respective Grimm Dust Monitors) The alternation pattern was randomly generated prior to the start of the field evaluation Difficulties encountered with the TVAs included mechanical breakdowns, suspected to result from elevated humidity and temperature levels, unknown response variation due to humidity, instrument drift, and the previously described work practices associated with diesel fuel These difficulties posed a much greater dilemma as the measured concentrations approached the predominant background levels Due to its increased sensitivity over the PID, only the FID measurements were used to determine the organic vapor control efficiency as detected above the auger The PID measurements were available as a backup, in the event of FID failure

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

All of the evaluation methods were incorporated into a control-on vs control-off field evaluation protocol in order to quantify the engineering control's performance Due to the nature of the engineering control design, switching between a control-on and a control-off test setting was limited to activating and deactivating the exhaust fan There was no feasible way to remove and reattach the exhaust hoods when switching between control settings Thus, any control effect (good or bad) created by the mere presence of the engineering control would have affected the overall performance evaluation results The sampling scenario was established in a randomized fashion prior to the start of the evaluation, one sequence of randomized pairs (control-on and control-off) for short-time pairs and a second sequence of randomized pairs for long-time pairs Further details concerning the statistical design and randomization strategy for the real-time and industrial hygiene samples is included in Appendix B

An indeterminate variable for all of the direct-reading instruments was the impact of background concentrations and environmental variables One way to minimize the unknown variable effects is through shorter sample periods collected closer in time In this way, any background and environmental effects would be more likely to influence the control-on and control-off testing scenarios in a similar manner In a unique modification to the evaluation protocol, the amount of time dedicated each day to the long period IH sampling was reduced to roughly three hours total This allowed the remainder of each day to be designated for the short-term sampling

ENGINEERING CONTROL DESIGN DESCRIPTION

The Champion phase two (field) evaluation was conducted on a single engineering control installed on a Champion Model 1110T asphalt paving machine The tested design consisted of a single slot-type exhaust hood running the full width of the tractor and located directly above the augers The size, shape, and orientation of the hood resulted in enclosing about 50 percent of the top of the auger area within the width of the tractor Due to the angled orientation of the exhaust hood, much of the auger area that was not physically enclosed was effectively enclosed by a continuous capture velocity near the surface of the auger area The plenum takeoff from the exhaust hood routed the exhaust air through the rear tractor wall and up through the paver deck A heavy-strength flexible duct completed the connection to a hydraulic exhaust fan located on the paver deck The fan was located approximately 6 feet in front of the left paver operator position An exhaust stack, attached to the exit side of the fan, discharged the captured fumes at a point about 5 feet above the deck and about 10 feet above the ground The exhaust stack outlet included a 45 degree forward angle that directed the high velocity exhaust upward and away from the paver operator

The Champion design focused upon capturing the fumes generated within that portion of the auger area bounded by the width of the tractor 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 was not protected by the exhaust hood In this position, fumes and vapors near the end of the auger were virtually non-controlled and ambient winds had an increased opportunity to disrupt fume containment throughout the auger area

DATA RESULTS

Wind Speed and Temperature

The HTA instruments that recorded wind speed and temperature were located at the screed operator and paver operator locations Median wind speeds were calculated for each control setting used in the randomization Although there was some indication of general trends associated with wind speed (see Figure 14 in Appendix B) there is no way to predict exposures based upon a given wind speed

The HTA temperature medians for most control setting periods were under 90 degrees F Some of the days had median temperatures less than 60 degrees F in the mornings On average, little difference in temperature was found between control-on and control-off settings when 5-minute periods (before and after a control setting change) were studied This estimate is based on 5-minute segments since temperature differences should 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 were made Multiple determinations were conducted and averaged within each run, resulting in a total of six average efficiency estimates The average of these was a 99 percent reduction The lower 95 percent confidence point for the true efficiency was 97 percent Thus, for the SF_6 determinations, the true efficiency of the engineering control can be said to be greater than 97 percent with 95 percent confidence The SF_6 evaluations were treated as a separate experiment Due to its reduced variability, the 95 percent lower confidence limits (LCL) were used as opposed to the 80 percent limits used when evaluating reductions in environmental contaminants

Environmental Contaminants

Roughly 200,000 data points were statistically evaluated as a result of the five-day paving evaluation Table 1 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)	IH Total Part	IH Benz Sol Part	Grimms (Aerosol)	Grimms Upper 25%	TVA (Vapor)	TVA Upper 25%	IH (Total PACs)	IH Upper 25%
Reduction Estimate	85	53	80	81	84	43	68	23	44	54	79
Individual LCL[1]	83	50	75	76	79	34	59	19	37	40	74
Simultaneous LCL[2]	80	45	57	59	64	15	40	13	24	0	56

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 perform the evaluation The hot mobile environment of asphalt paving work was an additional obstacle Given these limitations, and in consideration of the time and resource constraints associated with each field evaluation, NIOSH and its partners developed a "shotgun" approach to quantifying engineering control efficiency during asphalt paving The general concept was to use multiple evaluation techniques in a statistically designed testing strategy of control-off and control-on periods It was anticipated that some techniques may perform better than others and for that reason, redundant approaches were incorporated into the evaluation protocol Furthermore, new variations of the sampling protocol, such as the reduced duration for long-term sampling periods, were developed as the field evaluations progressed The Champion evaluation was the fifth field evaluation of asphalt paving engineering controls A discussion of each evaluation technique, its results, and its usefulness to the Champion engineering control evaluation is discussed below

Wind Speed and Temperature

Although some general trends were evident for at least one of the evaluation methods (FID at auger), the lack of a predictable relationship between the cross-paver (perpendicular to direction of paver travel), wind speed, and observed concentrations at each control setting appears to indicate that there are additional variables to determining individual exposure concentrations In considering wind velocity, related variables such as wind direction, adjacent geographic features, and the paver's own profile could easily contribute to the exposure quantity

The evaluation of temperature reductions due to the engineering controls was not an original objective of the field evaluation protocol After qualitative observations at an early field evaluation indicated that temperature reductions were a potential fringe benefit, the temperature probe on the HTA turning vane anemometer was identified to record any temperature reduction due to the engineering controls In hindsight, the HTA was not the correct instrument for recording temperature changes due to control of the auger area The HTA's temperature sensor is significantly shielded by the airfoil encircling the rotating vane anemometer Thus, the recorded temperature more accurately reflects that of the wind as opposed to the convective currents rising from the HMA in the auger area.

Given these considerations, the lack of a meaningful temperature reduction due to the control should be considered as only a cursory observation If Champion determines that a more detailed quantification of temperature reduction 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 = 98 7% 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

Environmental Contaminants

Auger Area–

The results depicted in Table I indicate that the engineering control captured and removed an average of 83 percent of the asphalt fume (DataRAM, PAC, and BSF) generated within the auger area In addition, there is general consistency among the DataRAM and IH results (η = 80-85%) The results for controlling organic vapor (TVA) also show a significant reduction in escaping contaminant (η = 53%) although not as impressive as the other evaluation methods This reduced performance for the TVA is consistent with results seen at other field evaluations and is likely associated with organic vapor contamination originating from sources other than the HMA in the auger area

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 without regard to sample type 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 23-fold lower than those observed immediately above the auger (based upon comparison of IH Total PAC results), the lower control efficiency at the non-auger positions was believed to partially result from the natural control-effects produced by environmental factors In other words, when the wind and environmental factors effectively reduce contaminant concentrations, there is less opportunity for the engineering control to affect exposures When the environmental factors are less effective in controlling the removal of auger source emissions, such as during a stagnant wind condition, the worker-area concentrations increase Under these conditions, the contribution of the engineering control becomes more important As a follow-up to this concept, the data were analyzed to determine what contribution the engineering control provided when the environmental factors were not as effective (i e , when work area exposures were at their highest) For this analysis, the data were analyzed to determine the engineering control's efficiency 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 74 percent (average upper 25 percent reduction for particulate and total PACs) Since, by design, the engineering control only captures fumes originating from the auger area, this analysis appears to verify that the auger area was the major contributing source of higher-level asphalt fume exposures

Interpreting the results for the TVA at the non-auger positions is a difficult task As discussed previously, the TVAs FID detector is a non-specific detector, (i e , the same concentration of two different organics can generate dramatically different instrument responses) thus it is not possible to determine the source, identify, or actual concentration of the measured contaminant given the available data It is interesting to note that while the upper 25 percent reduction ($\eta = 44\%$) is a substantial improvement over the results for all of the TVA data ($\eta = 23\%$), over 50 percent of the measured organic vapor concentration appears to be unaffected by fume control at the auger The source and identity of the unknown contaminant observed by the TVA remain unknown

Given the inconsistencies between the TVA data ($\eta_{upper\,25\%} = 44\%$) and the consistently higher determinations from the the Total PAC and real-time particulate methods ($\eta_{upper\,25\%} = 79$ and 68% respectively) and given the physical characteristic differences between the organic vapor monitored by the TVA and the asphalt fume particulate, NIOSH considers the TVA results at the non-auger positions to be non-representative of the exposure reductions to asphalt fume at these positions

CONCLUSIONS AND RECOMMENDATIONS

The scope of this report is limited to the Champion phase two (field) evaluation of a single engineering control installed on a Champion Model 1110T asphalt paving machine On average, the Champion design was successful in capturing and removing 83 percent of the asphalt fume (real-time particulate and IH samples) originating from the auger area The reduction in fume escaping from the auger resulted in an average reduction of 49 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 74 percent These performance values represent an achievable level of performance by the evaluated engineering control operated under the conditions observed during the Champion engineering control evaluation The Champion evaluation was the fifth of six field evaluations to be conducted as part of the engineering controls research partnership Although the testing methods used had only a minimal history in the challenging environment of asphalt paving, there was sufficient experience to warrant some modifications in the overall testing protocol Knowledge gained during this evaluation resulted in further limited changes to the evaluation protocol and potentially impacted subsequent evaluation results Lastly, many of the environmental and process variables were unique to the Champion 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 Champion field evaluation completed an important step in this process by successfully demonstrating an 83 percent capture of the auger-source asphalt fume and by reducing workers' exposures by 49 percent Effective July 1, 1997, Champion began providing engineering controls as standard equipment on all of their new highway-class pavers As the Champion engineering control is adopted into the industry, NIOSH recommends the following (1) Investigate ways to increase the existing level of auger-area enclosure, especially over the center portion of the auger area [From the observation standpoint, if HMA is flowing to the end of the auger, intuitively it is flowing at the center as well], (2) Monitor the worker/contractor acceptance of the current/future auger-area enclosure design and incorporate design changes if undesirable field-modifications are observed, (3) Monitor field conditions of asphalt paver engineering controls to determine how well the control design stands up to the rigorous demands of a paving environment, and, (4) Modify or supplement the existing hood enclosure to minimize escaping fume when the screed is extended beyond the width of the tractor

If desired, NIOSH engineers are available to assist in the design or design review of any of these recommendations

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APPENDIX A

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

PHASE TWO (FIELD) EVALUATION PROTOCOL

ASPHALT PAVING FIELD EVALUATION PROCEDURE

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

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

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

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

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

4 The Threshold Limit Value for sulphur hexafluoride is 1000 ppm While the generated concentrations will be below this level, the concentration in the cylinder is near 100 percent For this reason, the compressed cylinder will be maintained outdoors during use Should a regulator malfunction or some other major accidental release occur, observers should stand back and let the tank pressure come to equilibrium with the ambient environment

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

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

Evaluation Method A (Tracer Gas) The tracer gas evaluations will occur twice a day, morning and afternoon. These evaluation periods will correspond with paving periods which utilize the engineering controls. For this evaluation, we release a known quantity of sulphur hexafluoride (SF_6) into predetermined locations, then measure the amount of SF_6 captured and removed through the engineering control's exhaust duct. The SF_6 release is controlled by three mass flow controllers which are each calibrated for a predetermined flow rate of 99.98 percent SF_6. Each controller is connected to a PTFE distribution tube. One tube feeds SF_6 into each side of the paver's auger area, and the third tube feeds SF_6 directly into the engineering control's exhaust hood.

A hole, drilled into the engineering control's exhaust duct, allows access for a multi-point monitoring wand. The location for this hole is selected to allow for thorough mixing of the exhaust air stream. The monitoring wand is oriented so that the perforations are perpendicular to the moving air. A sample tube connects the wand to a Bruel & Kjaer (B&K) Model 1302 Photo-acoustic Infra-red Multi-gas Monitor positioned on the paver deck. The gas monitor analyzes the air sample and records the concentration of SF_6 within the exhaust stream. The B&K 1302 will be programmed to analyze an air sample approximately once every minute.

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

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

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

$Q_{(SF6)}$ = volume of SF_6 (cfm) introduced into the system. The flow rate in liters per minute (lpm) must be divided by 28.3 liters/cubic foot to convert the units to cfm.

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

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

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

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

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

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

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

<u>Evaluation Method B Real-time Monitoring (Wind, Temperature, Organic Vapor, Aerosol and Video Recording)</u> 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 <u>Wind, Temperature (dry bulb (db))</u> 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 <u>before going to the survey site</u>
- 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 (≤) 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

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

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

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

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

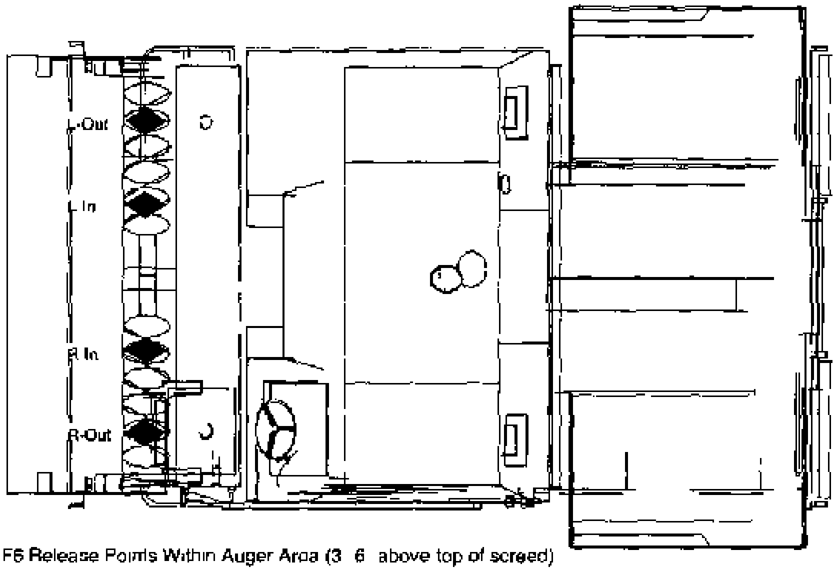
- Calibrate sampling pumps to flow at 2 lpm
- Construct pairs of sampling trains for eight area and three personal sampling positions (total of 22 samples per day)
- Color code each sampling train red=uncontrolled, blue=controlled sampling scenario
- Assign one red and one blue sampling train to each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

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

Additional Measurements

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

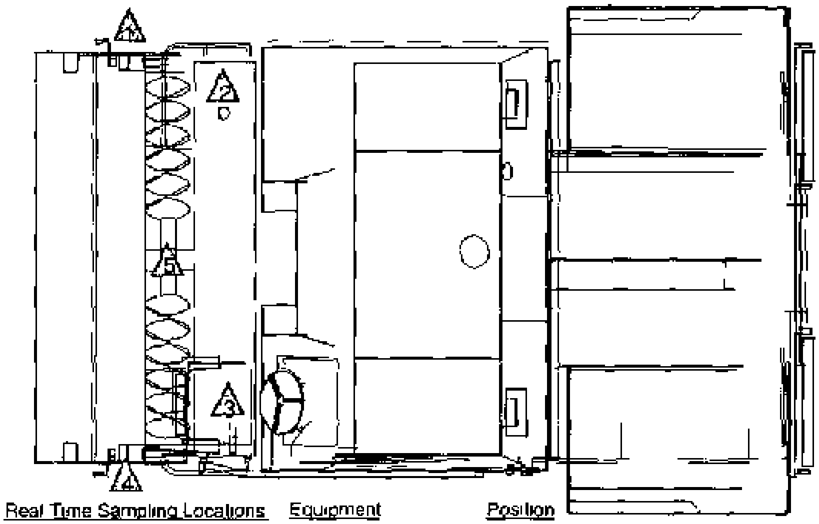
Figure 1 Tracer Gas Dosing And Sampling Locations



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

○ B&K Monitoring Point Within Engineering Control Exhaust Stack

Figure 2 Real-Time Sampling Locations



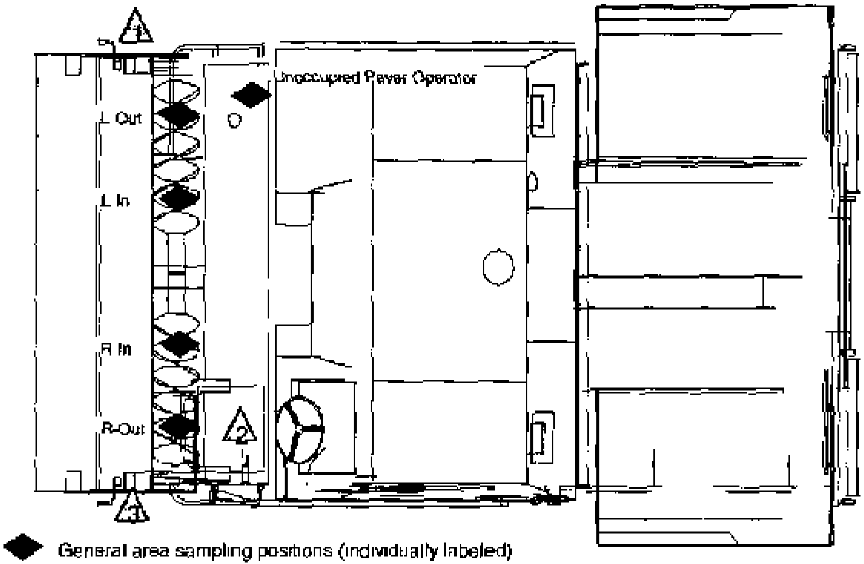
△ Real Time Sampling Locations

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

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

Parentheses denotes rotation among multiple positions

Figure 3: Total-PAC Sampling Locations



◆ General area sampling positions (individually labeled)

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

ATTACHMENT A

POLYCYCLIC AROMATIC COMPOUNDS AS A CLASS PROCEDURE

Analytical Overview

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

TOTAL PAC PROCEDURE

Sample Fractionation

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

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

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

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

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

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

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

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

9 Run the attached Benchmate program

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

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

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

Flow Injection Analysis

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

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

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

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

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

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

Calculations

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

ug/sample = 8 x ug/mL

APPENDIX B

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

CHAMPION PHASE TWO FIELD EVALUATION

STATISTICAL DESIGN AND DATA ANALYSIS

CHAMPION (SOUTH CAROLINA)

EXPERIMENTAL DESIGN

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

Although we call the periods either "short" or "long," **short periods were not all of the same length and long periods were not all of the same length**. "Short" periods varied in length between 1 and 3 truck loads, each of which usually lasted between 1.5 and 3.5 minutes. Three truck loads were needed when the control was on and SF6 evaluation was underway. "Long" periods varied in length, since the aim was to collect enough material on the tubes and filters to obtain samples above the limit of detection. For control-on samples, this meant that sampling continued for an hour of paving and for control-off samples, sampling usually lasted for at least 45 minutes of paving.

METHODS FOR DATA ANALYSIS

Some of the considerations involved in handling of the data are the following.

1. Figure 2 contains particulate results from the auger sample on day 1, period 2. There were 77 measurements with the control-off and 110 measurements with the control-on. Since these data were collected in batches of control-on and control-off, **it is not appropriate to treat the measurements individually** in making comparison of control-on and control-off settings. The reason is that the variability of measurements made in batches is usually different (usually smaller) from that of measurements which are collected in a randomized fashion. Since the randomization used in the study is within the periods, it makes sense to **calculate one number for each control-on and control-off setting within each period**. Since **the median** is not sensitive to measurements from the center of the distribution, the median is used in the analyses of all the real-time measurements. (These included vapor and particulate at the auger and away from the auger.) **Because of this insensitivity and because it seemed difficult to decide which of the many real-time measurements might be outliers, the median is a sensible estimator**

for the center of each control setting distribution. In Figure 2, the median of the 77 control-off measurements was 337,505 micrograms per cubic meter, compared with 34,560 micrograms per cubic meter for the control-on setting For the period shown in Figure 2, the medians appear to show the centers of the distributions quite well

For the **industrial hygiene samples**, each of which is collected for a period of not less than 45 minutes, the average of each type of sample was used, rather than the median **Because each sample is a time-weighted average over a relatively long period of time (compared to the short-term samples), the sample determinations themselves adjust for extreme values that occur in the course of sampling, and the average rather than the median seems appropriate.** This average was taken over all locations sampled during the control setting The industrial hygiene samples included total PAC at the auger (four locations), total PAC away from the auger (two or three personal samples and four area samples), and total particulate/benzene soluble fraction (BSF) analyses for samples at the auger (four locations)

2 For long-time periods, especially comparison of control-on and control-off depends on the data used to compute the medians 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.**

Since some of the short-time periods consisted of segments due to interruptions in delivery, some of these segments are spread out over a long period of time, and similar concerns would apply to them too

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 to include data for computation of the medians

A related question concerns deletion of real-time measurements at the beginning or end of a continuous sequence of measurements at a control setting Trucks were used for delivery of the asphalt for each day except the last **There were stops 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 It is often true that after a change in control setting or after a stop in paving activity, there is a period of time during which the measurements change their means This tendency is clear in the vapor measurements shown in Figure 3, especially for control-off **Because of this tendency, we have deleted a half minute of real-time measurements before and after a period of no paving that lasts for at least 25 seconds. 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.**

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 shown in the section "Determining Length of Period" indicate that by approximately 15 minutes the estimated effectiveness of the control is stable **The results also demonstrate that the 30 second deletion at the start of the control setting increases the estimated reduction.**

4 Another issue concerned **drift in the FID determinations** The TVAs were zeroed and spanned with samples containing no analyte and with samples containing analyte that should have given 100 ppm readings for FID This spanning was carried out both at the beginning of the day and at the end of the day This allowed for correction for drift in the zero responses of FID, by assuming linear drift of the zero response between the two end points Drift in the 100 ppm determinations was also assumed to be linear between the two endpoints This assumption allowed for determination of a factor for converting the 100 ppm responses at a particular sampling time t to the equivalent responses at the initial 100 ppm spanning time (t=0) These factors were applied to the zero-corrected FID determinations made at time t to convert them to the equivalent determination at time t=0, after which the initial instrumental response to zero span gas was added on **Thereby, changes in readings over time to the same air concentration would be corrected**

5 When the medians of many periods were studied together, it happened that there was **higher variability of the medians as the medians increased. This suggested that the natural log** of the medians was to be used when the data were analyzed The tendency of higher variability at higher loadings is most easily seen by comparing a day's data for control-on and control-off Data for day 2 are shown in Figure 4 for vapor at the auger Results are similar for particulate at the auger For both kinds of readings, control-off readings are higher and tend to have higher variability than control-on readings However, the two control settings are correlated, since as one goes up the other tends to go up Since the control-off medians increase more, the ratio of off to on is more variable at the higher loading pairs (1, 2, or 8) than at the lower loading pairs **This suggest the benefit of the log transformation, which will reduce the difference in variability. Also, the design used here, in which the data are collected in many short-time**

pairs of control-off and control-on uses the correlation to reduce the estimate of error and produce more precise comparisons. The analysis will be based on the difference of the natural logs of the control settings for each pair

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

In the analysis of the total PAC data, the average is calculated over the natural logarithms of determinations at the different locations sampled simultaneously for the same sample type For the non-auger total PAC samples, 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 only one sample mean at each control setting on each day.**

Since different sampling intervals were used for different instruments and since periods were of variable length, **the number of measurements on which the medians or averages was based varied considerably** from period to period and from instrument to instrument **Since it was not clear that length of period was related to precision of data, an unweighted analysis was always used.**

Because the industrial hygiene samples, total PAC, or weighing samples were long-time samples done simultaneously, it was possible to carry out a combined analysis of these data

For each day's data, averages on the natural log scale were obtained for each kind of sample at each control setting **The control effectiveness was estimated by including all sample types in the same split-plot analysis, and obtaining a separate estimate for each sample type, but pooling the residual variances so as to use a better estimate of the sub-plot variance with more degrees of freedom** This seemed acceptable, since the bulk of the variability of the measurements is sampling variability, which was thought to be similar, even though the total PAC and the weighing methods are quite different

7 As might be expected, reduction due to the control is greatest for the auger samples A suggested alternative for the non-auger particulate samples, both real-time and total PAC, was carried out **This was to estimate the percent reduction for the periods with the highest**

25 percent control-off values For the total PAC, these are the highest 25 percent of the individual location total PAC control-off determinations away from the auger For the real-time particulate or vapor, these are the highest 25 percent of the control-off medians where operator and screedman locations are treated individually The 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.**

8 For many of the comparisons that follow, the aim was **to establish confidence limits that hold simultaneously for all comparisons at the 80 percent confidence level at the auger and at the non-auger locations and also for the IH samples. Thus, for all comparisons simultaneously we can say that the error rate is 20 percent.** The probability that any confidence interval statements are in error is no more than 20 percent **Altogether if eight comparisons were allowed for, then each would be allowed a 2.5 percent error rate. Since the error rates add, the overall error rate will then be no more than 20 percent** The choice of an overall 20 percent error rate is somewhat arbitrary 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 vs 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, 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**

SF6 DETERMINATIONS

The average efficiency was 98.74. The estimated variance is 3 70 With six measurements, this yields a standard deviation of the mean of 0 785 Thus, **the 95 percent lower confidence limit on the true efficiency is 98.74 - 2.015 (0.785) =98.74-1.58=97.16**, where 2 015 is the Student's t 95 percentile, for 5 degrees of freedom **Thus, the true efficiency can be said to be >97.16 percent, with 95 percent confidence.**

EFFECTIVENESS OF CONTROL AT AUGER

The results for the TVA analyses of vapor and particulate at the auger are shown 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 two kinds of samples plus 80 percent confidence limits The percent reduction varied somewhat more over days for vapor than for particulate **For all days the percent reduction based on particulate data was about 85 percent. The lower (simultaneous) confidence limit was about 80 percent**, compared with a lower individual confidence limit of about 83 percent For the vapor days 1 and 3 yielded percent reductions of over 60 percent compared to less than 50 percent for the other three days **Over all days the estimated reduction was about 53 percent, with lower (simultaneous) confidence limit for of about 45 percent reduction and individual confidence limit of about 50 percent.** The control appeared to work somewhat differently for vapor than for particulate

Plots of the data indicate that **different amounts of contaminant were generated on different days.** Whereas days 1 and 3 had sample geometric means for vapor at the auger greater than 20 ppm, the three other days had sample geometric means less than 15 ppm On the other hand, the particulate geometric means also were much higher for days 1 and 3 even though the estimated efficiency of the control did not vary much over days For days 1 and 3, these geometric means for control-off exceeded 170,000 micrograms/cubic meter, and for the three other days, they were less than 105,000 Figure 6 plots geometric means for the real-time particulate data

EFFECTIVENESS OF CONTROL AT OPERATOR AND SCREED POSITIONS

The results for the vapor and particulate measurements at the screed and operator locations are plotted by day in Figure 7 **Day 4 appeared to be very different from the other days, in that there was much lower effectiveness of the control on that day for both vapor and particulate than on other days.** That this was not true for the auger data suggested that the factors causing the difference could have been ambient factors that would not alter effectiveness at the auger **The estimated reduction for the vapor was about 23 percent with (simultaneous) lower confidence limit of about 13 percent and (individual) confidence limit**

of about 19 percent. For the particulate, the estimated reduction due to the control was about 43 percent, with (simultaneous) lower confidence limit of about 15 percent, and (individual) lower confidence limit of about 34 percent.

A possible reason for the lower reductions of the vapor away from the auger was the low levels found Whereas vapor geometric means at the auger were at least 7 5 ppm and much higher than this for the control-off determinations The geometric means for the non-auger vapor data were less than 7 5 with the exception of two control-off determinations

The analysis of the upper 25 percent control-off particulate pairs (see Figure 7) yields a reduction of about 68 percent, with a lower confidence limit of about 40 percent for simultaneous comparisons and about 59 percent for individual comparisons For these results, medians are used from both the operator and the screed locations Only those pairs are included which have the control-off medians in the upper 25 percent of all control-off medians **For the vapor, the estimated reduction for the upper 25 percent comparisons is about 44 percent, with (simultaneous) lower confidence limits of 24 percent and (individual) lower confidence limit of 37 percent.** Since the estimates may be sensitive to the choice of upper 25 percent fraction, the analyses were also carried out using the upper 50 percent control-off pairs The reductions are then a little smaller For the particulate, the reduction is 59 percent and for the vapor 34 percent The lower simultaneous confidence limits are 31 and 24 percent, respectively

IH SAMPLES

Figure 8 is a plot of the percent reduction due to the control, based on the industrial hygiene sample data **The total PAC auger samples estimate a reduction due to the control of about 80 percent. The lower 80 percent (simultaneous) confidence limit is 57 percent, and the lower (individual) confidence limit is 75 percent. The PAC non-auger data, both area samples and personal samples, agree quite well with each other for all four days of sampling. For the combined area and personal samples, the estimated reduction is 54 percent, with 80 percent lower (simultaneous) confidence limit of 0 percent and lower (individual) confidence limit of 40 percent.** Day 3 data gave much lower results for the non-auger than the three other days

Figure 9 gives the daily geometric means of the non-auger samples by type (area or personal samples) and by control setting

The analysis of the upper **25 percent total PAC data (see Figure 10) yields an estimate of 79 percent. The lower (simultaneous) 80 percent confidence limit shows at least 56 percent reduction, and the lower (individual) 80 percent confidence limit indicates at least 74 percent reduction.** From Figure 10, it is apparent that the estimate depends on the choice of upper 25 percent rather than say the upper 50 percent For the upper 50 percent, the reduction due to the control is about 65 percent with the simultaneous lower confidence limit about

35 percent and the individual lower confidence limit about 56 percent

Figure 11 shows a relationship between benzene soluble determinations and total PAC determinations at the auger A relationship can be developed because there were filter samples (for BSF method analysis) paired with the total PAC samples at the auger **The approximate straight line relationship allows a crude conversion from the total PAC method to** benzene soluble equivalents These are shown in Figure 12 **The conversion results must be interpreted loosely, since there is no certainty that the PACs measured at the worker positions are 100 percent identical to those at the auger. However, the conversion is still useful since the only IH samples taken away from the auger were total PAC samples.** After "conversion" all breathing zone samples collected during control-on yielded average determinations less than 0 5 mg/cubic meter

The IH data do allow us to make another estimate of the efficiency of the control for vapors The filters that were used for gravimetric analyses had tube backups These tubes should collect only vapor, since the particulate is extracted via the filters Thus, the efficiency of the control can be compared based on the backup tube data (vapor) versus the filter data (benzene soluble fraction) The accompanying Figure 13 displays the efficiency by sampling day Although for three of the days the reduction due to the control is higher for the filter data, the overall average is only slightly higher **Thus, the differences in efficiency for vapor versus particulate seen in the real-time data do not show up in the IH data** It may be that because of the heat of the particulate near the auger, additional vapor is generated This could affect both control-on and control-off determinations

WIND AND TEMPERATURE MEASUREMENTS

The HTA temperature medians for most control setting periods were under 90 degrees F Some of the days had median temperatures less than 60 degrees in the mornings, but that depended on how early work started A comparison of interest is control-on period median temperatures versus control-off median temperature **On average there is almost no difference between the median temperatures at the two settings.**

Median wind speeds were 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 We wish to observe how days differed in windiness **Day 1 was the windiest day, with all median wind speeds larger than 200 feet per minute, and most of them larger than 400 feet per minute. Days 2, 3, and 4 were the quietest days, with most of the medians less than 250 feet per minute. Day 4 was the most variable, with median wind speeds ranging from 100 to 600 feet per minute.**

Figure 14 is a plot of median FID determinations near the auger versus median wind speed for the short-time periods of days 2, 3, and 4 **The median wind speeds are averages from the two**

HTAs. Days 2 and 4 data indicate that the median FID measurement decreases as the median wind speed increases. Similar results hold for the particulate determinations at the auger

CONCLUSIONS

	Part auger Real time	Vapor auger Real time	Total PAC-auge Indus Hygiene	Benz Sol Auger	Total Part - Auger	Part - non auger Real-time	Part non auger upper 25%	Vapor-non auger Real-time	Vapor-non auger upper 25%	Total PAC non auger Indus Hyg	Total PAC non auger upper 25%
EST	85	53	80	84	81	43	68	23	44	54	79
Indiv LCL	83	50	75	79	76	34	59	19	37	40	74
Simul LCL	80	45	57	64	59	15	40	13	24	0	56

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 (data points) we might use. Why choose? The reason is that we believe that samples closer together in time and sampling 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 1 875, 3 75, 7 5, 15, and 30 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 Deletion Time(sec)		Vapor Deletion time(sec)	
Duration(min)	0	30	0	30
1 875	1 77(0 20)	1 7(0 21)	0 62(0 091)	0 69(0 094)
3 75	1 82(0 17)	1 86(0 16)	0 63(0 093)	0 72(0 096)
7 5	1 87(0 15)	1 94(0 13)	0 63(0 085)	0 76(0 077)
15	1 83(0 14)	1 9(0 12)	0 65(0 080)	0 75(0 069)
30	1 82(0 14)	1 86(0 12)	0 65(0 079)	0 75(0 067)

For the particulate, we see that for time deleted at the start of the interval, there is not much benefit For 30 second deletion, if the periods are at least 3 75 minutes in duration, then there is not much difference in the estimate Estimates are all between 1 86 and 1 94, corresponding to reduction between 84 and 86 percent It may be there is no start-up effect for particulate There is not much difference for the 30 second deletion compared to no deletion

The vapor results differ in that deletion time is more important When 30 seconds are deleted, the differences from zero time deletion are much bigger than for particulate For zero deletion the average value above is 0 63, corresponding to about 47 percent reduction, and for 30 seconds deleted the average value is 0 73, corresponding to 52 percent reduction However, increasing duration does not change the estimates very much This may be because there were many interruptions For the short-time periods, for the time specified at a given control setting, the average fraction of time in which there was actual paving was about 65 percent Frequency of interruptions can be a reason that there is not much benefit from increasing duration

Within the long-time periods there is no evidence that longer duration alters results much Also there are many more short-time pairs at this site, so that the above results have more to do with short time pairs than with long-time pairs For the analyses, we will use the results for 15 minutes, so that we are using the entire short-time periods in most instances, and we will delete 30 seconds at the beginning and end of the interval The 15 minute intervals provide approximately constant estimate and standard error for both particulate and vapor

LIST OF FIGURES

FIG. 1 SAMPLING DESIGN USED IN STUDY

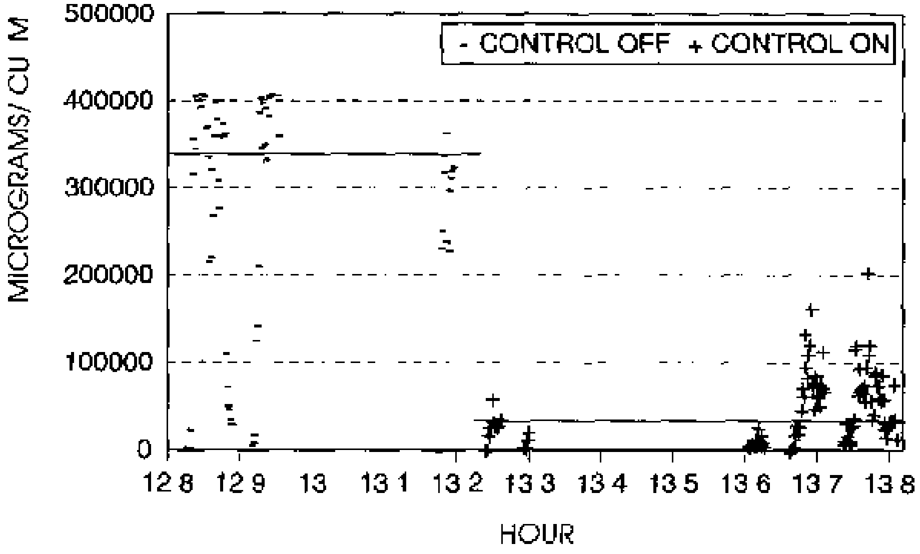
SHORT-TIME PERIOD AND LONG-TIME PERIOD RANDOMIZATION

	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5
EARLY	S	S	S	S	L
MID-DAY	L	L	L		L
LATE		S	S		

L=ONE (CONTROL-ON,CONTROL-OFF) PAIR,
S= SEVERAL (CONTROL-ON,CONTROL-OFF) PAIRS
SEQUENCE OF ON & OFF SETTINGS RANDOMIZED IN EACH PAIR

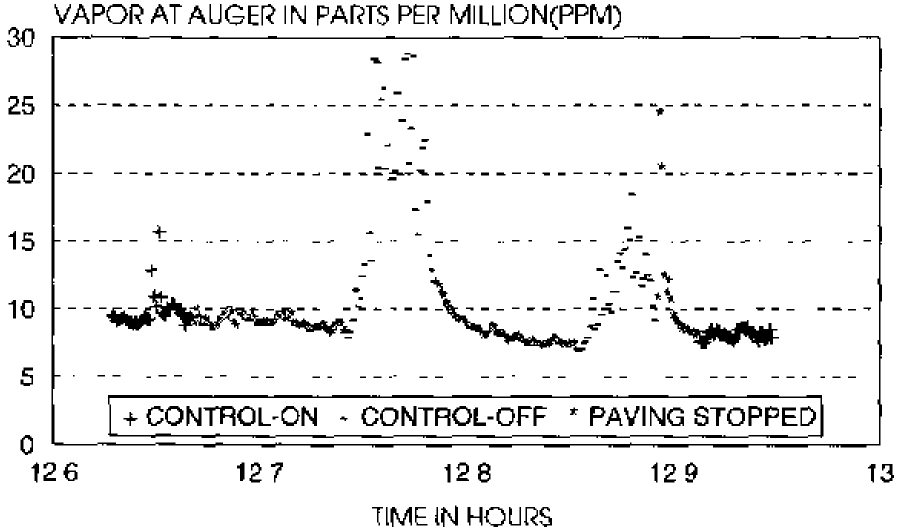
FIG 2 PARTICULATE DATA AT AUGER

DAY 1, PERIOD 2



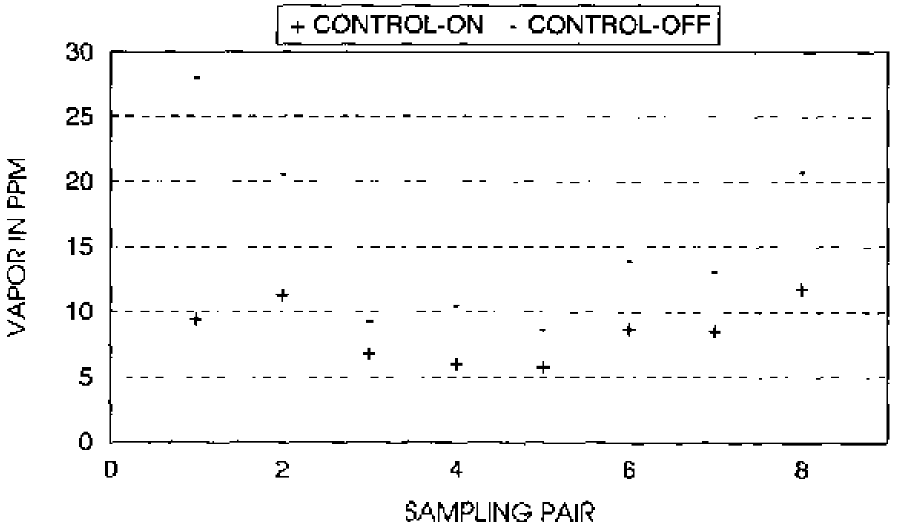
CONTROL- OFF MEDIAN 337504, CONTROL-ON MEDIAN 34560

FIG 3 DELAY IN MEASUREMENT CHANGES
WHEN CONTROL SETTING CHANGES



DATA WERE ANALYZED BY DELETING 1/2 MINUTE OF MEASUREMENTS AT START AND END OF EACH CONTROL SETTING

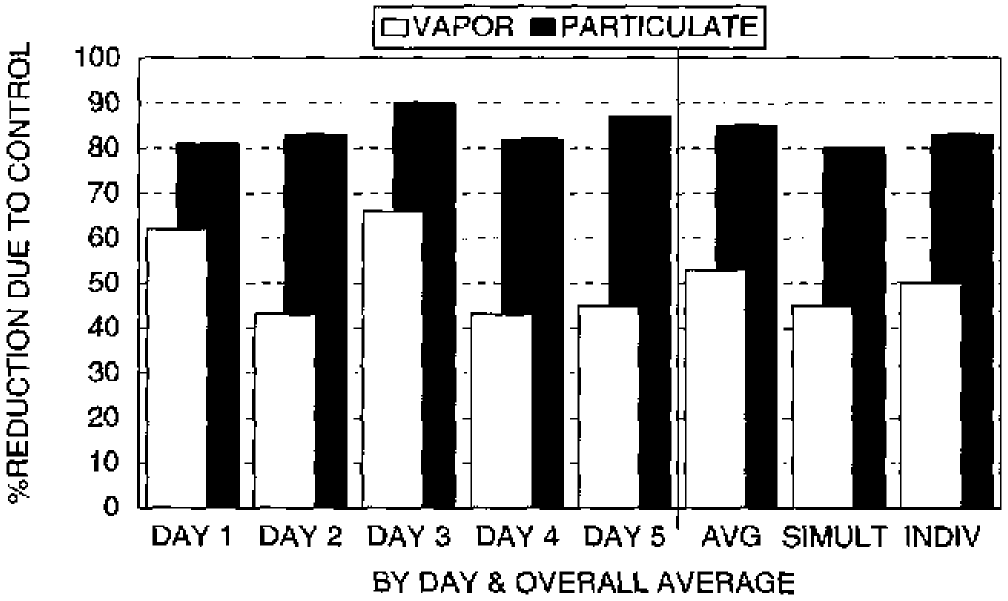
FIG 4. VAPOR MEDIANS AT AUGER FOR DAY 2 CONTROL-ON & CONTROL-OFF PLOTTED BY SHORT-TIME SAMPLING PAIR



SUBSTANTIAL VARIABILITY DURING DAY PAIRING(CONTROL ON CONTROL OFF) IMPROVES PRECISION

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

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



PARTICULATE & VAPOR DIFFER in % REDUCTION

FIG 6 GEOMETRIC MEANS OF PARTICULATE SAMPLE MEDIANS

AT AUGER AND AWAY FROM AUGER

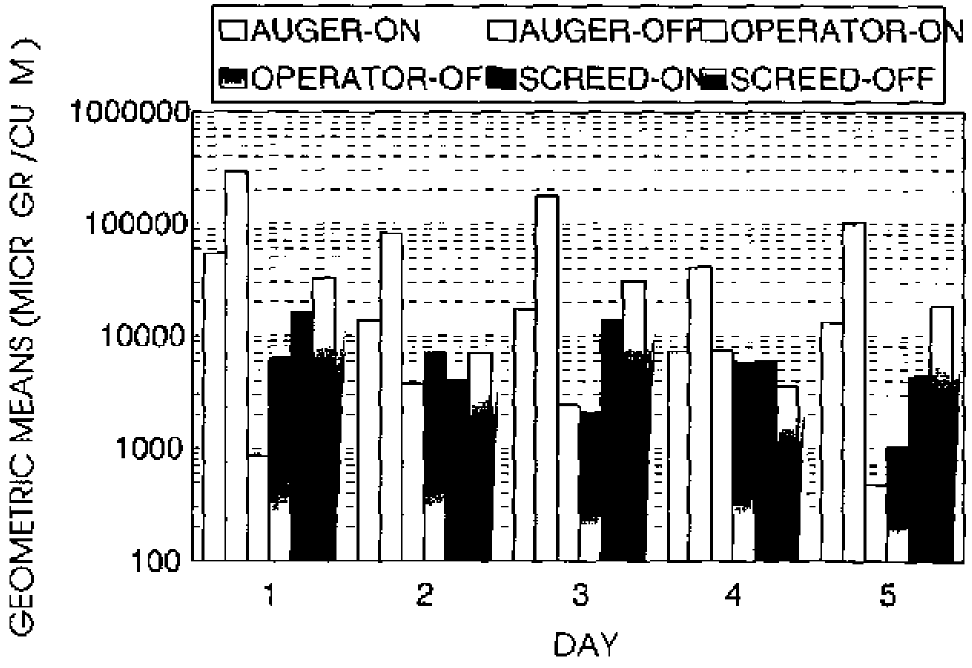
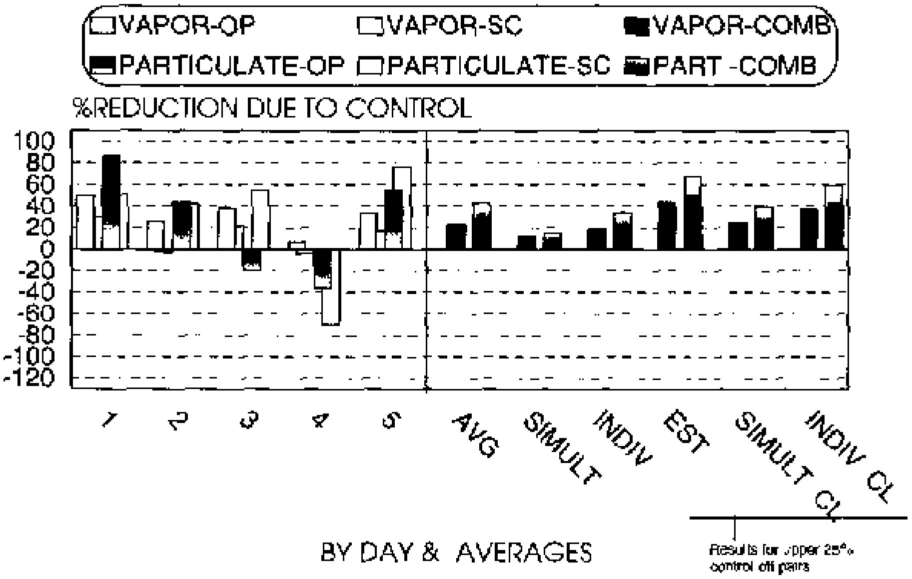


FIG 7 AWAY FROM AUGER. %REDUCTION BY DAY & OVERALL, BASED ON SAMPLE MEDIANS

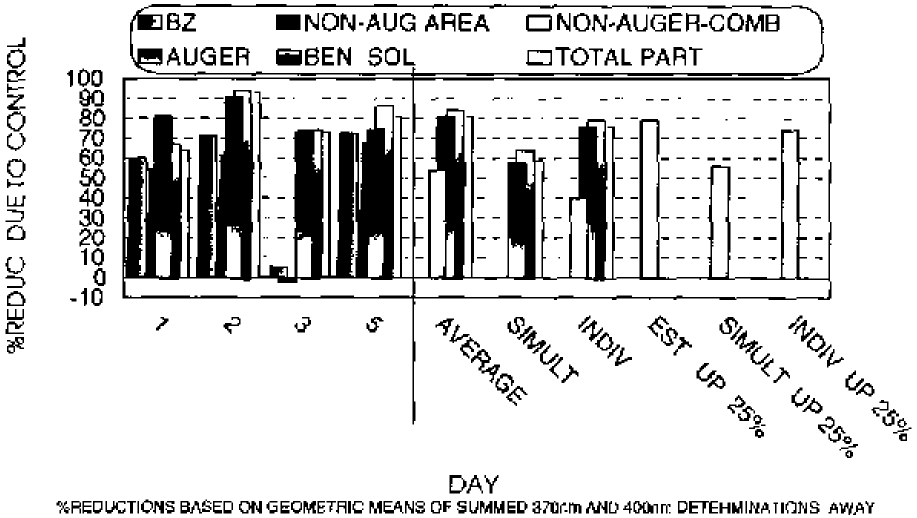
LOWER 80% CONFIDENCE LIMITS FOR VAPOR AND PARTICULATE FOR BOTH SIMULTANEOUS & INDIVIDUAL CONF LIMITS FOR AVERAGE AND FOR UPPER 25% CONTROL OFF PAIRS



AVERAGES FOR VAPOR ARE LOWER THAN AT AUGER DAY 4 PRODUCED VERY DIFFERENT RESULTS FOR PARTICULATE & VAPOR

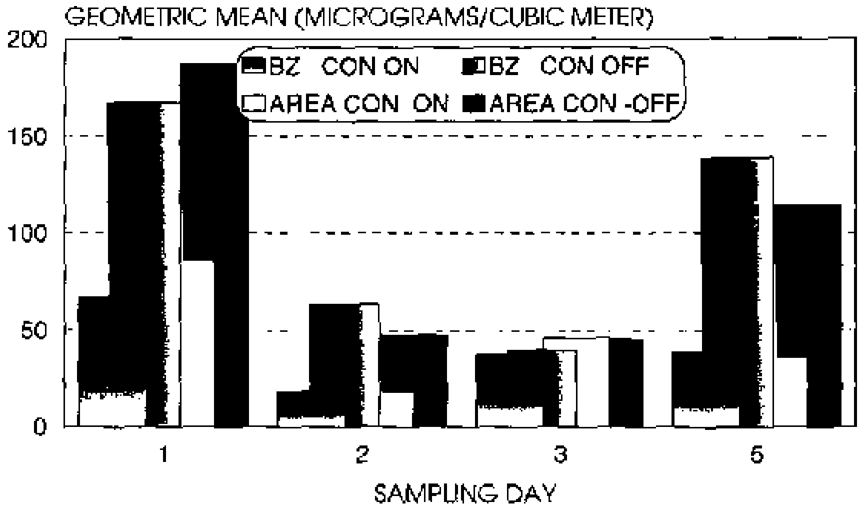
FIG 8: INDUSTRIAL HYGIENE SAMPLES %REDUCTION BY DAY

80% CONFIDENCE LIMITS SIMULTANEOUSLY & INDIVIDUALLY
ESTIMATES GIVEN FOR AVERAGES AND FOR UPPER 25 TOTAL PAC AWAY FROM AUGER



%REDUCTIONS BASED ON GEOMETRIC MEANS OF SUMMED 370nm AND 400nm DETERMINATIONS AWAY FROM AUGER SUBSTANTIAL REDUCTION GOOD AGREEMENT OF BREATHING ZONE & AREA SAMPLES 0 REDUCTION FOR NON AUGER AREA SAMPLES BASED ON SIMULTANEOUS CONFIDENCE LIMITS

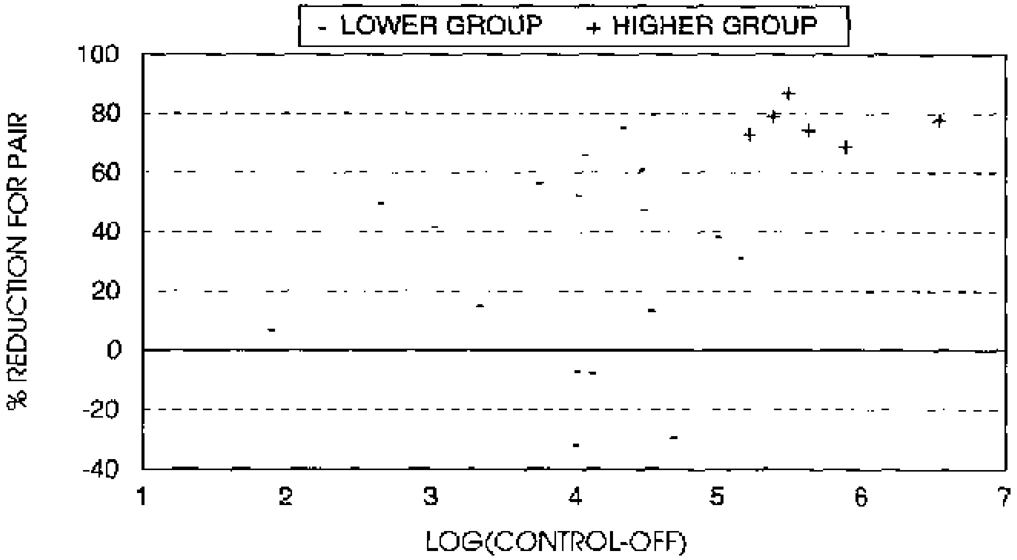
FIG. 9: IH SAMPLE GEOMETRIC MEANS:BREATHING ZONE SAMPLES & AREA SAMPLES AWAY FROM AUGER



NO IH SAMPLES TAKEN ON DAY 4 370nm and 400nm DETERMINATIONS ARE SUMMED

FIGURE 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

FIG 11 AUGER BENZENE SOLUBLE VS SUM OF INSTRUMENTAL RESPONSES (370NM + 400NM)

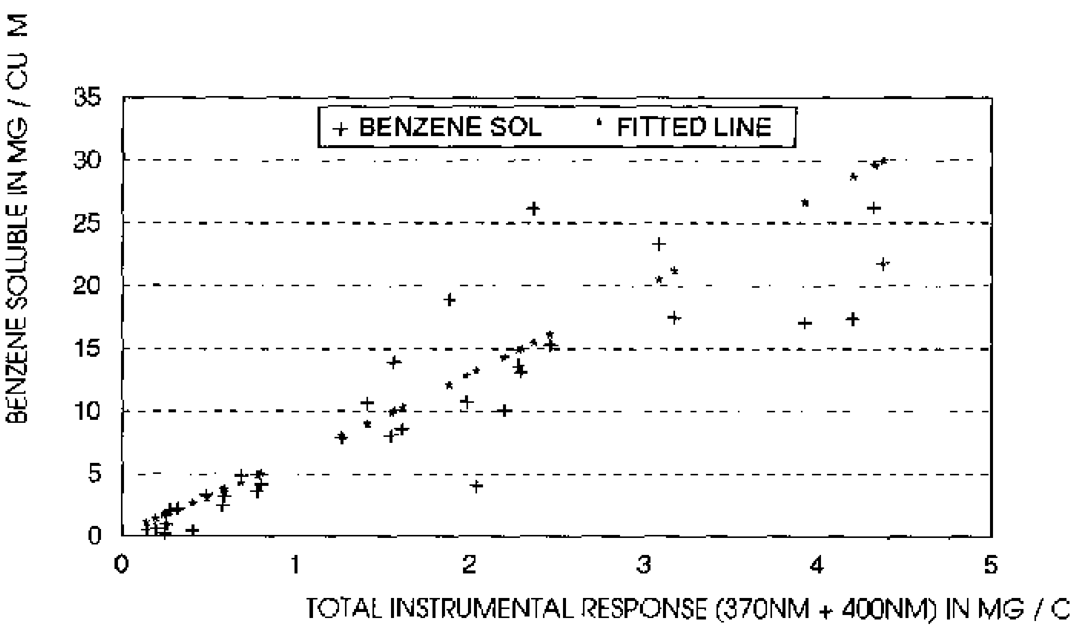


FIG 12 BREATHING ZONE & NON-AUGER PACS CONVERTED TO BENZENE SOLUBLE EQUIVALENTS

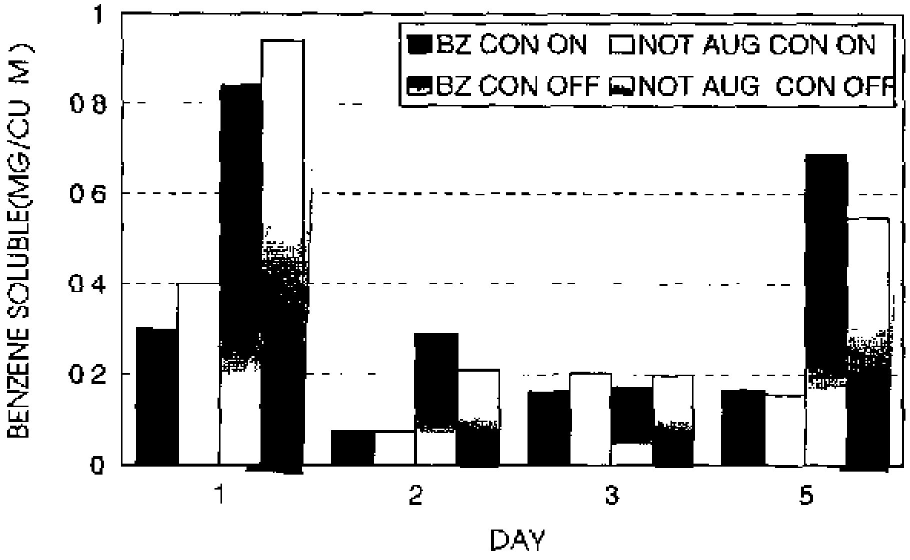
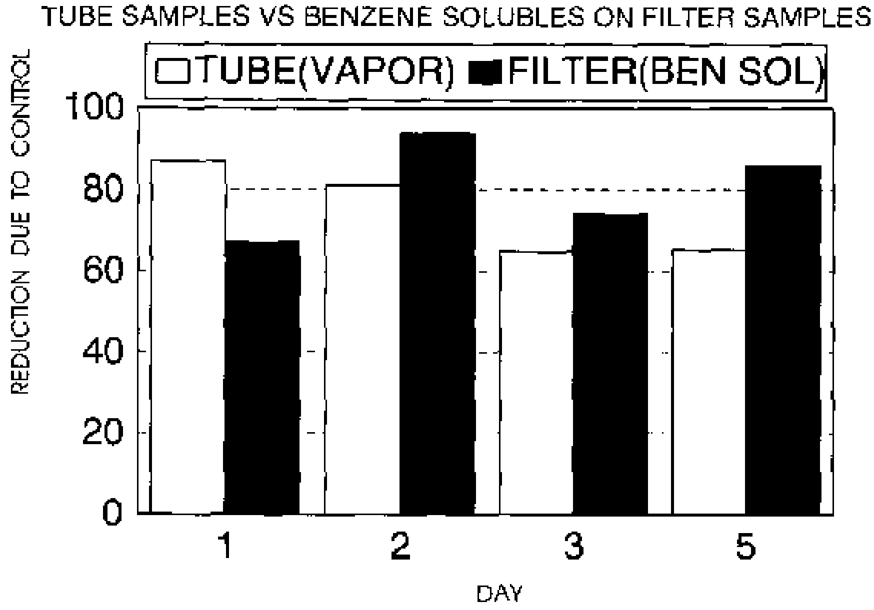
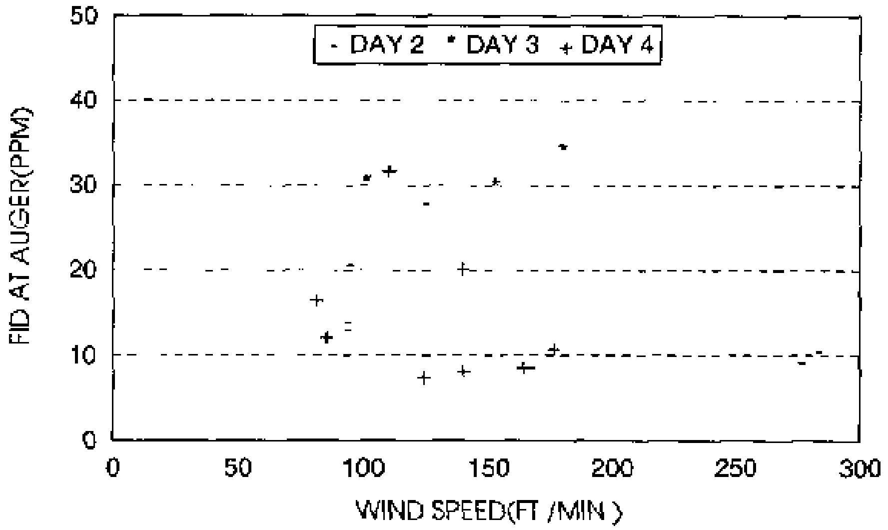


FIG 13 REDUCTION DUE TO CONTROL AT AUGER



OVER ALL DAYS TUBE & FILTER HAVE BETWEEN 77% & 84% REDUCTION

FIG 14 MEDIAN FID-AUGER VS MEDIAN WIND SPEED FOR CONTROL-OFF FOR DAYS 2,3,4
SHORT-TIME PERIODS ONLY



FOR DAYS 2 AND 4, CLEAR DECREASE IN FID AS WIND SPEED INCREASES